

WELDER

NSQF LEVEL - 4

2nd Semester

TRADE THEORY

SECTOR: Fabrication



Directorate General of Training

**DIRECTORATE GENERAL OF TRAINING
MINISTRY OF SKILL DEVELOPMENT & ENTREPRENEURSHIP
GOVERNMENT OF INDIA**



**NATIONAL INSTRUCTIONAL
MEDIA INSTITUTE, CHENNAI**

Post Box No. 3142, CTI Campus, Guindy, Chennai - 600 032

Sector : Fabrication

Duration : 1 - Year

Trade : Welder 2nd Semester - Trade Theory - NSQF level 4

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FOREWORD

The Government of India has set an ambitious target of imparting skills to 30 crores people, one out of every four Indians, by 2020 to help them secure jobs as part of the National Skills Development Policy. Industrial Training Institutes (ITIs) play a vital role in this process especially in terms of providing skilled manpower. Keeping this in mind, and for providing the current industry relevant skill training to Trainees, ITI syllabus has been recently updated with the help of Mentor Councils comprising various stakeholders viz. Industries, Entrepreneurs, Academicians and representatives from ITIs.

The National Instructional Media Institute (NIMI), Chennai, has now come up with instructional material to suit the revised curriculum for **Welder, 2nd Semester Trade Theory NSQF Level - 4 in Fabrication Sector under Semester Pattern**. The NSQF Level - 4 Trade Practical will help the trainees to get an international equivalency standard where their skill proficiency and competency will be duly recognized across the globe and this will also increase the scope of recognition of prior learning. NSQF Level - 4 trainees will also get the opportunities to promote life long learning and skill development. I have no doubt that with NSQF Level - 4 the trainers and trainees of ITIs, and all stakeholders will derive maximum benefits from these Instructional Media Packages IMPs and that NIMI's effort will go a long way in improving the quality of Vocational training in the country.

The Executive Director & Staff of NIMI and members of Media Development Committee deserve appreciation for their contribution in bringing out this publication.

Jai Hind

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RAJESH AGGARWAL

Director General/ Addl. Secretary
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New Delhi - 110 001

PREFACE

The National Instructional Media Institute (NIMI) was established in 1986 at Chennai by then Directorate General of Employment and Training (D.G.E & T), Ministry of Labour and Employment, (now under Directorate General of Training, Ministry of Skill Development and Entrepreneurship) Government of India, with technical assistance from the Govt. of the Federal Republic of Germany. The prime objective of this institute is to develop and provide instructional materials for various trades as per the prescribed syllabi (NSQF Level 4) under the Craftsman and Apprenticeship Training Schemes.

The instructional materials are created keeping in mind, the main objective of Vocational Training under NCVT/NAC in India, which is to help an individual to master skills to do a job. The instructional materials are generated in the form of Instructional Media Packages (IMPs). An IMP consists of Theory book, Practical book, Test and Assignment book, Instructor Guide, Audio Visual Aid (Wall charts and Transparencies) and other support materials.

The trade practical book consists of series of exercises to be completed by the trainees in the workshop. These exercises are designed to ensure that all the skills in the prescribed syllabus are covered. The trade theory book provides related theoretical knowledge required to enable the trainee to do a job. The test and assignments will enable the instructor to give assignments for the evaluation of the performance of a trainee. The wall charts and transparencies are unique, as they not only help the instructor to effectively present a topic but also help him to assess the trainee's understanding. The instructor guide enables the instructor to plan his schedule of instruction, plan the raw material requirements, day to day lessons and demonstrations.

In order to perform the skills in a productive manner instructional videos are embedded in QR code of the exercise in this instructional material so as to integrate the skill learning with the procedural practical steps given in the exercise. The instructional videos will improve the quality of standard on practical training and will motivate the trainees to focus and perform the skill seamlessly.

IMPs also deals with the complex skills required to be developed for effective team work. Necessary care has also been taken to include important skill areas of allied trades as prescribed in the syllabus.

The availability of a complete Instructional Media Package in an institute helps both the trainer and management to impart effective training.

The IMPs are the outcome of collective efforts of the staff members of NIMI and the members of the Media Development Committees specially drawn from Public and Private sector industries, various training institutes under the Directorate General of Training (DGT), Government and Private ITIs.

NIMI would like to take this opportunity to convey sincere thanks to the Directors of Employment & Training of various State Governments, Training Departments of Industries both in the Public and Private sectors, Officers of DGT and DGT field institutes, proof readers, individual media developers and coordinators, but for whose active support NIMI would not have been able to bring out this materials.

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R. P. DHINGRA
EXECUTIVE DIRECTOR

ACKNOWLEDGEMENT

National Instructional Media Institute (NIMI) sincerely acknowledges with thanks for the co-operation and contribution extended by the following Media Developers and their sponsoring organisations to bring out this Instructional Material (**Trade Theory**) for the trade of **Welder** under **Fabrication** sector.

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NIMI records its appreciation for the Data Entry, CAD, DTP operators for their excellent and devoted services in the process of development of this Instructional Material.

NIMI also acknowledges with thanks the invaluable efforts rendered by all other NIMI staff who have contributed towards the development of this Instructional Material.

NIMI is also grateful to everyone who has directly or indirectly helped in developing this Instructional Material.

INTRODUCTION

TRADE THEORY

The manual of trade theory consists of theoretical information for the Second Semester course of the Welder Trade. The contents are sequenced according to the practical exercise contained in the manual on Trade practical. Attempt has been made to relate the theoretical aspects with the skill covered in each exercise to the extent possible. This co-relation is maintained to help the trainees to develop the perceptual capabilities for performing the skills.

The Trade Theory has to be taught and learnt along with the corresponding exercise contained in the manual on trade practical. The indicating about the corresponding practical exercise are given in every sheet of this manual.

It will be preferable to teach/learn the trade theory connected to each exercise atleast one class before performing the related skills in the shop floor. The trade theory is to be treated as an integrated part of each exercise.

The material is not the purpose of self learning and should be considered as supplementary to class room instruction.

TRADE PRACTICAL

The trade practical manual is intended to be used in workshop. It consists of a series of practical exercises to be completed by the trainees during the Second Semester course of the Welder trade supplemented and supported by instructions/informations to assist in performing the exercises. These exercises are designed to ensure that all the skills in the prescribed syllabus are covered.

The manual is divided into five modules. The distribution of time for the practical in the five modules are given below.

Module 1	Inspection and testing	25 Hrs
Module 2	Gas metal arc welding	250 Hrs
Module 3	Gas tungsten arc welding	140 Hrs
Module 4	Plasma arc cutting & Resistance welding	35 Hrs
Module 5	Repair and maintenance	75 Hrs
	Project work	<u>50 Hrs</u>
	Total	<u>575 Hrs</u>

The skill training in the computer lab is planned through a series of practical exercises centred around some practical project. However, there are few instances where the individual exercise does not form a part of project.

While developing the practical manual a sincere effort was made to prepare each exercise which will be easy to understand and carry out even by below average trainee. However the development team accept that there is a scope for further improvement. NIMI, looks forward to the suggestions from the experienced training faculty for improving the manual.

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LEARNING / ASSESSABLE OUTCOME

On completion of this book you shall be able to

- **Test welded joints by different methods of testing. [Different methods of testing- Dye penetration test, Magnetic particle test, Nick break test, Free bend test, Fillet fracture test].**
- **Set GMAW machine and perform welding in different types of joints on MS sheet/ plate by GMAW in various positions by dip mode of metal transfer. [Different types of joints Fillet (T-joint, lap, Corner), Butt (Square & V); various positions - 1F, 2F, 3F, 4F, 1G, 2G, 3G].**
- **Set the GTAW machine and perform welding by GTAW in different types of joints on different metals in different position and check correctness of the weld [Different types of joints- Fillet (T-joint, lap, Corner), Butt (Square & V); different metals- Aluminium, Stainless Steel; different position- 1F & 1G].**
- **Perform Aluminium & MS pipe joint by GTAW in flat position.**
- **Set the Plasma Arc cutting machine and cut ferrous & non-ferrous metals.**
- **Set the resistance spot welding machine and join MS & SS sheet.**
- **Perform joining of different similar and dissimilar metals by brazing operation as per standard procedure [Different similar and dissimilar metals- Copper, MS, SS].**
- **Repair Cast Iron machine parts by selecting appropriate welding process [Appropriate welding process- OAW, SMAW].**
- **Hard facing of alloy steel components/ MS rod by using hard facing electrode.**

Inspection of weld (NDT) - Visual inspection

- Objectives:** At the end of this lesson you shall be able to
- explain the necessity of inspection and testing of weld
 - describe the different stages of visual inspection
 - explain the check points of visual inspection
 - state types of testing of welds.

Necessity of inspection: The purpose of inspection is to locate and determine the type of weld fault, strength and quality of joint and quality of workmanship.

Types of tests

- Non-destructive test (NDT)
- Destructive test
- Semi destructive test

Determining the quality of the weld without destroying the weld is called a non-destructive test (NDT). The job can be used after the test. The test to be carried out on welded specimens by cutting the job and destroying it is called destructive test. The job cannot be used after the test.

Sometimes the quality of a welded joint is tested by grinding, drilling, etching, filing etc. for finding machinability, microstructure etc. These tests are called semi-destructive tests. The tested job can be used after the test by rewelding the small area damaged during the test.

Visual inspection (non-destructive test): Visual inspection is observing the weld externally using simple hand tools and gauges to know whether there is any external weld defects. This is one of the important inspection methods without much expense. This method of inspection needs a magnifying glass, a steel rule, try square and weld gauges. Visual inspection is made in three stages namely:

- before welding
- during welding
- after welding

Visual inspection before welding

(The operator must be familiar with the type of work, electrode and welding machine)

The following factors are to be ensured.

The material to be welded is of weldable quality.

The edges have been properly prepared for welding as per thickness of the plate.

Proper cleaning of the base metal.

Setting of proper root gap.

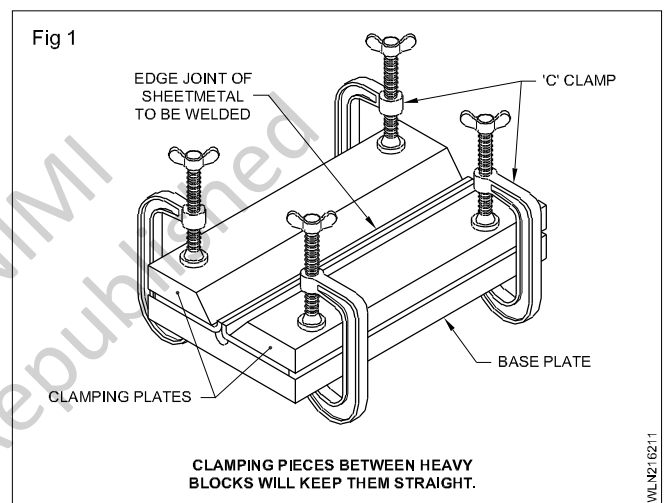
Proper procedure to be followed to control distortion.

Proper selection of blow pipe nozzle and filler rod, flux and flame.

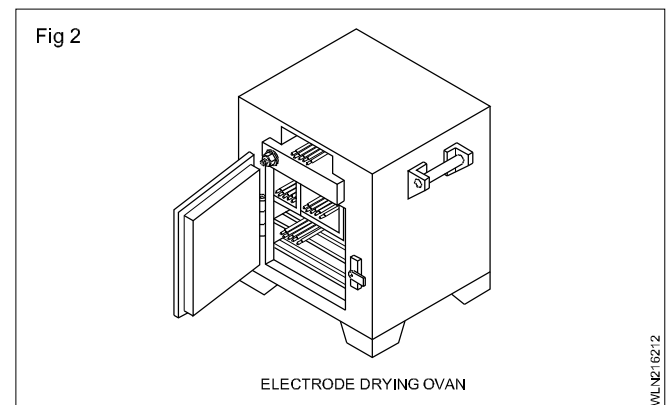
Polarity of the electrodes in the case of DC welding current.
Whether the cable connections are tight.

Current setting according to the size of the electrode and position of welding.

Whether any jigs and fixtures are necessary to ensure proper alignment. (Fig 1)



Proper facilities should exist for storing and drying of the electrodes. (Fig 2)



Visual inspection during welding

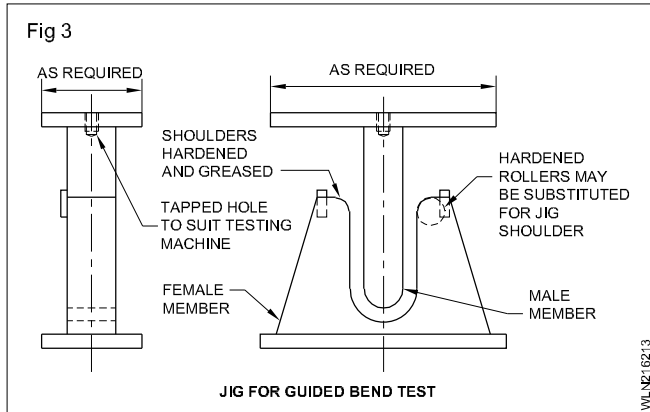
The following points are to be checked.

Studying the sequence of weld deposit.

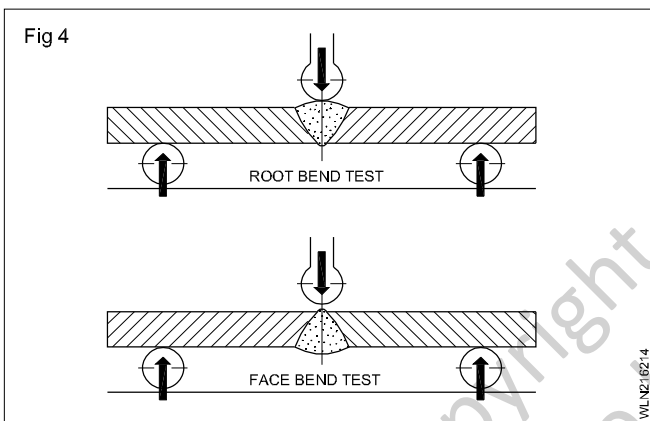
Examining whether each weld is cleaned adequately before making the next run in multi-run welding.

The following factors are to be ensured.

Guided bend test: A guided bend test is one in which the specimen as in Fig.3.



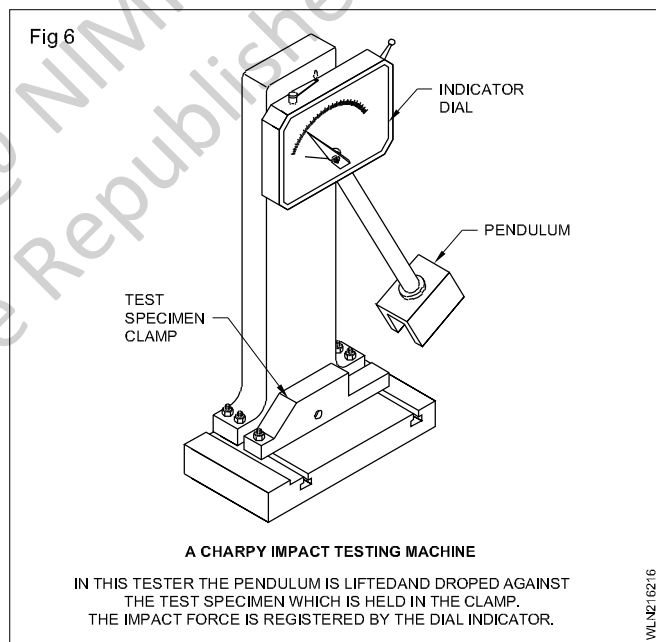
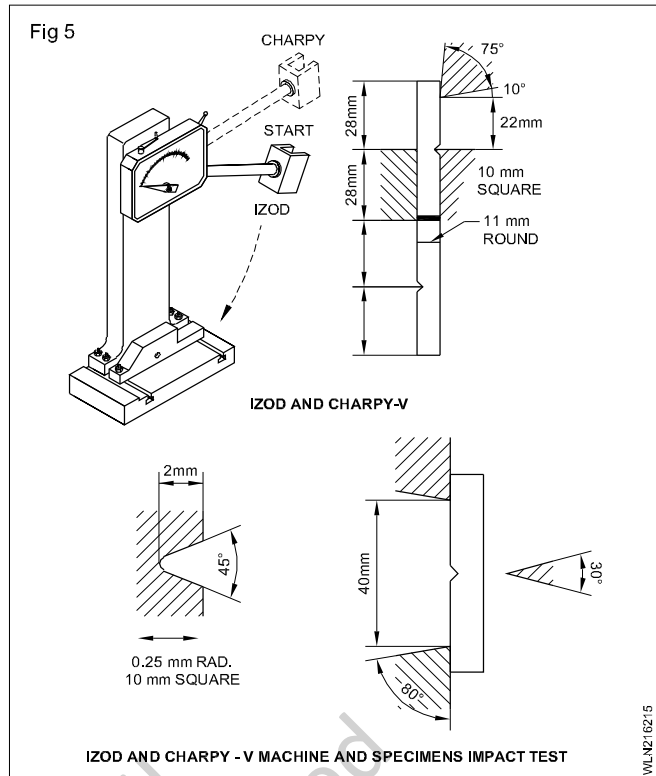
There are two types of specimens prepared for this - one for face bend and the other for root bend. (Fig.4) This test measures the ductility of the weld metal in a butt joint in a plate. This test shows most weld faults quite accurately and it is very fast. A sample specimen can be tested on destruction to determine (a) the physical condition of the weld and thus check on the weld procedure and (b) the welder's capability.



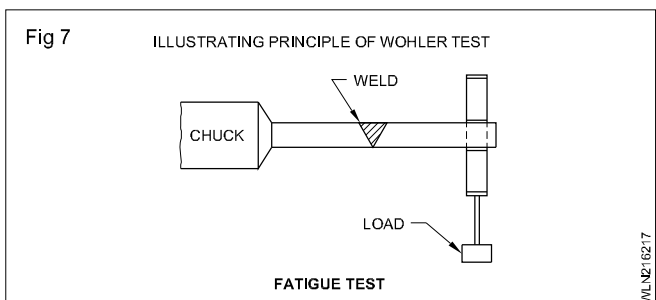
Impact test: Impact means application of a sudden force on an object. In an impact test of a weld, a test specimen (Fig.4) is prepared from a test plate. This is further machined to have a V notch as in Fig.5. The test specimen with 10 mm square cross-section is used for Charpy V impact test and one with 11 mm diameter circular cross-section is used for the Izod impact test. Fig.6 shows an impact testing machine.

The impact test is used to determine the impact value of welds and base metals in welded products to be used at low temperatures up to -40°C which are subjected to severe dynamic loading.

Fatigue test: When a welded joint is subjected to push and pull forces alternatively for a long period, it may fail due to the fatigue of the molecules. In this case the forces applied will rise to a maximum tension, decrease to zero, rise to a maximum compression and decrease again to zero. This cycle will be repeated which creates fatigue in the joint which will fail at much less loads than its maximum tension and compression strength.



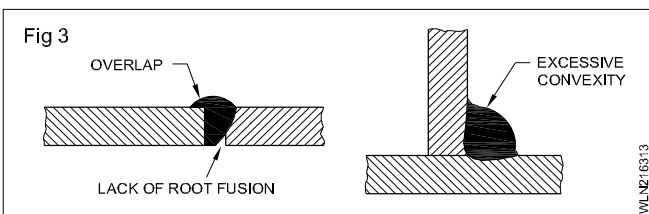
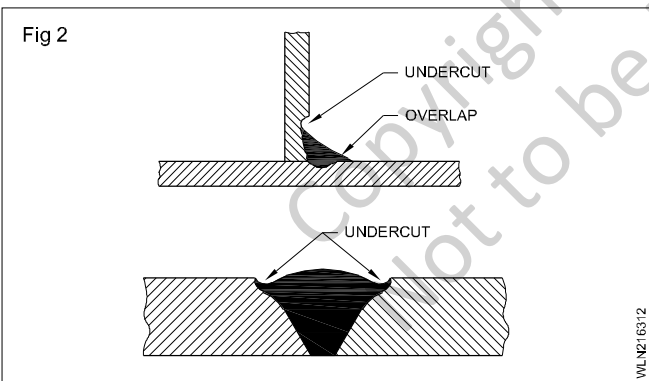
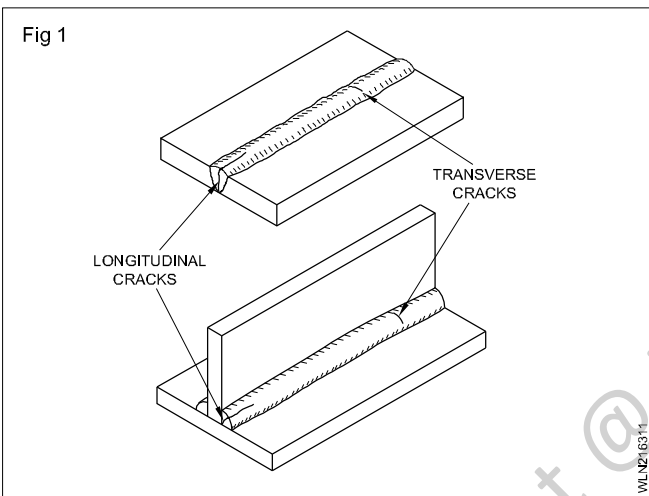
The resistance to fatigue of a welded joint is tested by fixing the welded specimen in a chuck and rotated at a particular speed with a load hung at the other end as shown in Fig.7. Fatigue tests are extremely useful while testing welded shafts, cranks and other rotating parts which are subjected to varying alternating loads.



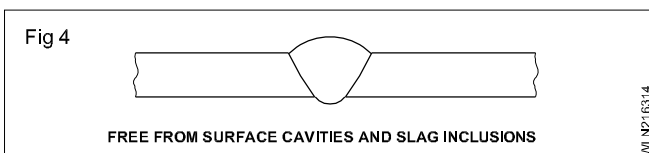
Measuring gauges

- Objectives:** At the end of this lesson you shall be able to
- describe the surface defects on weld
 - explain the measuring gauges
 - states the types of gauges.

Inspection after welding: Surface defects in and around the welds, such as cracks, (longitudinal and transverse) (Fig.1), undercut (Fig.2), overlap (Fig.3), excessive convexity of contour, the weld surface smoothness of the run and penetration, control of distortion, unfilled crater are to be inspected.



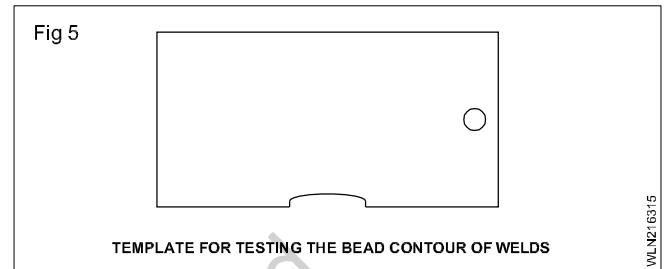
Freedom from surface cavities and slag inclusions. (Fig 4).
 Deposition of runs, single or multiple.
 Penetration bead in butt weld.



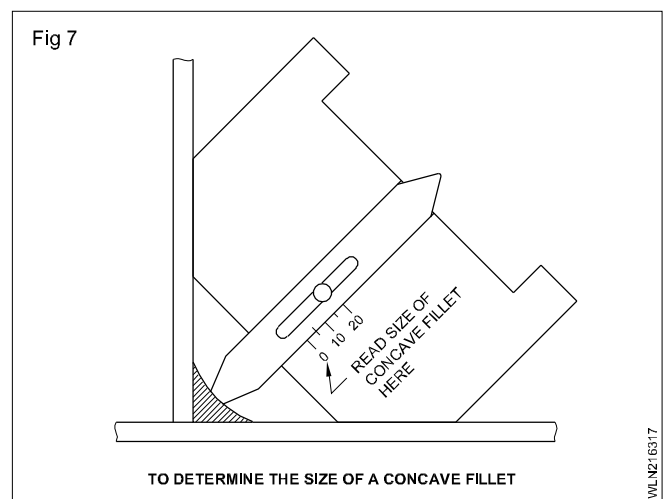
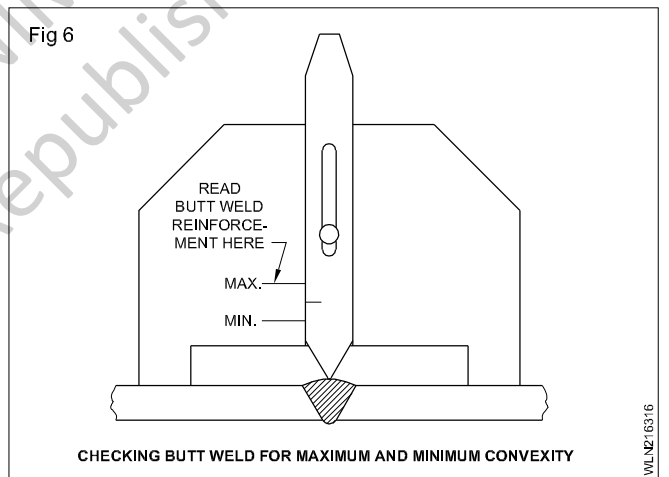
Quality of the weld metal.

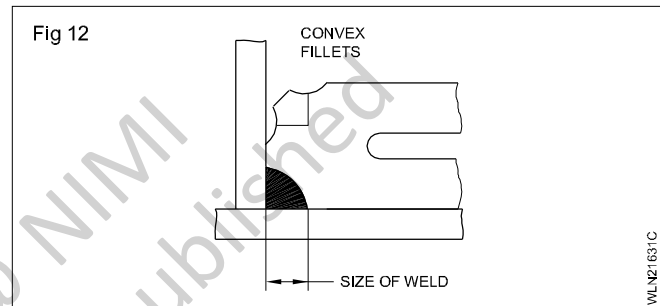
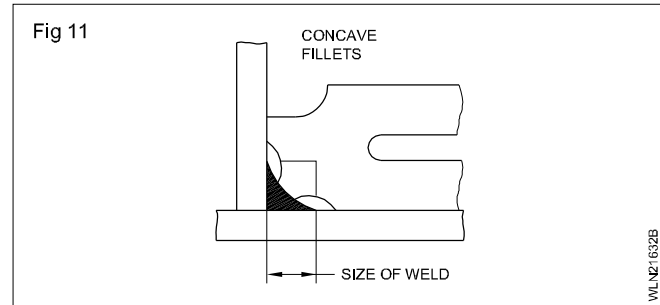
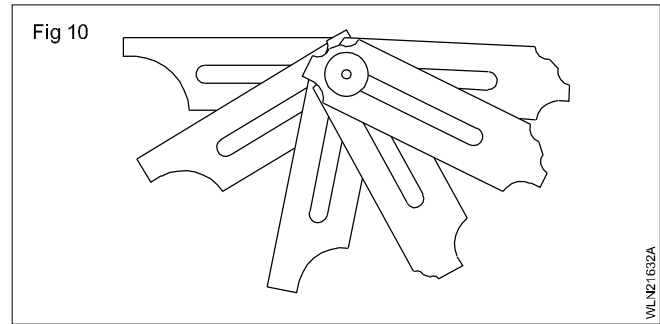
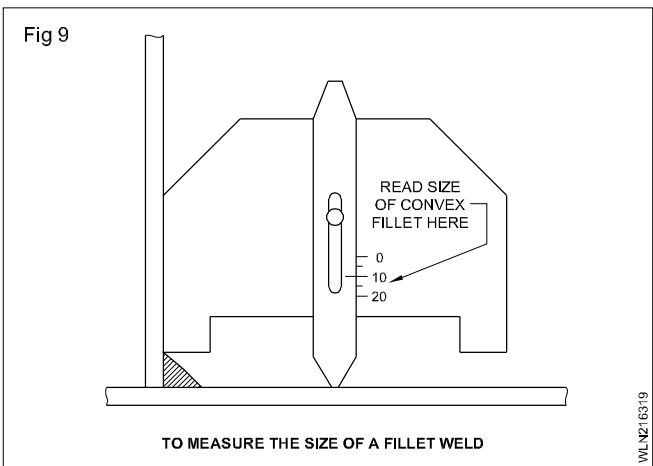
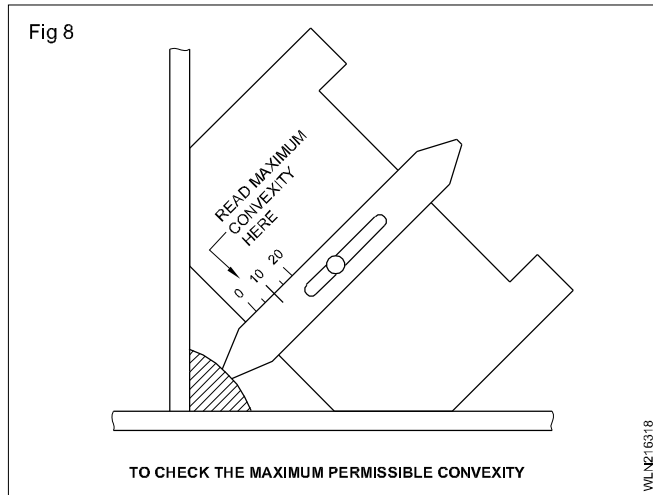
Measuring gauges used for inspection

A template may be used to check the contour. (Fig.5)



Use gauges for measuring both convex and concave in fillet weld and to check contour of weld. (Figs 6 to 12)





Methods of non-destructive tests

Objectives: At the end of this lesson you shall be able to

- explain the non-destructive testing methods
- explain the uses of the common non-destructive methods
- explain the uses of special non-destructive testing.

Non-destructive testing methods are classified as common testing and special testing methods.

Common non-destructive testing

- Visual inspection
- Leak or pressure test
- Stethoscopic test (Sound)

Special non-destructive tests

- Magnetic particle test
- Liquid penetrant test
- Radiography (X-ray) test
- Gamma ray test
- Ultrasonic test

Visual inspection: Visual inspection is the simplest, fastest, economical and most commonly used test for detecting defects on the surface of the welded job. The weld surface and joint are examined visually with naked eyes preferably with the help of a magnifying lens. Visual examination can help in detecting the following defects on the surface of the weld.

- Porosity
- Surface defects like surface cracks, external slag inclusions, overlap, spatters, unfilled crater, misalignment, distortion etc.
- Undercut
- Improper profile and dimensional accuracy
- Poor weld appearance
- Incomplete penetration.

Leak or pressure test: This test is used to test welded pressure vessels, tanks and pipelines to determine if leaks are present. The welded vessel, after closing all its outlets, is subjected to internal pressure using water, air or kerosene. The internal pressure depends upon the working pressure which the welded joint has to withstand. The internal pressure may be raised to two times the working pressure of the vessel. The weld may be tested as follows.

- 1 The pressure on the gauge may be noted immediately after applying the internal pressure and again after, say, 12 to 24 hours. Any drop in pressure reading indicates a leak.

2 After generating air pressure in the vessel, soap solution may be applied on the weld seam and carefully inspected for bubbles which would indicate leak.

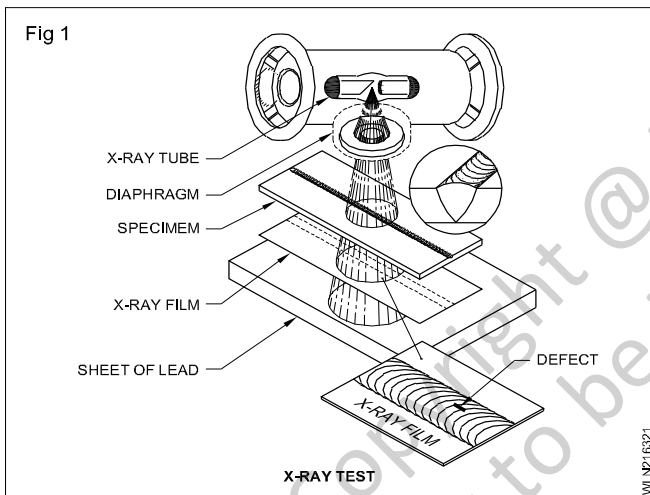
Stethoscopic (sound) test: The principle of this test is that defect-free weld metal gives a good ringing sound when struck with a hammer whereas a weld metal containing defects gives a flat sound.

An ordinary physician's stethoscope and a hammer may be used to magnify and identify the sound.

Structural welds and welds in pressure vessels have been successfully tested using this method.

Radiographic test: This test is also called X-ray or gamma ray test.

X-ray test: In this test internal photographs of the welds are taken. The test specimen is placed in between the X-ray unit and film. (Fig 1) Then the X-ray is passed. If there is any hidden defect, that will be seen in the film after developing it. Defects appear in the same manner as bone fractures of human beings appear in X-ray films. Below the X-ray film a lead sheet is kept to arrest the flow of X-ray further from the X-ray testing machine.

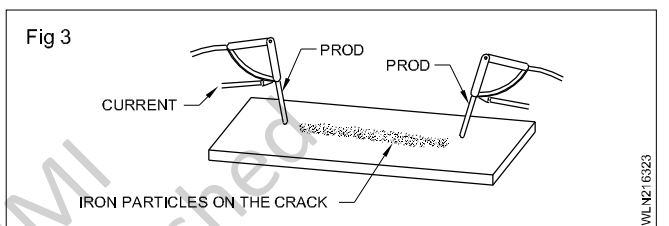
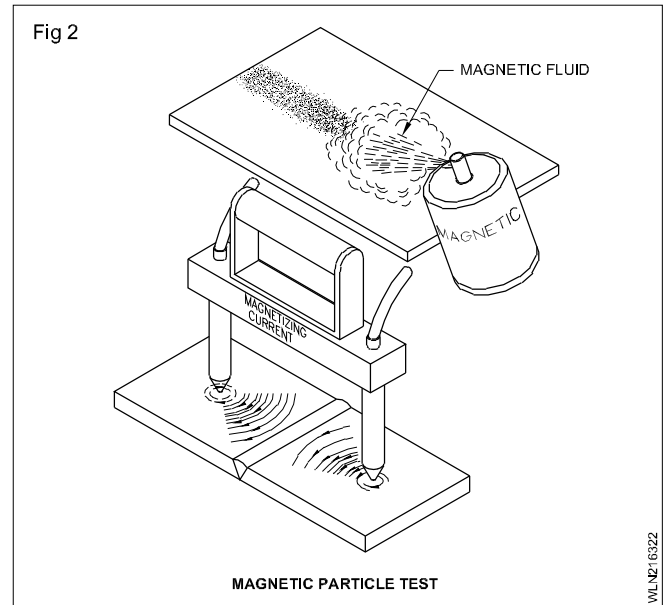


Gamma ray test: The short invisible rays given off by radium and radium compounds like cobalt 60 etc. are known as gamma rays. These rays penetrate greater thickness of steel than x-rays and the chief advantage of this process is portability. This test can be done at places where electricity is not available. These tests are used on high quality jobs like boilers and high pressure vessels and penstock pipes and nuclear vessels.

Magnetic particle test: This test is used to detect surface defects as well as sub-surface (up to 6 mm depth) defects in ferrous materials.

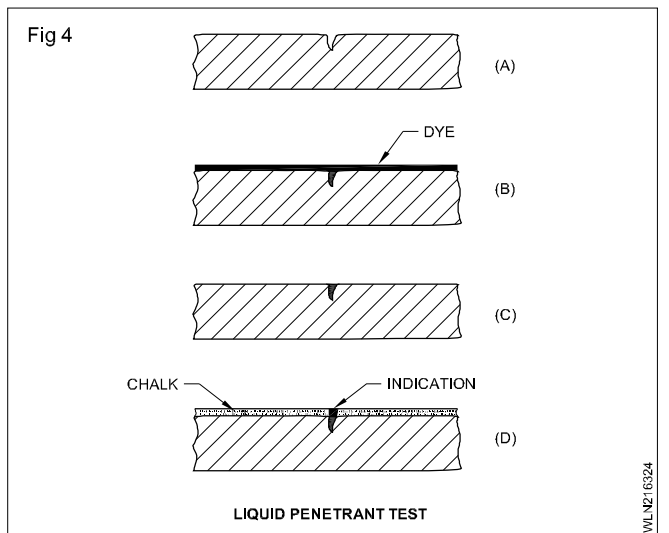
A liquid containing iron powder is first sprayed over the joint to be tested. When this test piece is magnetised, the iron particles will gather at the edges of the defect (crack or flaw) and can be seen as dark hair line marks with naked eyes. (Figs 2 & 3)

Liquid penetrant test; This test is based on the principle that coloured liquid dyes and fluorescent liquid penetrate into the cracks and are used to check for surface defects in metals, plastics, ceramics and glass. A solution of the



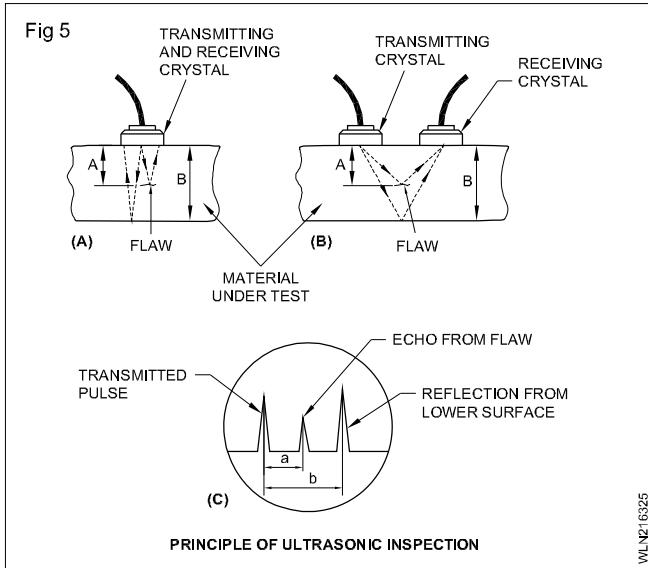
coloured dye is sprayed on the clean welded joint and allowed to soak. Then the dye is washed off using a cleaner, and the surface dried with soft cloth.

A liquid developer (white in colour) is then sprayed on the weld. The coloured dye comes out in the shape of surface defects into the white developer coating. The defect can be seen in normal light with naked eyes. (Fig 4)

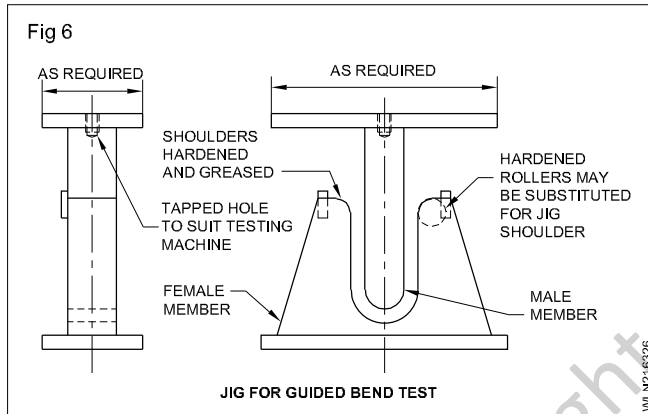


Ultrasonic test: Sound waves of high frequency are used in this test. This test is used to find out the discontinuities in the weldment. The sound waves can penetrate from a very small thickness of plate to 6 to 10 metres of steel.

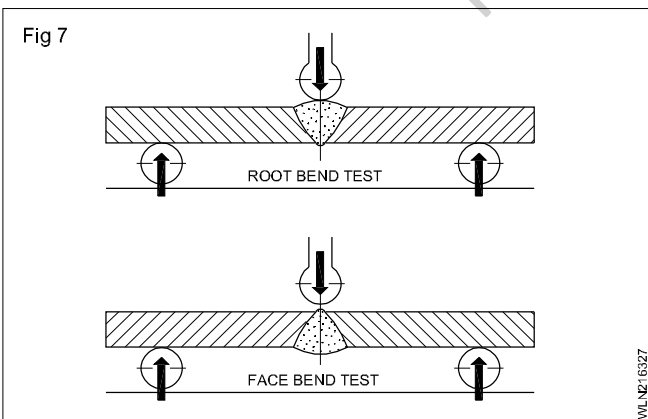
A sound wave producing transmitter is placed on the job. The echo of the sound waves is directly shown on the calibrated screen attached with the ultrasonic testing unit. (Fig 5)



Guided bend test: A guided bend test is one in which the specimen as in Fig. 6.

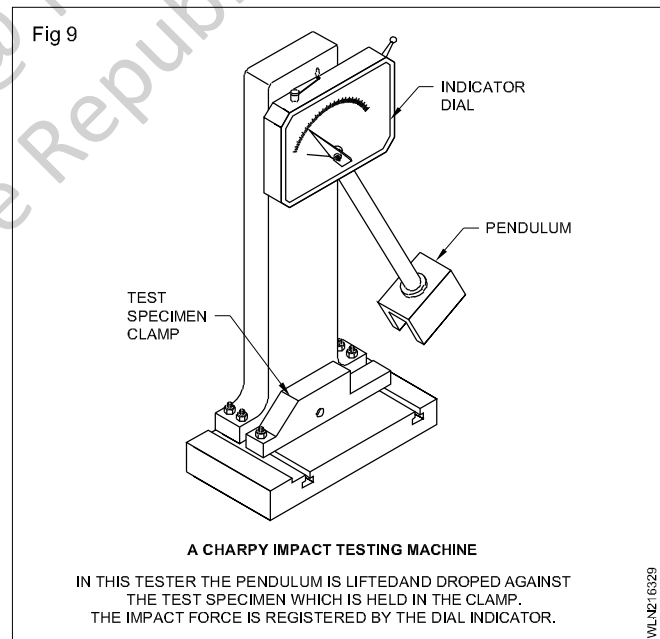
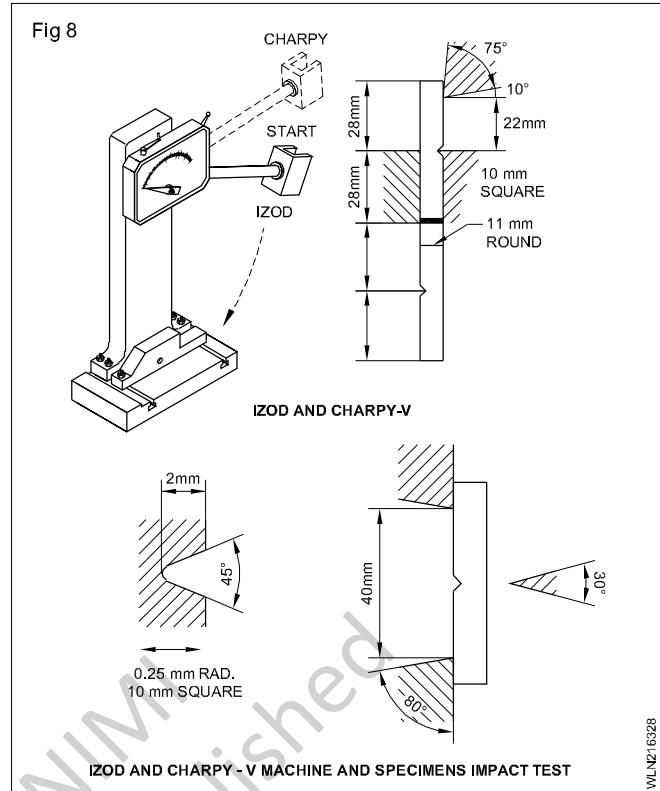


There are two types of specimens prepared for this - one for face bend and the other for root bend. (Fig. 7) This test measures the ductility of the weld metal in a butt joint in a plate. This test shows most weld faults quite accurately and it is very fast. A sample specimen can be tested on destruction to determine (a) the physical condition of the weld and thus check on the weld procedure and (b) the welder's capability.



Impact test: Impact means application of a sudden force on an object. In an impact test of a weld, a test specimen (Fig. 8) is prepared from a test plate. This is further machined to have a V notch as in Fig.8. The test specimen with 10 mm square cross-section is used for charpy V

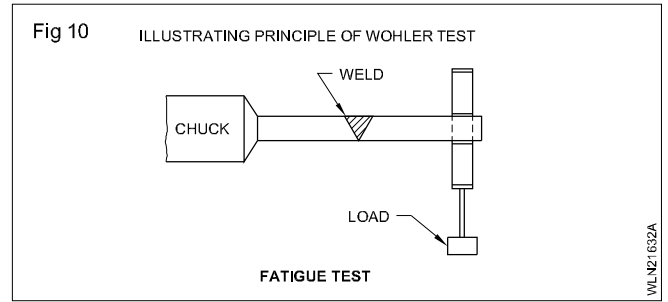
impact test and one with 11 mm diameter circular cross-section is used for the izod impact test. Fig.9 shows an impact testing machine.



The impact test is used to determine the impact value of welds and base metals in welded products to be used at low temperatures up to -40°C which are subjected to severe dynamic loading.

Fatigue test: When a welded joint is subjected to push and pull forces alternatively for a long period, it may fail due to the fatigue of the molecules. In this case the forces applied will rise to a maximum tension, decrease to zero, rise to a maximum compression and decrease again to zero. This cycle will be repeated which creates fatigue in the joint which will fail at much less loads than its maximum tension and compression strength.

The resistance to fatigue of a welded joint is tested by fixing the welded specimen in a chuck and rotated at a particular speed with a load hung at the other end as shown in Fig.10 Fatigue tests are extremely useful while testing welded shafts, cranks and other rotating parts which are subjected to varying alternating loads.



Destructive tests

Objectives: At the end of this lesson you shall be able to

- explain the necessity for destructive tests
- explain the different methods of destructive test of weldments
- explain the advantages and limitations of workshop and laboratory tests
- identify the specimen for destructive tests.

Introduction: Welded joints are tested without damaging or destroying the welded structure under non-destructive testing methods which were explained earlier. Now to know the property of material used for welding and to know the strength of a weld joint and also to judge the skill of the welder, a destructive test is to be performed on a welded specimen which was destroyed during the testing. There are two main methods of destructive testing. They are:

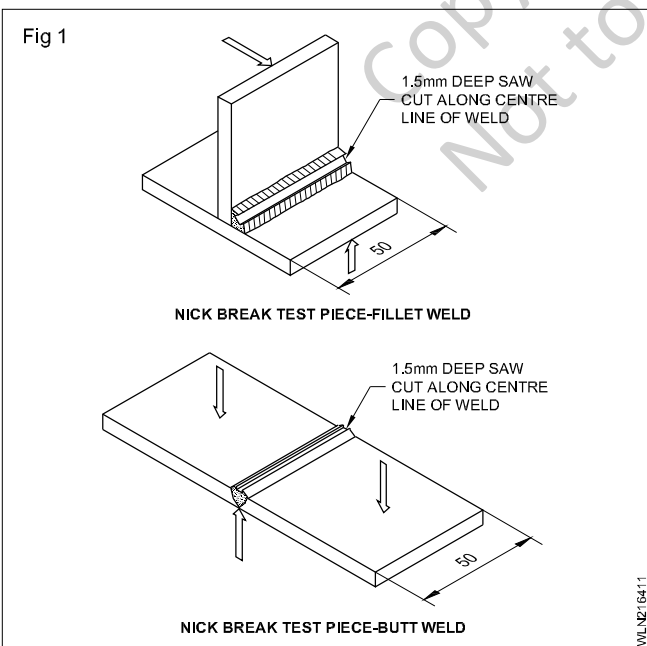
- workshop tests
- laboratory tests

Workshop tests

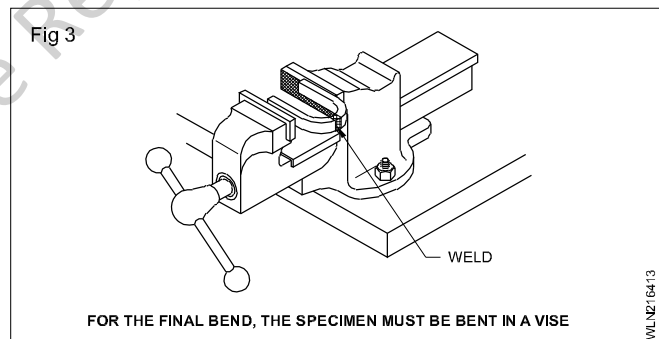
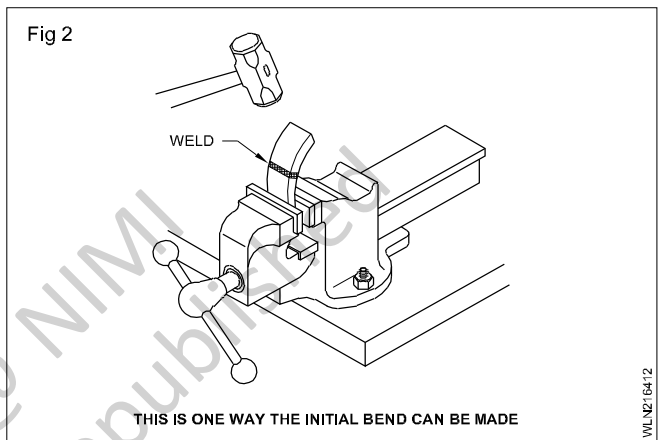
These are the tests that can be performed in the workshop.

- Nick break test
- Free bend test in a vice
- Fillet fracture test (by using a bending bar)

Nick break test: In a nick break test a saw cut of about 1.5mm to 2mm depth is made along the centre line of the weld, and a hammer blow is given on the reverse of the joint as shown in the figure. (Fig 1). The joint will break along the saw cut and by observing the fractured surface, various defects like slag inclusions, lack of fusion, lack of penetration, etc. can be identified.



Free bend test: The welded joints are fixed on a vice and bent by applying forces by hammer/bending bar to determine the defect in the weld done by a trainee in a workshop. (Figs 2&3) The workshop tests are usually used to break open the weld in a workshop using a vice and hammer for visual inspection.



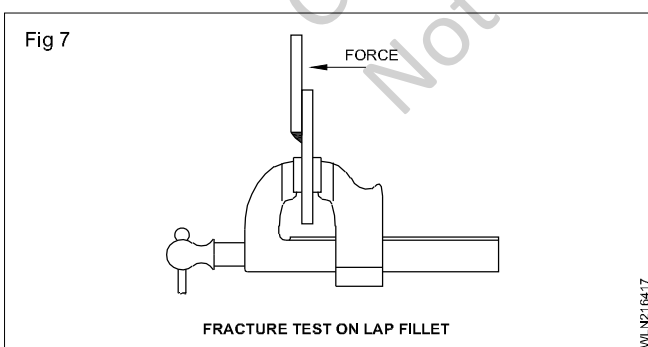
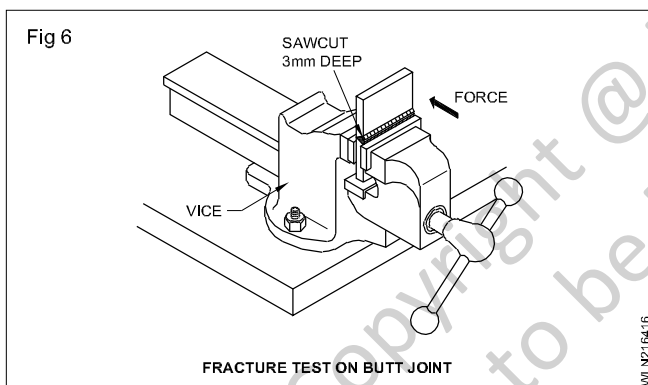
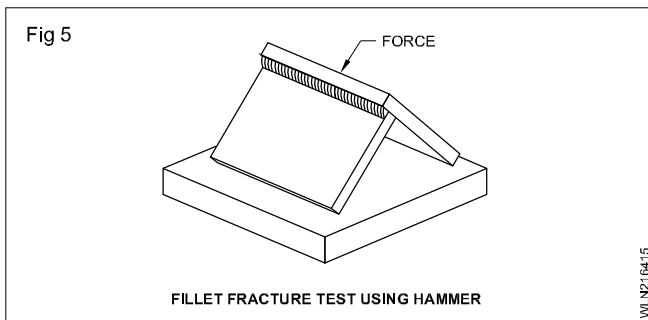
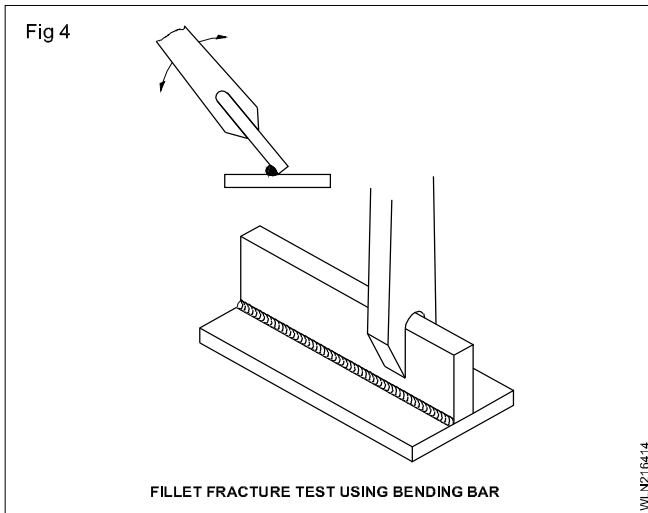
Advantages and limitations: The time taken to perform the test is less. Cost of testing is less. This test is useful for testing the welders in the beginning when the weld contains many defects. Does not give the actual strength of the joint. Cannot be used for testing the quality of weld consumables. (electrodes and filler rods)

Examination of fractured weld: The fractured weld may exhibit and show the following internal defects. (Figs 4, 5, 6, and 7)

- Lack of fusion
- Incomplete penetration
- Slag inclusions
- Blow-holes or porous weld

Laboratory tests

The laboratory tests conducted on welds are the:



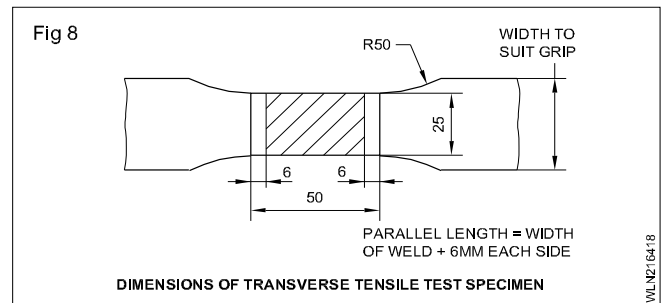
- tensile test
- guided bend test
- impact test
- fatigue test.

Tensile test: A tensile test is conducted to know the tensile strength and ductility (i.e. elongation) of a weld.

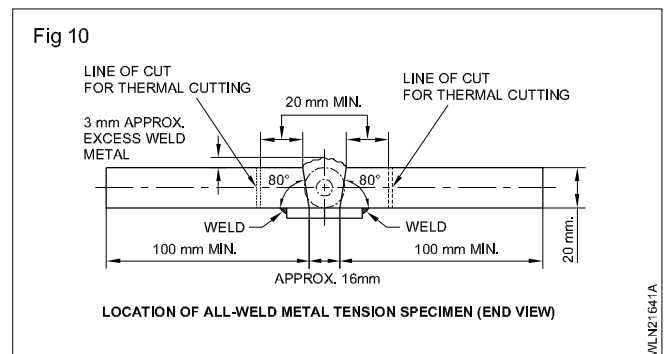
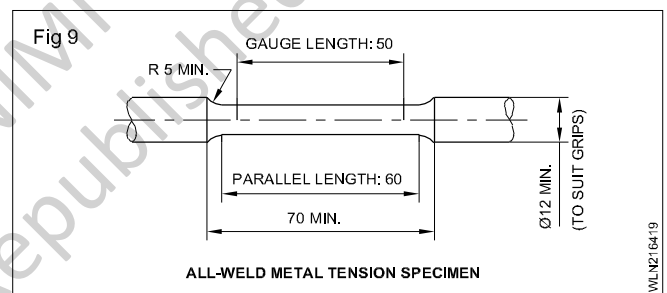
Two types of test specimens are prepared for the tensile test.

They are

- transverse tensile test specimen (Fig 8)



- all-weld metal tensile specimen. (Figs 9 and 10)



The tensile test gives the values of the tensile strength of the weld and the percentage of elongation of the weld. This reveals the suitability of a joint welded with certain electrodes and base metals for a particular service condition.

Economy in welding & simple estimation

Objectives: At the end of this lesson you shall be able to

- describe the method of cost estimation
- explain about economy in welding
- explain the principle, application, advantages and limitations of electron beam, electro slag, friction and laser beam welding
- describe the parts of the above advanced welding equipment.

The following factors are to be considered for cost estimation.

Material cost: Material cost involves the cost of all basic materials such as steel sheets, plates, rolled sections, forgings, angle irons, forgings, casting etc. as may be used.

Fabrication cost: Fabrication cost involves cost of (1) preparation (2) welding and (3) finishing.

Preparation cost: Preparation cost involves cost of material handling, cutting, machining or shearing plates or sections, preparing the edges for welding, forming, fitting up, positioning, labour for these operations etc.

Welders should ensure that the plates and sections are prepared for welding, either by machining or by flame cutting in accordance with the recommendations of the design office.

The effects of inaccurate edge preparation and poor fit up resulting in extra welding and the consequent additional welding costs are illustrated in Figs 1 and 2.

Welding cost: The welding cost involves the cost of electrodes, power consumed, welding labour etc.

In determining the direct welding cost, the following factors are taken into consideration.

- Cost of electrodes - this being dependent on the type and size of electrode and edge preparation employed.
- Power consumed

$$\text{Power cost} = \frac{V \times A}{1000} \times \frac{T}{60} \times \frac{1}{E} \times \text{rate per unit}$$

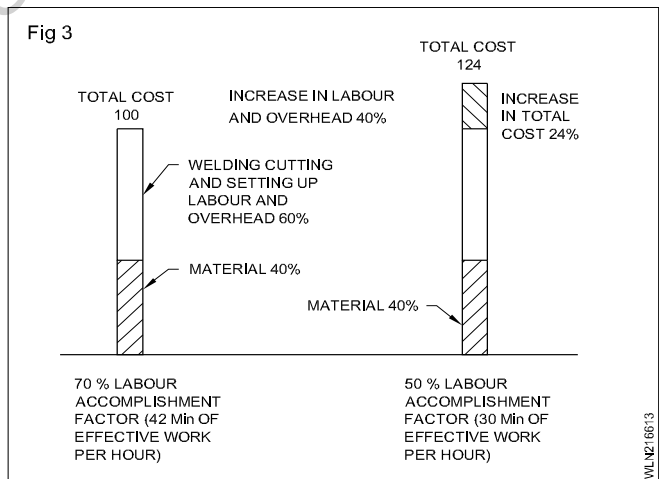
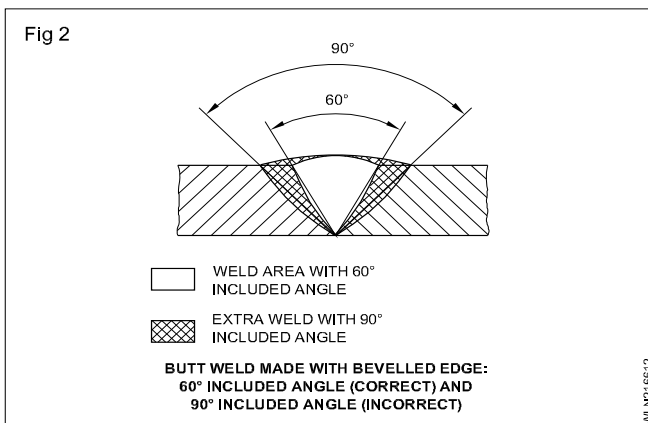
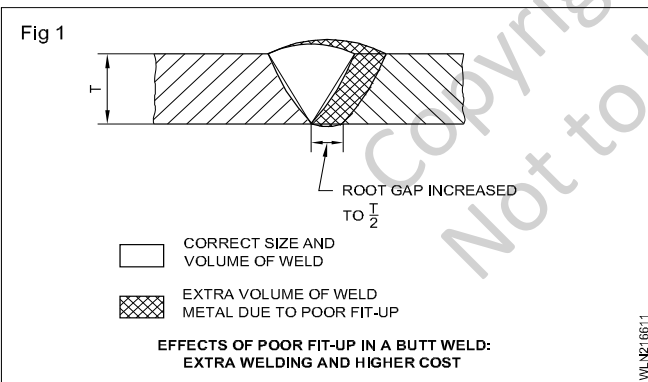
where V = Voltage, A = Current in amperes

T = Welding time in minutes

E = Efficiency of the machine.

E is assumed to be 0.6 in the case of a welding transformer and 0.25 in the case of a welding generator.

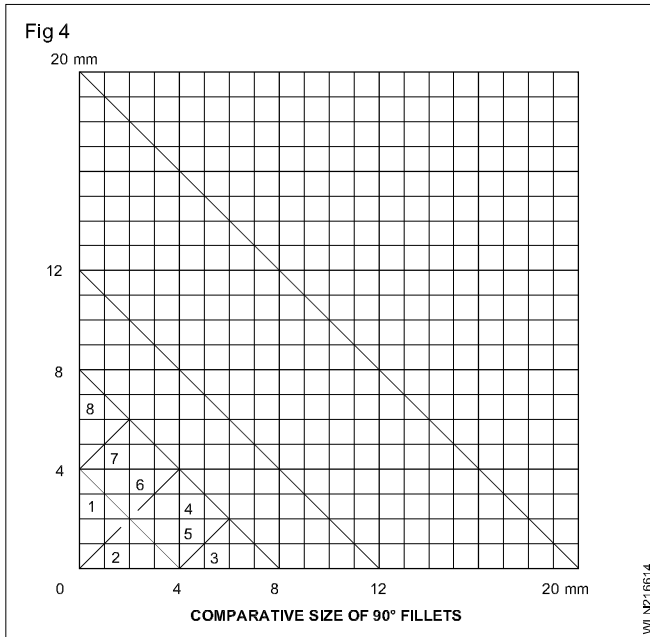
- Speed of welding
- Welding labour cost (Fig 3)
- Position of welding



Finishing cost: Finishing cost involves cost of all post welding work, such as machining, grinding, sand-blasting, pickling, heat treatment, painting etc. and the labour involved in carrying out these operations.

Overhead cost: Overhead costs involve all other costs, such as office and supervisory expenses, lighting, depreciation on capital, etc. which are not to be directly charged to a job. There exists an elaborate and accurate system of computation and allocation of overhead expenses to the various stages of manufacturing process.

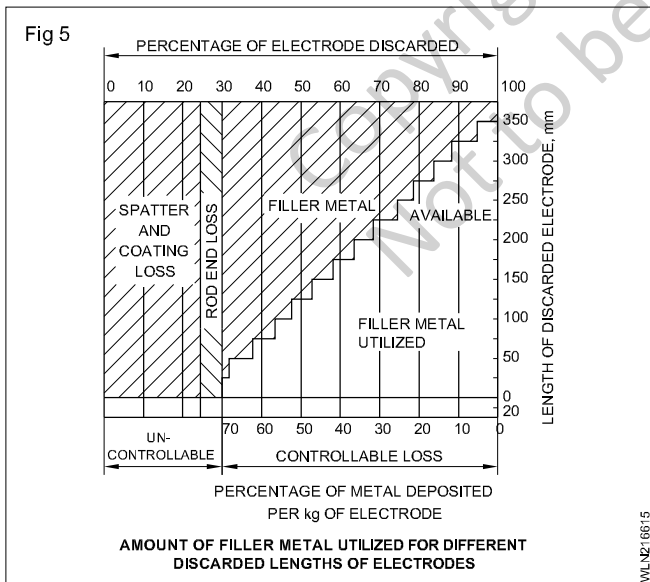
Economics of welding: Over-welding, that is excessive build up in the case of butt weld and fillet welds larger than those specified, should always be avoided. (See size comparison in Fig 4)



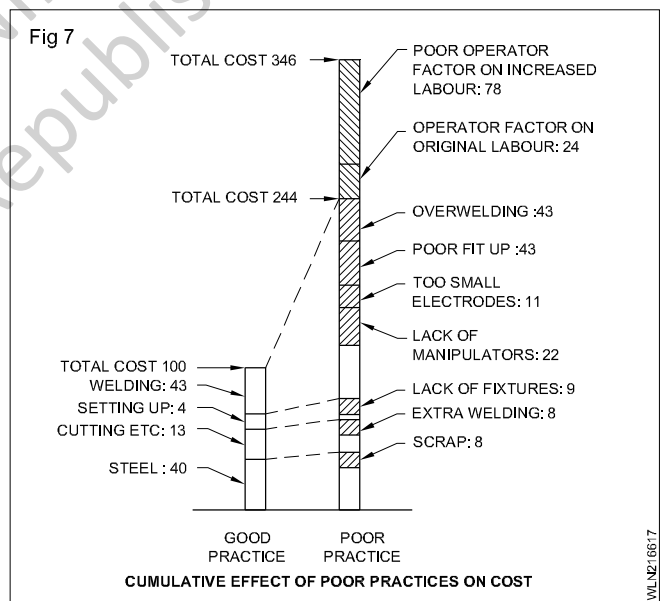
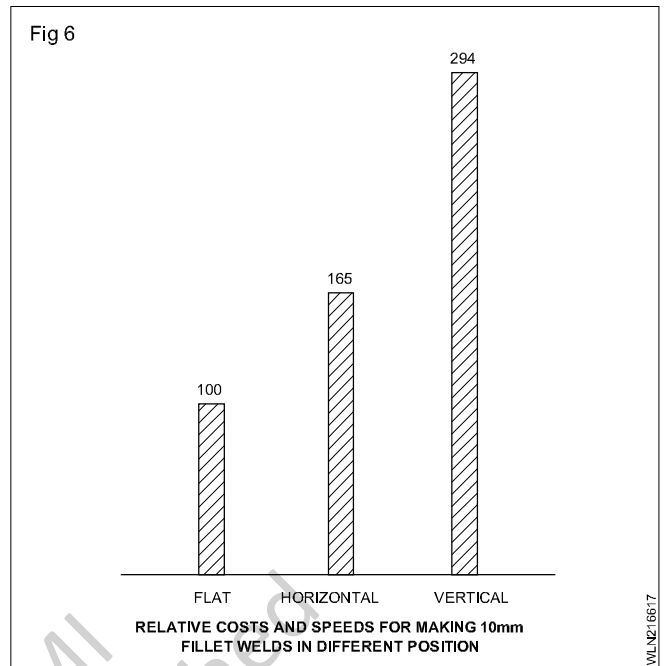
Ensure that the largest size of electrode compatible with the plate thickness is used. Use of smaller electrode will increase labour hours and excessive distortion.

Use proper welding current. Excessive current will lead to excessive spatter loss and unsatisfactory weld.

Avoid excessive stub end loss; ensure that most of the usable portion of the electrode is used. The stub end should never be more than 50mm. (Fig 5)



The most convenient position of welding is in the down hand (flat) position. Whenever possible welding should be carried out in the flat position. A graphic form of the relative cost and speed of welding is shown in Fig 6 & 7.



Safety in GMAW

Objective: At the end of this lesson you shall be able to
• **safety precaution to be followed in the process.**

Safety in GMA welding/CO₂ welding

The general safety precautions for arc welding (SMAW) are also applicable to GMAW.

Ultra violet light

During MIG welding Ultra Violet Light production is at the higher end of the scale and suitable eye protection must be used.

Adequate eye protection should always be worn. If welding for long periods, flash goggles with A#12 lens shade should be worn under the arc helmet. A#11 lens is recommended for nonferrous GMAW and A#12 for ferrous GMAW. All welding should be done in booths or in areas protected by curtains. This is done to protect others in the weld area from arc flashes.

Heat

Welding in any form produces heat which can cause burns and the possibility of fire.

Suitable clothing must be worn. This is done to protect all parts of the body from radiation or hot metal burns. Leather clothing offers the best protection from burns.

Fumes

Fumes from the MIG welding process are produced by the burning of contaminants on the surface of the material being heated.

The MIG welding of galvanised metal is extremely dangerous to the operator because of zinc poisoning unless suitable protection is used.

Ventilation should be provided. This ventilation and/or filtering equipment is necessary to keep the atmosphere around the welder clean. Carbon monoxide is generated when doing GMAW and using CO₂ as a shielding gas. It is suggested that all welding be done in well ventilated areas.

Ozone is also produced when doing GMAW and ozone is a highly toxic gas. Metals still covered with chlorinated hydrocarbon solvents will form poisonous, toxic phosgene gas when welded.

Protect arc cables from damage. Do not touch uninsulated electrode holders with bare skin or wet gloves. A fatal shock could result. Welding in wet or damp areas is not recommended.

Shielding gas cylinders must be handled with caution.

Welding environment safety rules

- keep the welding area clean
- keep combustibles out of the weld area
- maintain good ventilation in the weld area
- repair or replace damaged power cables
- make sure the part to be welded is securely grounded/earthed
- welding helmets should have no light leaks. Should not have scratches or cracks
- use the proper colored lens with correct shade number in the helmet
- wear safety glasses when grinding
- do not see the arc with bare eyes
- use safety screens or shields to protect your area
- wear proper clothing. Your entire body should be covered to protect you from arc radiation

GTAW safety

Objective: At the end of this lesson you shall be able to

- state the safety precautions to be followed in TIG welding process.
-

GTAW/TIG welding is a skill which may be performed safely with a minimum of risk if the welder used good common sense and safety rules. It is recommended that you establish good safety habits as you work in this industrial area. Check your equipment regularly and be sure that your environment is safe. Safety in TIG welding covers the following major areas and includes

Electrical current: Primary current to the electrical powered welding machine is usually 220V A/C or more, and this amount of voltage can cause extreme shock to the body and possible death. For this reason

- never install fuses higher than specified
- always ground/earth the welding machine properly
- install electrical components as per the codes given by the electricity boards
- ensure electrical connections are tight
- never open a welding machine when it is operating
- lock primary voltage switches, open and remove fuses when working on electrical components inside the machine
- welding current supplied by the power supply has a maximum of 80 open circuit volts. At this low voltage, the possibility of lethal shock is very small. However, it will still produce a good shock. To reduce the possibility of this occurrence.
 - keep the welding power supply dry
 - keep the power cable, ground cable and torch dry
 - do not weld in damp area. If you must, wear rubber boots and gloves
 - make sure the ground clamp is securely attached to the power supply and the work piece
 - High frequency components in some GTAW machines produce a spark for starting the initial arc or maintenance of the arc during the alternating current welding. The high frequency voltage is very high, however the amperage is very low. Since the amperage is so low, the high frequency voltage will not usually travel through the body and is therefore not as dangerous as other currents.

Inert gases: Inert gases used in GTAW are produced and distributed to the user in two forms: high pressure gas and liquid. All storage vessels used for inert gases are approved by the department of transportation and are so stamped on the vessel name plate or the cylinder wall.

Most of the gases used in GTAW are inert, colourless and tasteless. Therefore special precautions must be taken when using them. Nitrogen, argon, and helium are non toxic. However they can cause asphyxiation (suffocation) in a confined or closed area that does not have adequate ventilation. Any atmosphere that does not contain at least 18 % oxygen can cause dizziness, unconsciousness or even death. The gases cannot be detected by the human senses and will be inhaled like air. So ensure the welding area is well ventilated with good air circulation.

Welding environment safety rules

- keep the welding area clean
- keep combustibles out of the weld area
- maintain good ventilation in the weld area
- repair or replace damaged power cables
- make sure the part to be welded is securely grounded/earthed
- welding helmets should have no light leaks. Should not have scratches or cracks
- use the proper colored lens with correct shade number in the helmet
- wear safety glasses when grinding
- do not see the arc with bare eyes
- use safety screens or shields to protect your area
- wear proper clothing. Your entire body should be covered to protect you from arc radiation
- when welding on cadmium coated steels, copper or beryllium copper use special ventilation to remove fumes from the weld area.

Introduction to GMAW

Objectives: At the end of this lesson you shall be able to

- state the main difference between shielded metal arc welding and CO₂ welding
- state the principle of CO₂ welding.

Introduction to CO₂ welding: Fusion welding of metal plates and sheets is the best method of joining metals because in this process the welded joint will possess the same properties and strength as the base metal.

Without a perfectly shielded arc and molten puddle, the atmospheric oxygen and nitrogen will get absorbed by the molten metal. This will result in weak and porous welds.

In shielded metal arc welding (SMAW) the arc and molten metal are protected/shielded by the gases produced by the burning of the flux coated on the electrode.

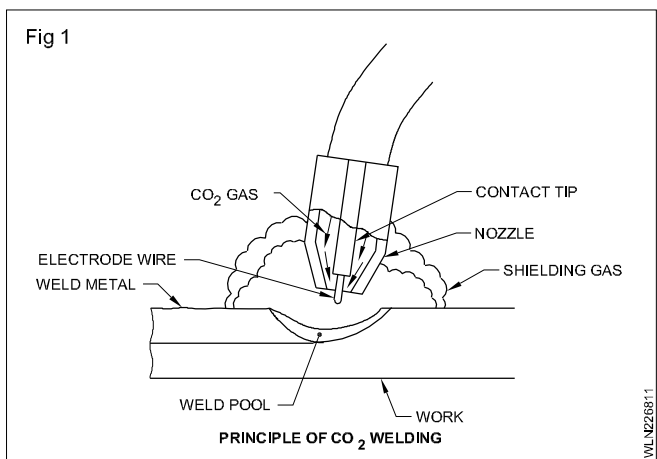
The above mentioned shielding action can be done by passing an inert gas such as argon, helium, carbon-dioxide through the welding torch/gun. The arc is produced between the base metal and a bare wire consumable electrode fed continuously through the torch.

Principle of GMA welding: In this welding process, an arc is struck between a continuously fed consumable bare wire electrode and the base metal. The heated base metal, the molten filler metal and the arc are shielded by the flow of inert/noninert gas passing through the welding torch/gun. (Fig.1)

If an inert gas is used to protect the arc produced by a consumable metal electrode, this process is called Metal Inert Gas Welding (MIG).

When carbon-dioxide is used for shielding purposes, it is not fully inert and it partly becomes an active gas. So CO₂ welding is also called as Metal Active Gas (MAG) welding.

MIG/MAG welding is a name with respect to gas used for shields purpose
On the other hand Gas Metal Arc Welding is the common name.



Basic equipment for a typical GMAW semiautomatic setup: (Fig 2)

- Welding Power Source - provides welding power.
- Wire Feeders - controls supply of wire to welding gun.
- Supply of Electrode Wire.
- Welding Gun - delivers electrode wire and shielding gas to the weld puddle.
- Shielding Gas Cylinder - provides a supply of shielding gas to the arc.

Other names

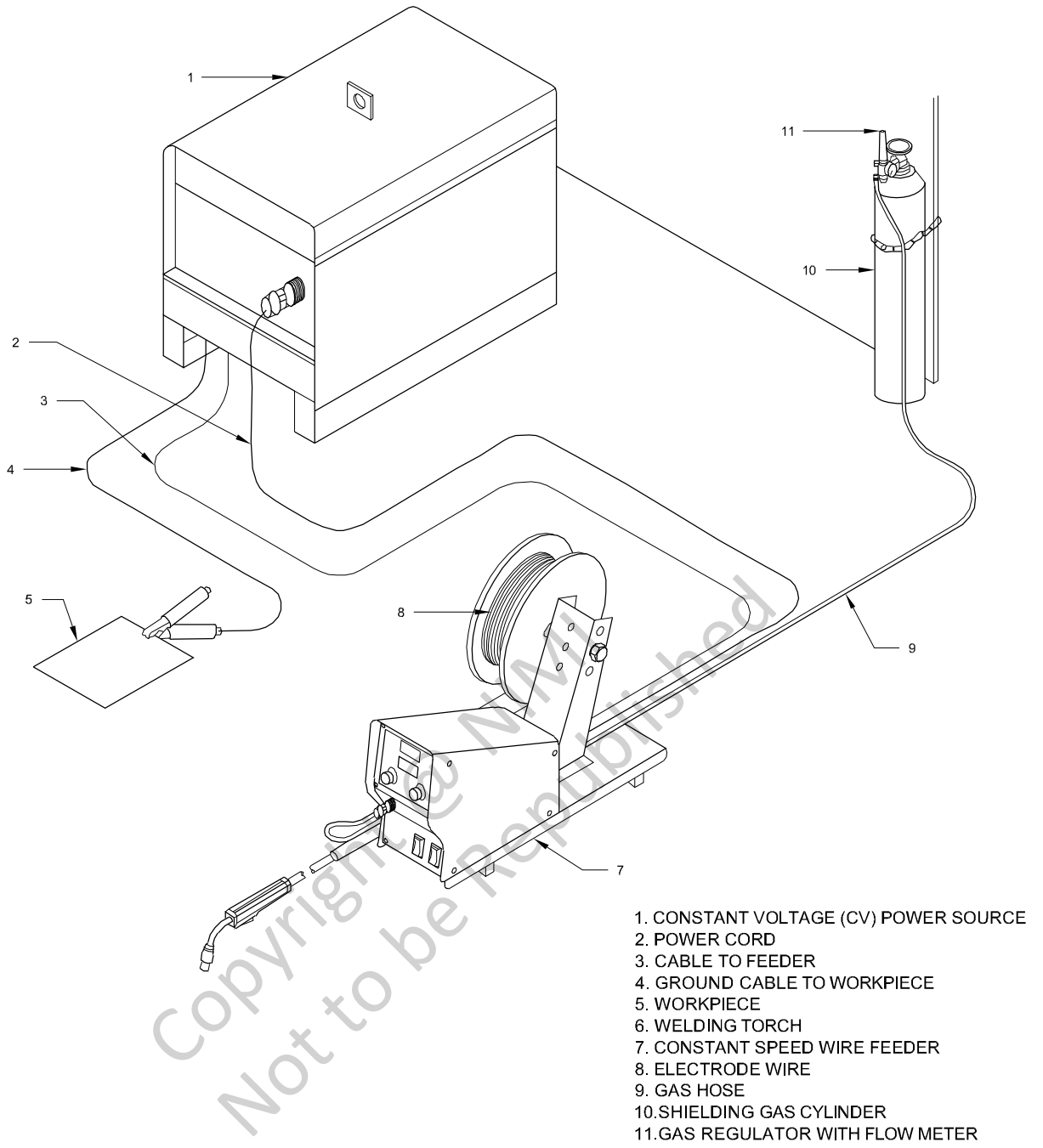
- MIG (Metal Inert Gas) welding,
- MAG (Metal Active Gas)/CO₂ Welding
- GMAW (Gas Metal Arc Welding)

GMAW can be done in three different ways:

- **Semiautomatic welding** - equipment controls only the electrode wire feeding. Movement of welding gun is controlled by hand. This may be called hand-held welding.
- **Machine welding** - uses a gun that is connected to a manipulator of some kind (not hand-held). An operator has to constantly set and adjust controls that move the manipulator.
- **Automatic welding** - uses equipment which welds without the constant adjusting of controls by a welder or operator.

On some equipment, automatic sensing devices control the correct gun alignment in a weld joint.

Fig 2



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Introduction to GMAW equipment and accessories

Objective: At the end of this lesson you shall be able to
• state the power sources for GMAW

MIG welding power sources have come a long way from the basic transformer type power source to the highly electronic and sophisticated types we see around today.

Even though the technology of MIG welding has changed, the principles of the MIG power source have, in most cases, not. The MIG power sources use mains power and converts that mains power into CV (constant voltage), DC (direct current) power suitable for the MIG welding process.

MIG welding power sources control voltage – this is done by either voltage stepped switches, wind handles, or electronically. The amperage that the power source produces is controlled by the cross sectional area of the wire electrode and the wire speed, ie the higher the wire speed for each wire size, the higher the amperage the power source will produce.

Because the output of the MIG power source is DC (direct current) the terminals on the front will have + positive and negative on the output side. The principles of electric circuits states that 70% of the heat is always on the positive side.

This means that the lead that is connected to the positive side of the welder, will carry 70% of the total energy (heat) output.

The characteristics volt, ampere curves (A & B) are shown in Fig.1.

Curve A (For SMAW): On the output slope or voltampere curve A, a change from 20 volts to 25 volts will result in a decrease in amperage from 135 amps to 126 amps. With

a change of 25 percent in voltage, only a 6.7 percent change occurs in the welding current in curve A. Thus if the welder varies the length of the arc, causing a change in voltage, there will be very little change in the current and the weld quality will be maintained. The current in this machine, even though it varies slightly is considered constant.

This is called drooping characteristic power source. Also called constant current (CC) power source.

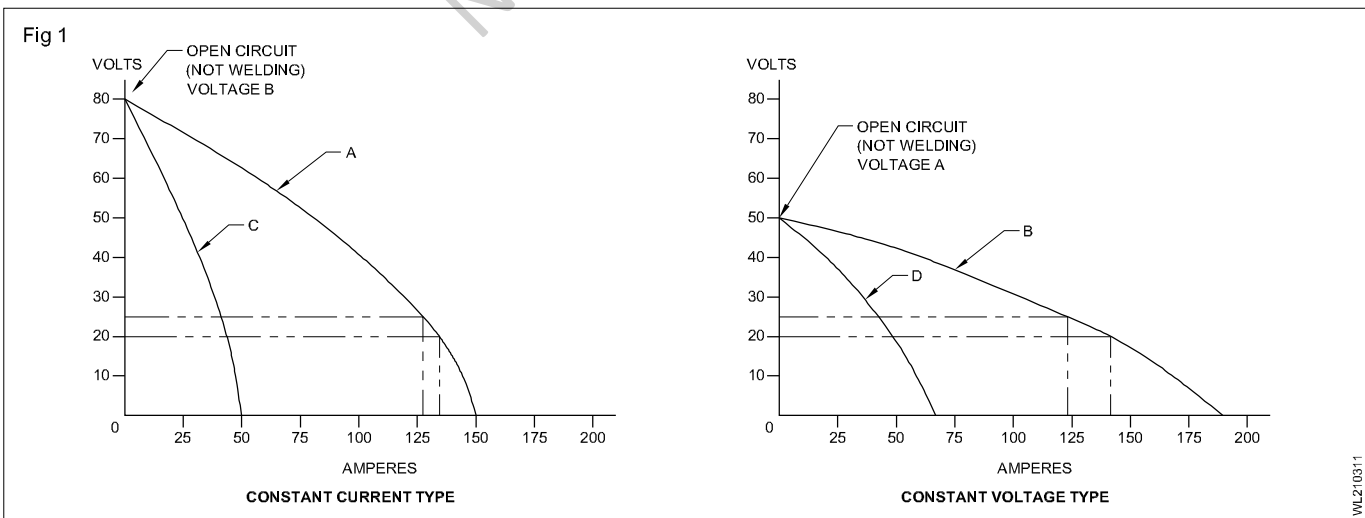
This type of power source is used in SMAW & GTAW process.

Curve B (For GMAW): The open circuit voltage curve for a setting of 50 volts on the machine is shown as curve B in the Fig.1. The same 20 volt to 25 volt (25 percent) change in the welding voltage will result in a drop in current from 142 amps to 124 amps or 13.3 percent. This slower sloping volt ampere curve output causes a large change in amperage with the same small change in voltage. A welder may wish to have this slower sloping (flatter) volt-ampere output curve.

This is called flat characteristic power source. Also called constant Voltage (CV) power source.

This type of power source is used in GMAW & SAW process.

With a flatter output slope the welder can control the molten pool and electrode melt rate by making small changes in the arc length. Control of the molten pool and electrode melt rate are most important when welding in the horizontal, vertical and overhead positions.



GMAW (MIG/MAG) torches

Objective: At the end of this lesson you shall be able to

- state the types and functions of torches.

MIG/MAG torch connection

The torch connection is the system in which the MIG torch is connected to the wire feeder. There are various types of MIG torch connections. Different manufacturers can use any one of many systems to connect their torch to the wire feeder.

When ordering a new Torch tell the supplier

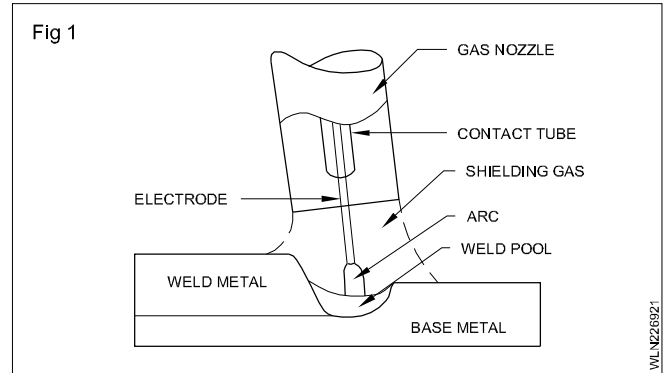
- the type of torch you need, including amperage rating
- the type of connection on the feeder so the torch can be supplied to match the connection

The Torch connection is also the area where the wire electrode, welding current and welding gases are passed onto the welding torch. This means these components should be checked for damage or leaky seals etc, so the connection will do its job correctly.

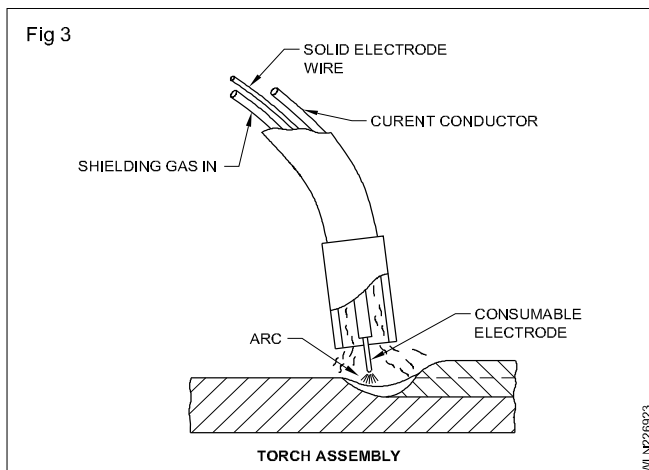
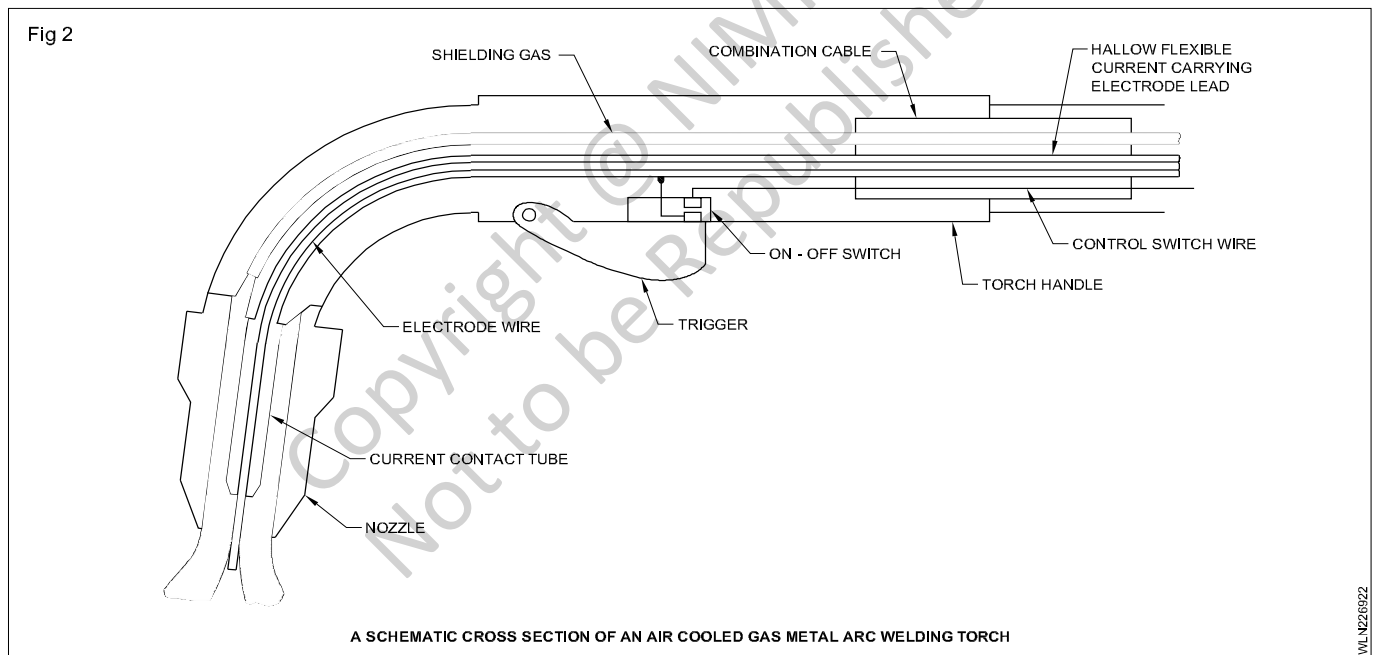
MIG/MAG torches

The MIG Torch is connected to the wire feeder, and its job

is to deliver the wire electrode, shielding gas and the electrical welding current to the welding area. There are a lot of different shapes and styles of MIG Torch out in the marketplace but they all have things in common. (Fig. 1 & 3).



- 1 Aircooled (less than 200 Amps) or watercooled (above 200 Amps) (Fig 2)



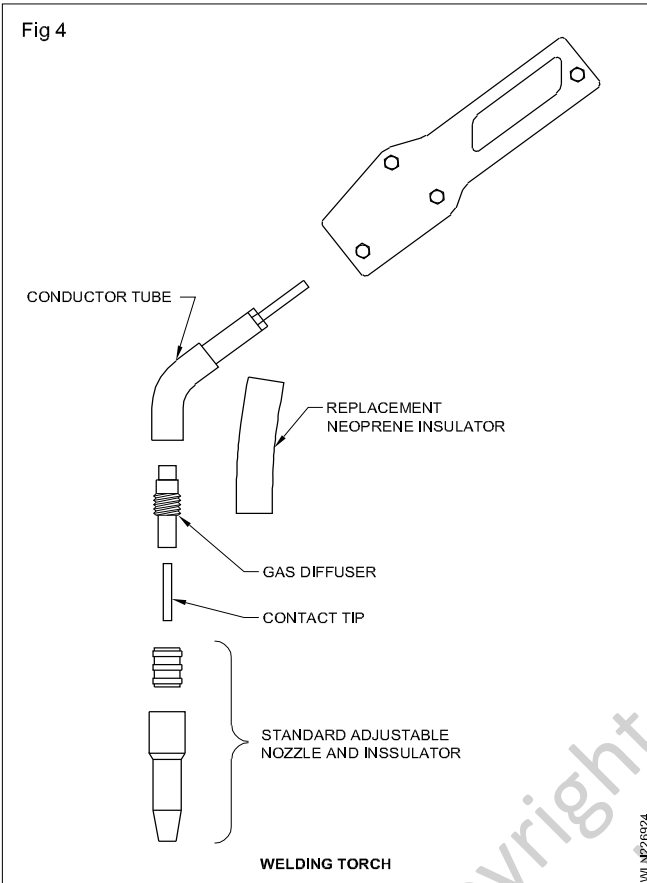
- 2 Current rating. The operator must select the correct size Torch. Using a torch that is not sufficiently rated for the machine may result in the Torch overheating. This may result in a poor weld and damage to the torch. A Torch with an excessive rating will be larger and heavier than the smaller Torch, which could result in discomfort for the operator.
- 3 They all have parts that will wear out (consumables eg liners, tips, diffuser, nozzle, etc.)

Let's take a look at each part (Fig 4)

Liner: The liner causes the most problems. First, they have a life span that is approximately one to four rolls of MIG wire depending on the quality of the liner and wire.

The life of the liner will also be increased if the operator removes and cleans it by soaking in non-corrosive and a non-toxic solvent. Each wire size needs to have the correct wire size liner. Be aware some liners may fit more than one size of wire.

There are also different materials for different types of wire electrode, eg **steel or stainless liners for solid wires and Teflon liner for aluminium.**



The liner length is most important. In the field it is very common to find even newly fitted liners that have been cut too short. This results in the wire being able to move around behind the welding tip and leading to bad wire feeding. The liner has to be fitted correctly and different MIG Torch will often have a different way of ending up with a liner that is the correct length.

Don't just take out the old liner and cut the new one to the same length. It could end up with an incorrect result. Please refer to MIG Torch manual.

All MIG Torch should be laid out straight on the floor before trimming the liner, to prevent the new liner being cut too short. Do not cut the liner if the torch lead is coiled up.

Gas diffusers The gas diffuser's job is to make sure that the shielding gas is delivered to the shielding nozzle correctly. It is designed to make the gas come out as straight as possible and equally supplied around inside the gas shield nozzle. Diffusers can be made of different materials, eg copper, brass or fibre. Some diffusers will also be the tip holder.

Contact tip holder This is the item which holds the welding tip in place. Again, tip holders can be very different in

design and are very often unique to that brand of MIG torch.

Contact tips The Contact tip/tube is the key to good welding. First of all, it is the way that welding amperage is delivered to the welding wire electrode, often with a very high amperage.

Most contact tips are made of copper alloy, the better the alloy the better the tip will pass current to the wire electrode and the less wear the MIG tip will have; also the less the tip will oxidize.

The size is important. The right size contact tip must be selected. If the selected tip size is too large the wire electrode will not make a good contact, leading to poor welding performance.

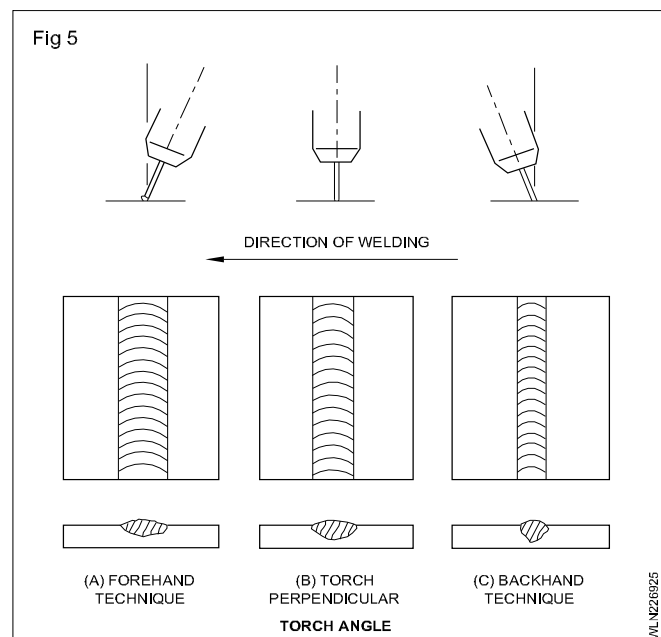
If a contact tip selected is too small, the wire electrode will feed poorly and may even jam in the contact tip.

Nozzle: Guns are available with a straight or curved nozzle. The curved nozzle provides easy access to intricate joints and difficult-to-weld.

Torch angle

The position of gun and electrode with respect to the joint affects the weld bead shape and penetration rather than arc voltage or travel speed. The gun is usually maintained within 10 - 20° on either side of the vertical. Depending on which way the gun is incline, the technique is referred to as forehand and backhand. The various electrode positions and techniques and their effects are shown in Fig 5. It is observed that as the electrode is changed from perpendicular to the forehand technique, the weld bead becomes shallower and wider and has less penetration.

Backhand technique gives a more stable arc, less spatter and a narrower, more convex weld bead with deep penetration. Perpendicular technique is used more in automatic welding and avoided in semi-automatic mode because the end of the gas nozzle restricts the operator's view of the weld pool.

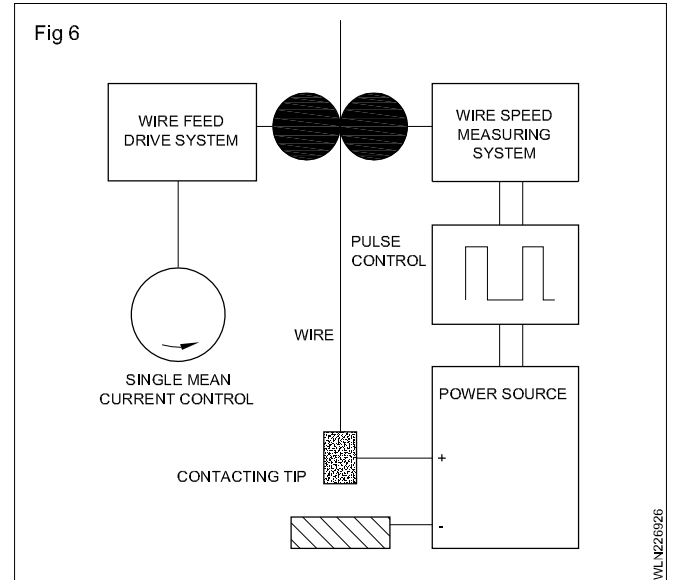


Synergic Control

The complexity of setting welding parameters in conventional DC and pulsed GMAW promoted the development of equipment with 'Single-knob' controls known as Synergic Control. These systems relied on selection of combinations of present welding (e.g. Wire feed speed/mean current and voltage) by means of a single control.

This is possible now because of development of electronic power regulation and micro processor control and programmable equipment which can supply a large number of predetermined welding conditions as well as allowing users to record and retrieve their own customised parameters.

Although in the pulsed GMAW process the optimum welding parameters can be accurately predetermined, if a change in mean current is required the control settings must be recalculated and a number of the welding parameters reset. This could impose significant practical problems including the possibility of error and resultant deterioration in operating performance. Fortunately it is possible to store both the predetermined parameters and the control equations in the equipment and automatically adjust the output in response to a single input signal. This system is known as Synergic Control (Fig. 6).



Advantages, disadvantages of GMAW over SMAW process and applications

Objectives: At the end of this lesson you shall be able to

- state the advantages and disadvantages of Co_2 welding over shielded metal arc welding process
 - state the applications of Co_2 welding.
-

Advantages: Welding is economical due to less edge preparation and no stub loss.

Produces joints with deep penetration.

Thin and thick materials can be welded.

It can be used for welding of carbon steels, alloy steel, stainless steel, copper and its alloys, aluminium and its alloys.

Welding in all positions can be done.

Deposition rate is more.

No solid flux is used. So needs no cleaning of slag after each run.

Reduced distortion.

Disadvantages

Welding equipment is costly, more complex and less portable.

Since air drifts may disturb free flow of the shielding gas, GMAW may not work well in outdoor welding.

Applications: This process can be used for welding carbon, steel alloy steels, stainless steel, aluminium, copper, nickel and their alloys, titanium etc.

Light and heavy fabrication work.

This process is successfully used in ship building fabrication of pressure vessels and automobile industries.

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Process variables of GMAW

Objectives: At the end of this lesson you shall be able to

- state the type of edge preparation done for CO₂ welding
- state and explain different welding parameters to be set for CO₂ welding
- explain the welding procedure while using CO₂ welding process.

GMA welding process parameters/variables

The following parameters must be considered in the welding procedure of GMAW/CO₂ welding.

- Electrode size
- Rate of wire feed (Welding current)
- Arc voltage
- Stick out
- welding position
- Shielding gas
- Travel speed
- electrode position

Electrode: Best results are obtained by using the proper size wire for the thickness of the metal to be welded and the position in which the welding is to be done.

Electrode wires should be of the same composition as that of the material being welded.

Basic wire diameters are 0.8 mm, 1.0 mm, 1.2 mm, 1.6 mm and 2.4 mm.

Welding current: The wire feed speed will control the current. A wide range of current values can be used with each wire diameter. This permits welding metal of various thicknesses without having to change the wire diameter. The current selected should be high enough to secure the desired penetration and low enough to avoid under-cutting or burn through.

The success of GMA welding is due to the concentration of high current density at the electrode tip.

General data on current selection is given in the table given below.

The current varies as the wire feed varies.

Ranges of wire feed rate in CO₂ welding (Current is shown in brackets)
Wire feed speed, m/min]

Wire dia. (mm)	Spray type arcs (28 - 32 V)	Short circuiting arcs (16-22 V)
0.8	5.0-15 (150-250 amps)	2.5-7.5 (60-160 amps)
1.2	5.0-15 (200-350 amps)	2.0-3.8 (100-175 amps)
1.6	5.0-8.8 (350-500 amps)	1.5-2.0 (120-180 amps)

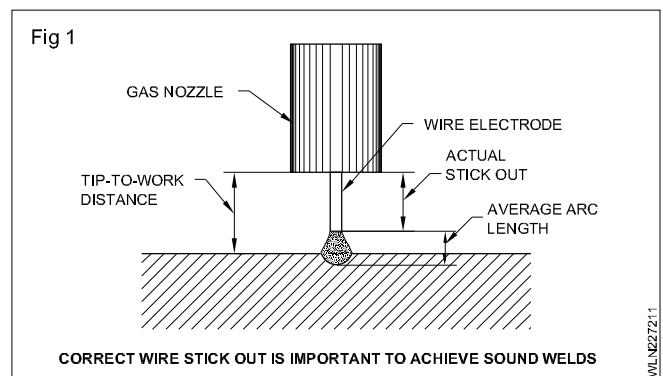
Arc voltage: This is a very important variable in GMAW/CO₂ welding process, mainly because it determines the type of metal transfer by influencing the rate of droplet transfer across the arc. The arc voltage to be used depends on the base metal thickness, type of joint, electrode composition and size, shielding gas composition, welding position, type of weld and other factors.

For details refer to the table of General guide to welding conditions.

Arc travel speed: The linear rate at which the arc moves along the joint, termed arc travel speed, affects the weld bead size and penetration.

If the arc travel speed is lowered, the weld pool becomes larger and shallower. As the travel speed is increased, the heat input rate of the arc is decreased; consequently there is decreased penetration and narrower weld bead. When the travel speed is excessive, undercutting occurs along the weld bead, because the deposition of the filler metal is not sufficient to fill the paths melted by the arc.

Stick out: It is the distance between the end of the contact tube and the tip of the electrode. (Fig 1)

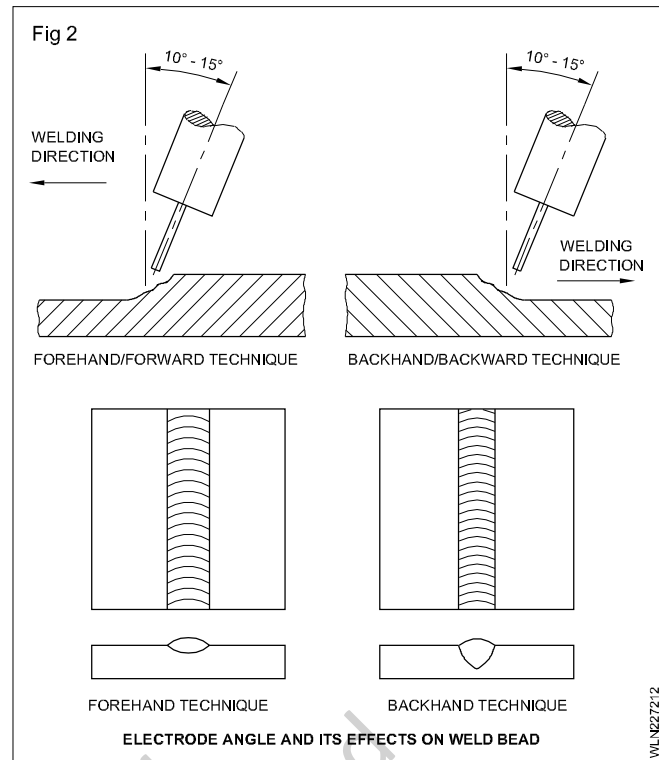


Too long a stick out results in excess weld metal being deposited at low arc heat, giving rise to badly shaped weld and shallow penetration.

When the stick out is too short, excessive spatter gets deposited on the nozzle, which can restrict the shielding gas flow and cause porosity in the weld.

Recommended stickout is 6 to 13 mm for a short circuiting arc, and 13 to 25 mm for the spray transfer arc.

Electrode position: In all welding processes, the position of the gun and electrode with respect to the joint affects the weld bead shape and penetration. The welding can be done either by using Forehand/Forward technique or by using Backhand/ Backward technique. The gun angles are usually maintained within 10 to 15° as shown in Fig 2.



Modes of metal transfer in GMAW

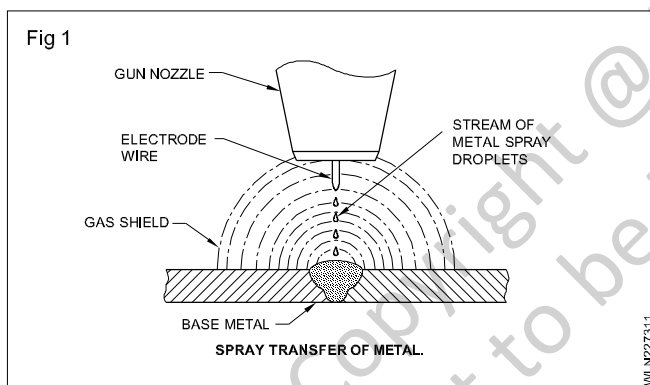
Objective: At the end of this lesson you shall be able to
 • state and explain the different types of metal transfer in CO₂ welding.

Types of metal transfer: In GMAW/CO₂ welding process, the weld metal is transferred from the electrode wire to the base metal in different methods/modes. Though there are many methods, only the following four methods are used popularly used in industries.

- Spray transfer (Free flight)
- Globular transfer (Intermediate)
- Short circuit or Dip transfer
- Pulsed transfer

The type of metal transfer that occurs will depend on the electrode wire size, shielding gas, **arc voltage** and welding current.

Spray transfer: In spray transfer very fine droplets of the electrode wire are rapidly projected through the arc from the end of the electrode to the workpiece. (Fig.1) Spray transfer requires high current density (28 to 32V).



To obtain a good spray mode of welding shielding gases containing a blend of argon is used. The spray method of metal transfer can be used with most of the common welding wire electrodes (eg mild steel, aluminium, stainless steel).

The advantages of metal spray transfer are

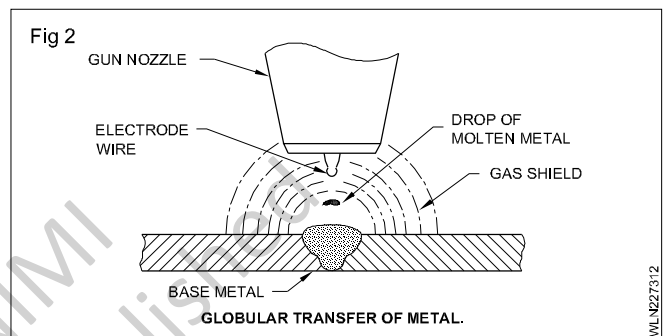
- i high deposition rates
- ii good travel speeds
- iii good looking weld appearance
- iv little weld spatter
- v good weld fusion
- vi very good on heavy sections

The disadvantages of the spray mode are

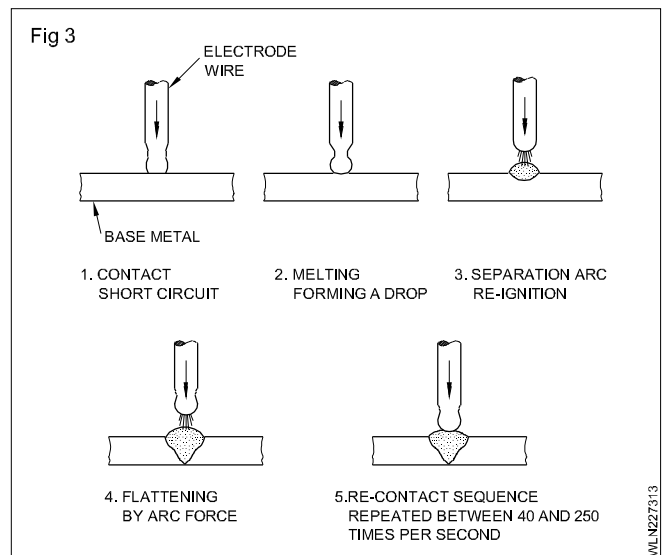
- i higher capacity power source needed
- ii weld position is limited to flat and horizontal fillet
- iii the cost of using a more expensive mixed gas
- iv higher radiated heat is produced so extra protection is needed

Globular transfer: In globular transfer, only a few drops are transferred per second at low current values, while many drops are transferred at high current values. This transfer occurs when the welding current is low. (Fig. 2). The voltage range is 23 to 27V.

The spatter produced in this transfer is more and hence it is less preferred. But this is a good transfer method for using CO₂ gas as a shielding gas.



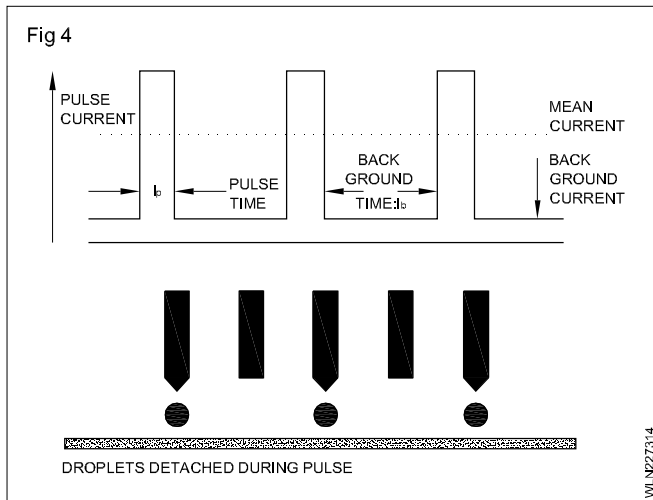
Short circuit transfer (DIP transfer): In short circuit transfer, as the molten wire is transferred to the weld, each drop touches the weld puddle before it breaks away from the advancing electrode wire. The circuit is shorted and the arc is extinguished. (Fig 3). The voltage range is 16 to 22V.



It permits welding thinner sections with greater ease, and is extremely practical for welding in all positions.

Pulsed spray transfer (Fig 4)

Pulsed spray transfer has a steady stream of metal droplets crossing the welding arc. The pulsed power source supplies the welding arc with two types of welding current.



- 1 **Peak current** - this current allows the formation of metal droplets which then cross the welding arc.
- 2 **Background current** - the background current will keep the arc alive, but doesn't allow for any weld metal transfer.

Pulsed spray transfer allows time for the weld puddle to freeze a little on the background current cycle, which allows for

- i more control of the weld puddle.
- ii more time for impurities to float to the top of the weld pool resulting in cleaner and stronger welds.

Advantages

- i able to spray thinner metals
- ii less heat input
- iii stronger welds
- iv more weld control
- v out-of-position welding
- vi Little spatters

Disadvantages

- i higher set up costs
- ii needs operator training
- iii lower deposition rate

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Wire feed system

Objective: At the end of this lesson you shall be able to
 • state the functions of wire feeder and different types of drive rollers.

Wire feeder (Fig 1)

The wire feeder is the part of the MIG/MAG welding set up that:

- i) Controls the speed of the wire electrode and pushes this wire from the feeder through the welding torch to the workpiece.
- ii) Provides the path for welding current to be passed from the welding power source through the interconnecting lead to the feeder and then to the welding torch.
- iii) Provides gas flow control through a solenoid valve. The gas is fed down from the gas regulator to the weld area via the feeder and then the MIG welding torch.

Wire feeders come in many different shapes and sizes, but they all do the same basic job roles. Feeders can be separated from the power source or built into the power source itself. Feeders are made up of different parts, each having a different job role.

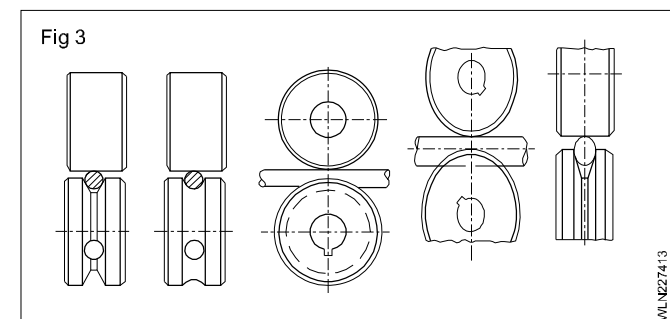
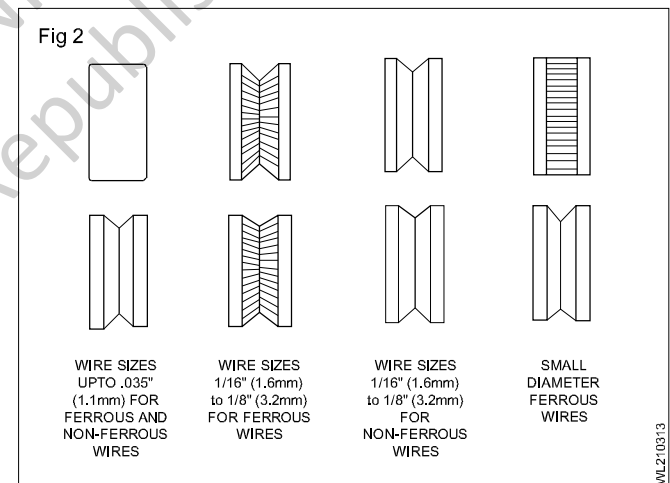
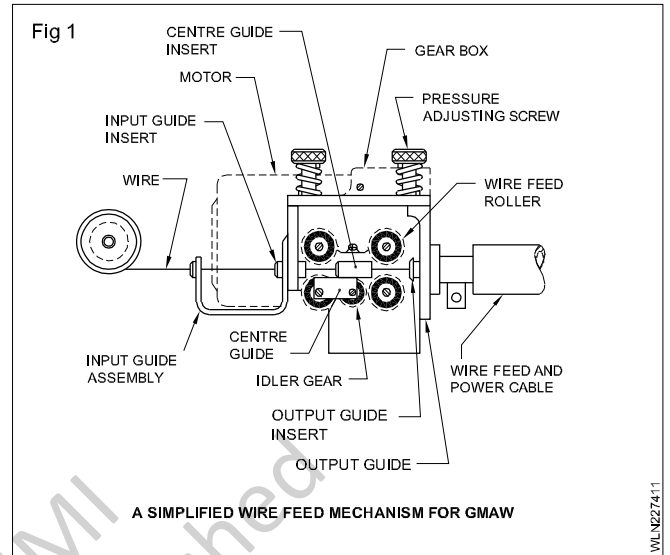
Wire spool holder. This is designed to hold the spool of the correct wire size in place on the feeder to ensure the wire electrode is on the correct input angle for the drive roller to be able to do its job properly.

Drive motor MIG/MAG welding relies on smooth and constant wire feed. The wire drive motor has the job of turning the drive rollers (this can be one or more sets of rollers). Undersize drive motors can result in poor feeding of the wire electrode down the MIG welding torch. This will have the effect of making the overall performance of the MIG machine sub-standard as compared to a machine with a quality drive system.

Drive rollers: The drive rollers grasp the wire electrode and continuously feed the wire down the MIG torch into the welding arc (Fig 2 & 3). The rollers need to be selected by :

- i) the wire size
- ii) the type of wire to be fed. Each type of wire may need a different style of roller groove – eg
 - V rollers for steel and other hard wires
 - V-Knurled for Fluxcored wire
 - U-Grooved for aluminium and other soft wires

The idea of using the correct roller is to have a good wire drive without crushing the wire. The pressure roller is also used to set the wire tension. This must be set with enough pressure to feed the wire electrode, but not too much tension as to crush the wire.



- iii) all guides must be as close as possible to the drive roller to prevent the possibility of the wire bunching up.

Wire feed controls

The wire feeder will have its own built-in control system. The number of controls that will be built into the feeder will depend on the type of feeder but the most common are

i) Wire speed - this control is the adjustment for how fast the drive rollers will turn and as stated earlier, the faster the wire speed for each wire size the more amperage the power source will produce. The wire speed controls can be labelled as wire speed, eg ipm (inches per minute) or mpm (metre per minute), or as a percentage from the slowest speed being zero to the highest speed being 100%. Usually mpm will be the range of 1 m/min to 25 m/min.

The amperage being set by the wire speed setting will also have an effect on the speed of travel and the deposition rate of the wire (how fast the weld metal is being put onto the weldpiece); with the advantage of, the higher the amperage the thicker the material that can be welded.

ii) Purge switch - Some feeders have a purge switch. This is to allow the gas flow setting to be set on the gas regulator without turning of the wire feed roller or without any welding power being turned on.

iii) Burnback - Burnback is the setting of the degree that the wire electrode will melt back towards the contact tip at the completion of the weld. If there is too much burnback the wire electrode will melt back onto the contact tip, possibly damaging it. If there is not enough burnback set, the wire electrode will not melt away from the weldpool and can be left stuck to the weld metal.

iv) Spot timers or stitch modes are to be found on some feeders. These controls normally control the time the drive roller will turn for after the trigger contactor has been activated.

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Welder - Gas metal arc welding

Welding wires used for GMAW, standard diameter and codification as per AWS

Objective: At the end of this lesson you shall be able to
 • state the chemical composition of different electrode wires.

Electrode wire - consumable wire for GMAW: Performance & metal transfer characteristics are largely governed by the diameter of the wire and the machine settings such as arc voltage and amperage and chemical properties of the filler wire employed.

Machine settings: Diameter of the wire and ampere/ current employed for welding decide the type of metal transfer. The various recommended diameter, voltage and current ranges are tabulated in tables below for welding mild steel, low alloy steel and stainless steel.

Approx. machine settings for short circuit metal transfer on mild and low alloy steel

Electrode diameter(mm)	Arc voltage	Amperage range
0.8	16-22	80-190
1.2	17-22	100-225

Approx. machine settings for spray arc transfer on mild and low alloy steel

Electrode diameter(mm)	Arc voltage	Amperage range
0.8	24-28	150-265
1.2	24-30	200-315
1.6	24-32	275-500

Approx. machine settings for short circuit transfer on series 300 stainless steel

Electrode diameter(mm)	Arc voltage	Amperage range
0.8	17-22	50-180
1.2	17-22	100-210

Approx. machine settings for spray transfer on series 300 stainless steel

Electrode diameter(mm)	Arc voltage	Amperage range
0.8	24-28	160-210
1.2	24-30	200-300
1.6	24-32	215-325

Chemical properties: Chemical compositions of the filler wire play a very important role. The main composition, apart from the major elements, in the case of mild steel welding, will contain deoxidisers like Si, Mn to take care of porosity due to oxidation of carbon in the steel. Typical composition of mild steel filler wires are listed in the table. We are using ER70S-6 for most of our carbon steel fabrication.

Specification of electrode wires

The GMAW electrode specification as per AWS is as given below.

Eg: E 70S-2 or ER70S-2 or E70T-2

E — Electrode

ER — Electrode can also be used as a filled Rod in GTAW.

70 — 70 x 1000 PSI — Tensile strength of the weld metal in pounds per square inch.

S — Solid wire / Rod

T — Tubular wire used in FCAW.

2 — Chemical composition of the wire.

Chemical composition, Weight percent

AWS classification	c	Mn	Si	P	S	Cu	Ti	Zr	Al
70S-2	0.07	0.90 to 1.40	0.40 to 1.40	0.025	0.035	0.5	0.05 to 0.15	0.02 to 0.12	0.05 to 0.15
70S-3	0.06 to 0.15	0.90 to 1.4	0.45 to 0.7						
70S-6	0.07 to 0.15	1.4 to 1.85	0.8 to 1.15						

Wire electrodes selection

The selection of the wire electrode to be used in the MIG/MAG process is a decision that will depend on

- 1 the process being used (eg, solid wire or fluxcore wire)
- 2 the composition of the metal being welded
- 3 welding indoors or outdoors
- 4 joint design
- 5 cost
- 6 mechanical properties of the weld material and those that are a match for the base material.

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Types of shielding gases for GMAW

Objectives: At the end of this lesson you shall be able to

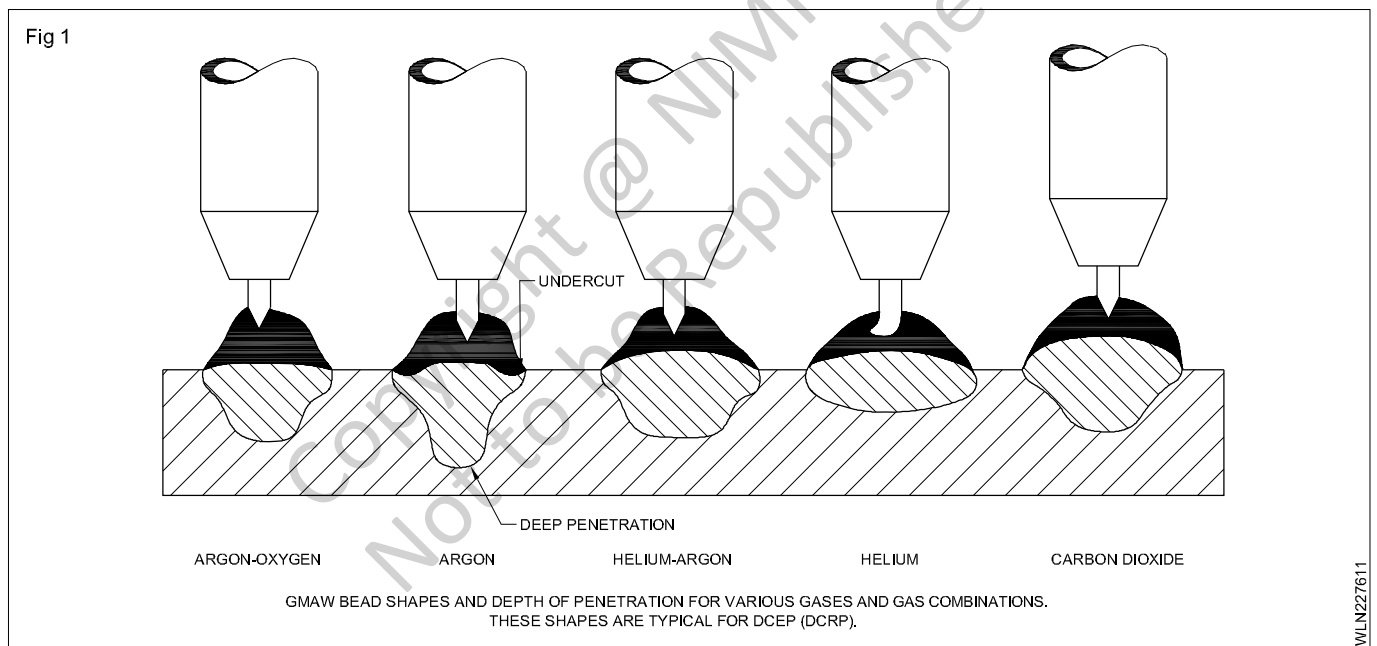
- state the different types of shielding gases used in Gas Metal Arc Welding (GMAW) process
- state the effects of different shielded gases and gas mixtures on ferrous and non-ferrous metals
- select the inert gas or gas mixtures for welding different metals using different modes of metal transfer
- explain why a gas heater is used in CO₂ welding plant.

There are three types of shielding gases used for GMAW. They are inert gases, reactive gases and gas mixtures.

Inert gases: Pure argon and helium gas are excellent for protecting the arc, metal electrode and weld metal from contamination. Argon and helium are generally used for GMAW of non ferrous metals. Helium has very good conductivity and conducts heat better than argon. Therefore helium is chosen for welding thicker metals as well as high conductivity metals like copper and aluminium.

For thinner metal welding, lower conductivity argon is the better choice. Also argon is often used for welding out of position because of its lower thermal conductivity. Argon gas is 10 times heavier than helium gas, hence less argon gas is required to provide a good shield as compared to helium gas.

The weld bead contour and penetration are also affected by the gas used. Welds made with argon generally have deeper penetration. They also have a tendency to undercut at the edges. Welds made with helium have wider and thicker beads. Fig.1 shows the shape of welds made with various gases and gas mixtures.



Argon used with the gas metal arc spray transfer process tends to produce deeper penetration through the center line of the bead. Spray transfer occurs more easily in argon than in helium.

Reactive gases and gas mixtures used in GMAW

Carbondioxide: Carbondioxide (CO₂) has a higher thermal heat conductivity than argon. This gas requires a higher voltage than argon. Since it is heavy, it covers the weld well. Therefore less gas is needed.

CO₂ gas is cheaper than argon. This price difference will vary in various locations. Beads made with CO₂ have a very good contour. The beads are wide and have deep penetration and no undercutting.

The arc in a CO₂ atmosphere is unstable and a great deal of spattering occurs. This is reduced by holding a short arc. Deoxidizers like aluminium, manganese or silicon are often used.

The deoxidizers remove the oxygen from the weld metal. Good ventilation is required when using pure CO₂. About 7-12 percent of the CO₂ becomes CO (carbon monoxide) in the arc. The amount increases with the arc length.

A 25% higher current is used with CO₂ than with argon or helium. This causes more agitation of the weld puddle, hence entrapped gases raises to the surface of the weld, so low weld porosity.

Argon carbondioxide: CO₂ in argon gas makes the molten metal in the arc crater more fluid. This helps to eliminate undercutting when GMA welding carbon steels.

CO₂ also stabilizes the arc, reduces spatter and promotes a straight line (axial) metal transfer through the arc.

Argon-Oxygen: Argon-oxygen gas mixtures are used on low alloy carbon and stainless steels. A 1-5 percent oxygen mixture will produce beads with wider, less finger shaped, penetration. Oxygen also improves the weld contour, makes the weld pool more fluid and eliminates undercutting.

Oxygen seems to stabilize the arc and reduce spatter. The use of oxygen will cause the metal surface to oxidise slightly. This oxidization will generally not reduce the

strength or appearance of the weld to an unacceptable level. If more than 2% oxygen is used with low alloy steel, a more expensive electrode wire with additional deoxidisers must be used.

The desirable rate of gas flow will depend on the type of electrode wire, speed and current being used and the metal transfer mode.

As a rule small weld pools 10 L/min
 medium weld pools 15 L/min
 and large spray weld pools 20-25 L/min

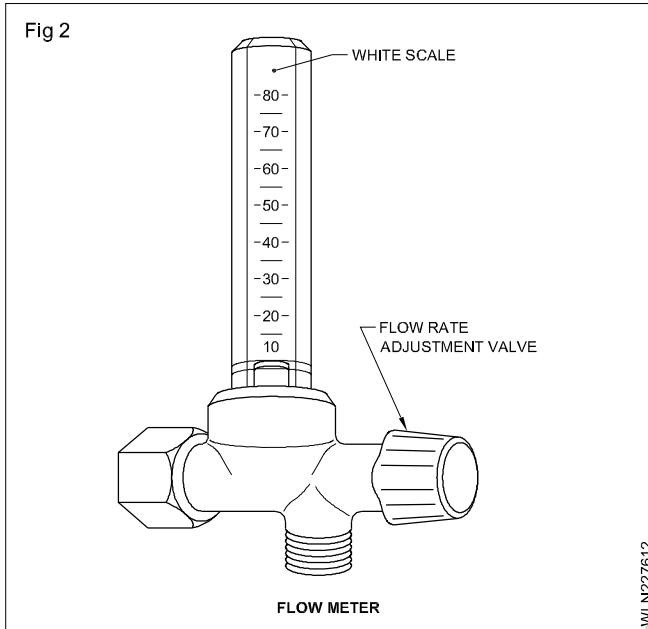
Too much gas flow can be just as bad as not having enough. The reason being that if the gas flow is too high it will come out of the MIG Torch.

Suggested gases and gas mixtures for use in GMAW spray transfer

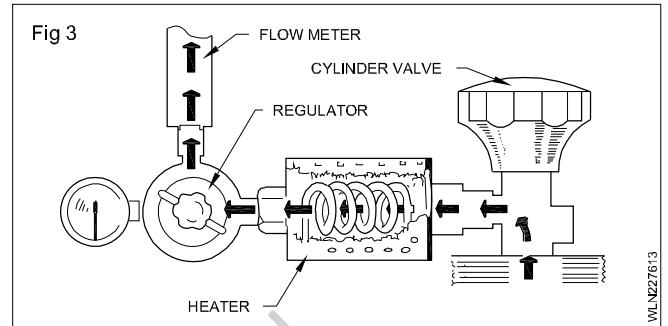
Metal	Shielding gas	Advantages
Aluminium	Argon	0.1 in.(2.5mm) thick; best metal transfer and arc stability; least spatter
	75% Helium 25% argon	1-3 in.(25-76mm) thick; higher heat input than argon
Copper, nickel and alloys	Argon	Provide good wetting; good control of weld pool for thickness up to 1/8 in.(3.2mm)
Magnesium	Argon	Excellent cleaning action
Carbon Steel,	Argon 5-8% CO ₂	Good arc stability; produces a more fluid and controllable weld pool; good coalescence and bead contour, minimizes undercutting ; permits higher speeds compared with argon.
Low alloy Steel	Argon 2% oxygen	Minimizes undercutting; provides good toughness
Stainless Steel	Argon 1% oxygen	Good arc stability; produces a more fluid and controllable weld pool, good coalescence and bead contour, minimizes under cutting on heavier stainless steels
	Argon 2% oxygen	Provides better arc stability, coalescence and welding speed than 1% oxygen mixture for thinner stainless steel materials
Aluminium copper, magnesium, nickel and their alloys	Argon and argon helium	Argon satisfactory on sheet metal argon-helium preferred on thicker sheet metal
Carbon steel	Argon 20-25% CO ₂	Less than 1/8 in.(3.2mm) thick; high welding speeds without melt through; minimum distortion and spatter; good penetration
	CO ₂	Deeper penetration; faster welding speeds; minimum cost
Stainless Steel	90% helium 7.5% argon 2.5% CO ₂	No effect on corrosion resistance small heat affected zone; no undercutting; minimum distortion; good arc stability

CO₂ gas cylinder and regulator: The shielding gas required for GMAW/CO₂ welding is supplied from a gas cylinder through an outlet valve and regulator.

Gas flow meter: It is a unit which has graduations marked on the glass tube. A flow rate adjustment valve fixed to the flow meter controls the rate of flow of inert gas/CO₂ gas to the welding gun in litre per minute. Fig. 2.



Gas Preheater for CO₂ welding (Fig 3): Carbon dioxide is filled in cylinders in liquid form. i.e., the CO₂ at room temperature and high pressure condenses into liquid form. Therefore while welding the liquid CO₂ has to be in gaseous form as they enter into the welding torch. CO₂ liquid boils and expands into gas as it passes through the regulator. This causes the gas to cool. If moisture is present in the regulator inlet, it will condense and freeze in the regulator, causing blocking of the gas passage. Therefore to avoid cooling a gas heater is connected to the cylinder to increase the temperature of the gas leaving the cylinder. Hence a uniform gas flow is maintained during welding.



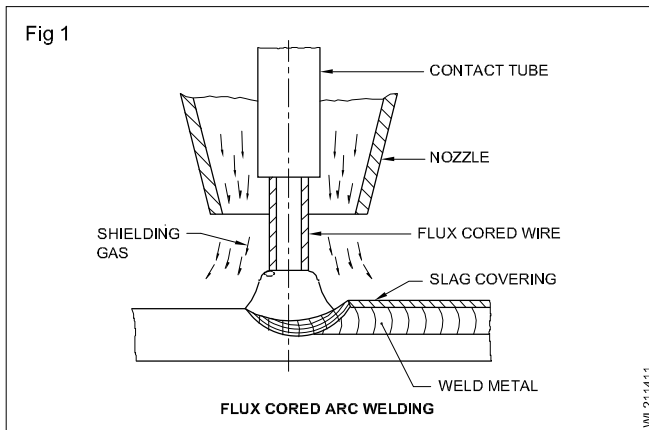
Welder - Gas metal arc welding

Flux Cored Arc Welding (FCAW)

Objectives: At the end of this lesson you shall be able to

- explain the flux cored arc welding and narrow gap welding process
- explain the type of metal transfer in flux cord Arc welding
- classification of flux cored wires

Flux Cored Arc Welding (FCAW) Fig.1 is an arc welding process in which the heat for welding is produced by an arc established between the flux cored tubular consumable electrode wire and the workpiece.



There are two major versions of the process, namely self shielded type (in which the flux performs all the functions of shielding) and the 'gas shielded type', which requires additional gas shielding.

The gas shielded type FCAW is widely employed for welding of carbon steel, low alloy steel and stainless steel in flat, horizontal and overhead positions.

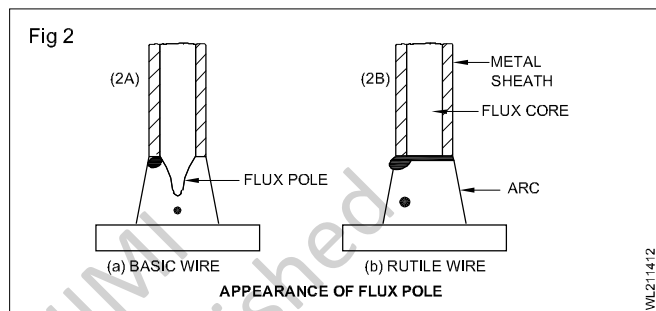
However, the self shielded type FCAW is mainly used for carbon steel welding and the quality of weld produced by this type is generally inferior to that of welds made with gas shielded type.

Equipment: The noticeable differences in the equipment used for GMAW and FCAW, are in the construction of welding torch and feed rollers.

The welding torch used for self shielded wire is very simple in construction as there is no need for the gas nozzle. Similarly the feed rollers used for flux cored wires have to ensure positive feeding of the wire without applying too much pressure on the soft tubular wire.

Metal transfer in FCAW: The metal transfer in FCAW differs significantly from GMAW process. FCAW process exhibits two distinctly different modes of metal transfer, namely large droplet transfer and small droplet transfer. However, both are classified as free flight transfer. The FCAW process does not produce a stable dip transfer as that of solid wire GMAW. The large droplet transfer occurs at the lower current voltage ranges. At higher current voltage ranges, the transfer mode changes to smaller

droplet transfer. An important aspect to be observed during FCAW metal transfer is the presence of the 'flux pole' at the core of the arc column, protruding into the arc. The 'flux pole' appears only during welding with basic type flux cored wire. Fig.2(a) However, with rutile wire 'flux pole' does not occur and the metal transfer is of spray type. Fig.2(b)



Classification of flux cored wires: The basic functions of the flux contained within the tubular wire include providing protective slag on the weld bead, introducing the required alloying elements and deoxygenators into the weld pool and providing stability to the arc, besides producing the required shielding medium to protect the arc and weld pool.

Flux cored wires are now available for welding of plain carbon steel, low alloy steel and stainless steel and also for hard facing applications. These wires based on the nature of flux, may be classified as rutile gas shielded, basic gas shielded, metal cored and self shielded.

Rutile gas shielded wires have extremely good arc running characteristics, excellent positional welding capabilities and good slag removal and mechanical properties.

Basic gas shielded wires give reasonable arc characteristics, excellent tolerance to operating parameters and very good mechanical properties.

Metal cored wires contain very little mineral flux, the major constituent being iron powder and ferro alloys. These wires give smooth spray transfer in Argon/CO₂ gas mixtures. They generate minimum slag and are suitable for mechanised welding applications. Self shielded wires are available for general purpose down hand welding.

The flux cored wires are available in both seamless and folded types. The seamless type is generally coated with copper, whereas the folded type wires (i.e. close butt and overlapped type) are treated with special compounds.

Deposition rate and efficiency: Deposition rate is defined as the weight of metal deposited per unit time. The deposition efficiency is defined as the ratio of weight of weld metal effectively deposited to the weight of wire consumed.

In GMAW welding the deposition efficiency is generally between 93% to 97% and in FCAW the corresponding figure is between 80% to 86%. These values are determined by the spatter losses and slag formation. The low deposition efficiency in the case FCAW is due to the slag formation.

Generally the spatter loss can be minimised by using Argon/CO₂ mixed gas instead of CO₂ gas.

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Edge preparation of various thickness of metals (GMAW)

Objectives: At the end of this lesson you shall be able to

- state the edge preparation of GMAW
- describe the various types of welding process for required preparation.

Base metal preparation: For GMAW/CO₂ welding the edges and the plate surfaces for welding of ferrous and non-ferrous metals are cleaned similar to Shielded Metal Arc Welding process. The groove angle for single V butt joint in case of CO₂ welding is 40° to 45° only when compared to 60° used for shielded metal arc welding (Figs 1, 2 & 3). The edge preparation required for the various types of welding process.

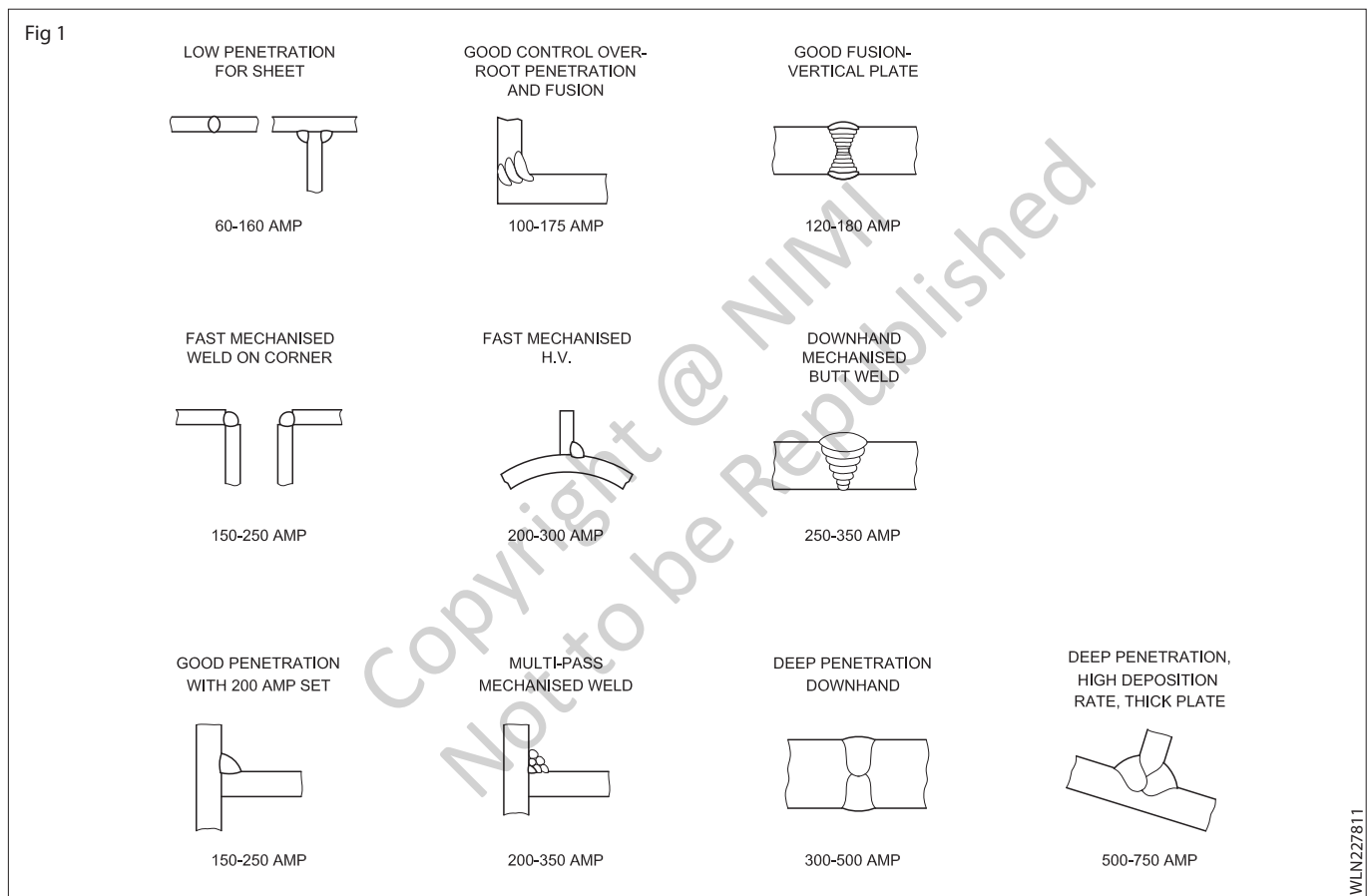


Fig 2

MATERIAL THICKNESS	PROCESS				
	MANUAL METALLIC ARC	MANUAL CO ₂ DIP. TRANSFER	MANUAL CO ₂ SPRAY TRANSFER	MACHINISED CO ₂	SUBMERGED ARC
0.9					
1.6					
3					
5					
6					
10					
12.5					

WLNZ27812

Fig 3

MATERIAL THICKNESS	PROCESS				
	MANUAL METAL ARC	MANUAL CO ₂ DIP TRANSFER	MANUAL CO ₂ SPRAY TRANSFER	MACHINISED CO ₂	SUBMERGED ARC
19					
25					
38					
76					

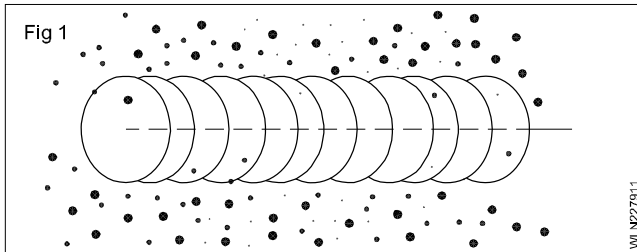
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GMAW defects, causes and remedies

Objective: At the end of this lesson you shall be able to

- state the weld defect, explain the causes and remedy if the defects.

Excessive spatter



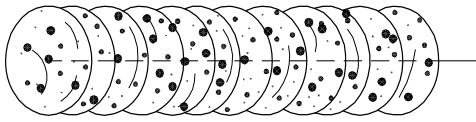
Excessive Spatter : scattering of molten metal particles that cool to solid form near weld bead.

Possible causes	Corrective actions
Wire feed speed too high. Voltage too high. Electrode extension (stickout) too long. Workpiece dirty. Insufficient shielding gas at welding arc. Dirty welding wire.	Select lower wire feed speed. Select lower voltage range. Use shorter electrode extension (stickout). Remove all grease, oil, moisture, rust, paint, undercoating, and dirt from work surface before welding. Increase flow of shielding gas at regulator/flowmeter and/or prevent drafts near welding arc. Use clean, dry welding wire. Eliminate pickup of oil or lubricant on welding wire from feeder or liner.

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Porosity

Fig 2



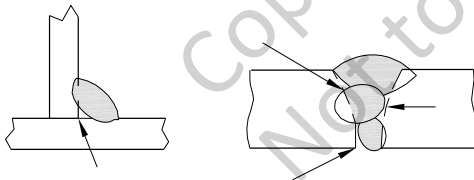
VVLN227912

Porosity — small cavities or holes resulting from gas pockets in weld metal.

Possible causes	Corrective actions
<p>Inadequate shielding gas coverage.</p> <p>Wrong gas.</p> <p>Dirty welding wire.</p> <p>Workpiece dirty.</p> <p>Welding wire extends too far out of nozzle.</p>	<p>Check for proper gas flow rate.</p> <p>Remove spatter from gun nozzle.</p> <p>Check gas hoses for leaks.</p> <p>Eliminate drafts near welding arc.</p> <p>Hold gun near bead at end of weld until molten metal solidifies.</p> <p>Use welding grade shielding gas; change to different gas.</p> <p>Use clean, dry welding wire.</p> <p>Eliminate pick up of oil or lubricant on welding wire from feeder or liner.</p> <p>Remove all grease, oil, moisture, rust, paint, coatings, and dirt from work surface before welding.</p> <p>Use a more highly deoxidizing welding wire.</p> <p>Be sure welding wire extends not more than (13 mm) beyond nozzle.</p>

Incomplete fusion

Fig 3



VVLN227913

Incomplete Fusion — failure of weld metal to fuse completely with base metal or a preceding weld bead.

Possible causes	Corrective actions
<p>Workpiece dirty.</p> <p>Insufficient heat input.</p> <p>Improper welding technique.</p>	<p>Remove all grease, oil, moisture, rust, paint, coatings, and dirt from work surface before welding.</p> <p>Select higher voltage range and/or adjust wire feed speed.</p> <p>Place stringer bead in proper location(s) at joint during welding.</p> <p>Adjust work angle or widen groove to access bottom during welding.</p> <p>Momentarily hold arc on groove side walls when using weaving technique.</p> <p>Keep arc on leading edge of weld puddle.</p> <p>Use correct gun angle of 0 to 15 degrees.</p>

Excessive penetration

<p>Fig 4</p> <p>EXCESSIVE PENETRATION GOOD PENETRATION</p> <p style="text-align: right; font-size: small;">WLN27914</p>		<p>Excessive Penetration — weld metal melting through base metal and hanging underneath weld.</p>
<p>Possible causes</p> <p>Excessive heat input.</p>	<p>Corrective actions</p> <p>Select lower voltage range and reduce wire feed speed.</p> <p>Increase travel speed.</p>	

Lack of penetration

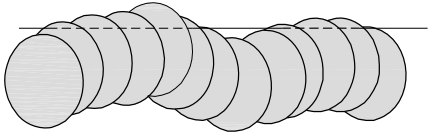
<p>Fig 5</p> <p>LACK OF PENETRATION GOOD PENETRATION</p> <p style="text-align: right; font-size: small;">WLN27915</p>		<p>Lack of Penetration — shallow fusion between weld metal and base metal.</p>
<p>Possible causes</p> <p>Improper joint preparation.</p> <p>Improper weld technique.</p> <p>Insufficient heat input.</p>	<p>Corrective actions</p> <p>Material too thick. Joint preparation and design must provide access to bottom of groove while maintaining proper welding wire extension and arc characteristics.</p> <p>Maintain normal gun angle of 0 to 15 degrees to achieve maximum penetration.</p> <p>Keep arc on leading edge of weld puddle.</p> <p>Be sure welding wire extends not more than (13 mm) beyond nozzle.</p> <p>Select higher wire feed speed and/or select higher voltage range.</p> <p>Reduce travel speed.</p>	

Burn through

<p>Fig 6</p> <p style="text-align: right; font-size: small;">WLN27916</p>		<p>Burn-Through — weld metal melting completely through base metal resulting in holes where no metal remains.</p>
<p>Possible causes</p> <p>Excessive heat input.</p>	<p>Corrective actions</p> <p>Select lower voltage range and reduce wire feed speed.</p> <p>Increase and/or maintain steady travel speed.</p>	

Waviness of bead

Fig 7



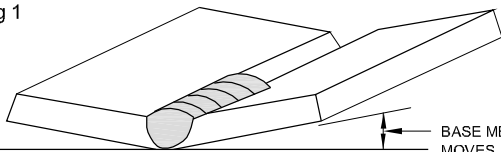
WVLN22791.7

Waviness of Bead — weld metal that is not parallel and does not cover joint formed by base metal.

Possible causes	Corrective actions
Unsteady hand.	Support hand on solid surface or use two hands.

Distortion

Fig 1



BASE METAL
MOVES IN
THE DIRECTION
OF THE WELD BEAD

WVL28102.1

Distortion — contraction of weld metal during welding that forces base metal to move.

Possible causes	Corrective actions
Excessive heat input.	<p>Use restraint (clamp) to hold base metal in position.</p> <p>Make tack welds along joint before starting welding operation.</p> <p>Select lower voltage range and/or reduce wire feed speed.</p> <p>Increase travel speed.</p> <p>Weld in small segments and allow cooling between welds.</p>

Welder - Gas metal arc welding

Heat in put and techniques

Objective: At the end of this lesson you shall be able to

- describe the effects of heat on the properties of metals.

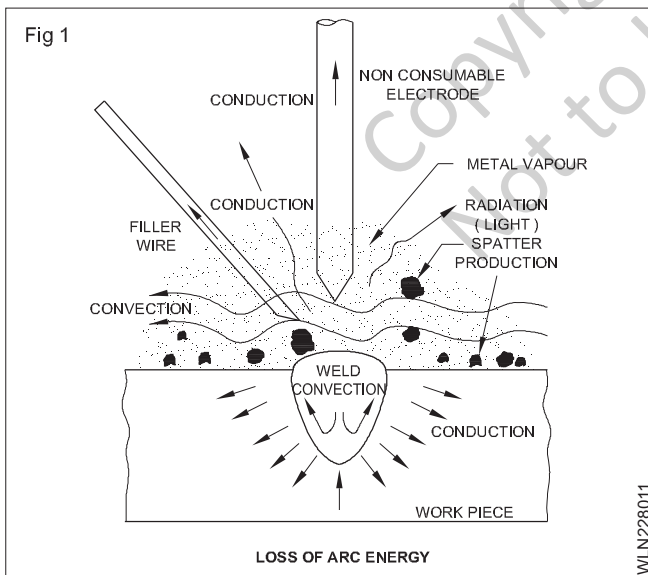
Weldments, preheating, heat affected zone, interpass temperature.

Introduction: During welding, the parent metal is heated to melting point and after that it is allowed to cool rapidly. The adjacent portion to the welded zone is also heated by to a lower temperature. This causes certain phase transformations and on rapid cooling, due to heat transfer through the colder portion of parent metal and atmosphere, the materials hardness and hence mechanical properties are also affected.

The width of parent metal that is affected due to the above cycle is called 'Heat Affected Zone'. It is quite clear that the hardness depends on rate of cooling. Higher the cooling higher will be the hardness. In order to control the cooling rate pre-heating and interpass temperature controls are adopted.

In order to relieve the welding induced stresses and to achieve better metallurgical structure to meet service conditions, post - weld heat treatment is followed.

Heat input: The energy supplied by the welding arc in a fusion welding process is called arc energy and is calculated from current voltage and welding speed. However all the arc energy is not utilized for welding; some of it is invariably lost as shown in Fig.1



The extent of energy loss varies with the welding process, welding parameters, type of material, preheat temperature etc. To account for the energy loss and estimate the actual energy given to the workpiece, a term known as heat input is employed.

The heat input of a single pass weld is calculated by multiplying the efficiency of the welding process and arc energy. Therefore heat input at best can serve as a rough guide to the amount of heat supplied to the workpiece.

Temperature changes in welding: Heat moves from one area to another whenever there is a difference in temperature. Just as water flows downhill, so that flows down the temperature hill, warning cold objects at the expense of warmer ones.

When the source is moved away, the heat in the weld is conducted outward into the plate. The temperature of the weld has fallen, while the plate temperature near the weld is rising.

The weld has cooled still further and the plate temperature is still rising. The metal reaches a maximum temperature less than the melting point of the weld metal, and cooling sets in.

Heat Affected Zone (HAZ): The energy applied to create a weld joint is dissipated by conduction to the base metal, welding fixtures and the environment. That part of the base metal experiencing various thermal cycles is called the heat affected zone (HAZ)

During welding, the HAZ does not undergo welding but experiences complex thermal and stress alterations. The imposition of welding thermal cycles on the base material causes in the properties of the HAZ.

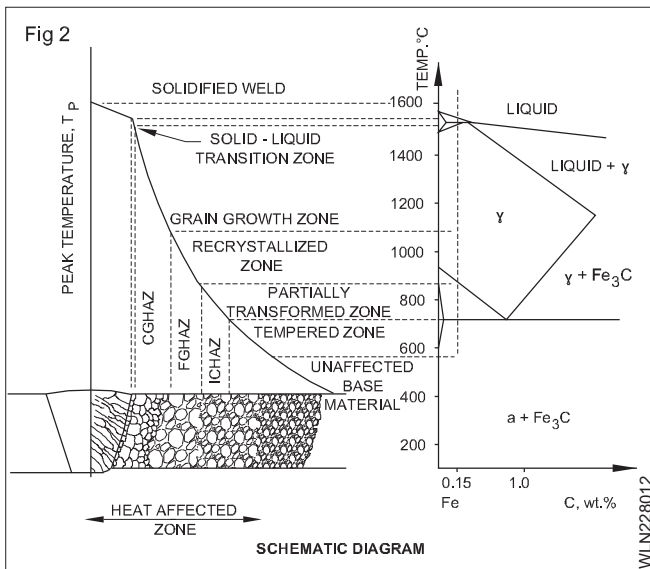
A welding thermal cycle is characterized by heating rate, peak temperature and cooling rate. Thermal cycles are also affected by heat input, preheating temperature, plate thickness and joint geometry.

Weld joint: A weld joint consists of several zones.

- 1 Weld metal or mixed zone which is essentially a solidified structure.
- 2 Unmixed zone in the base metal adjacent to the fusion line where the base metal has melted but is not mixed with the filler material.
- 3 Partially melted zone which has been thermal cycles with peak temperatures and,
- 4 Heat affected zone which has not melted but is exposed to thermal cycles with temperature less than the solids temperature.

Each zone because of its characteristic micro structural features has different properties.

Heat affected zone microstructure: The relevant portion of the iron-carbon phase diagram along with a schematic sketch of a weld and HAZ is shown in Fig.2



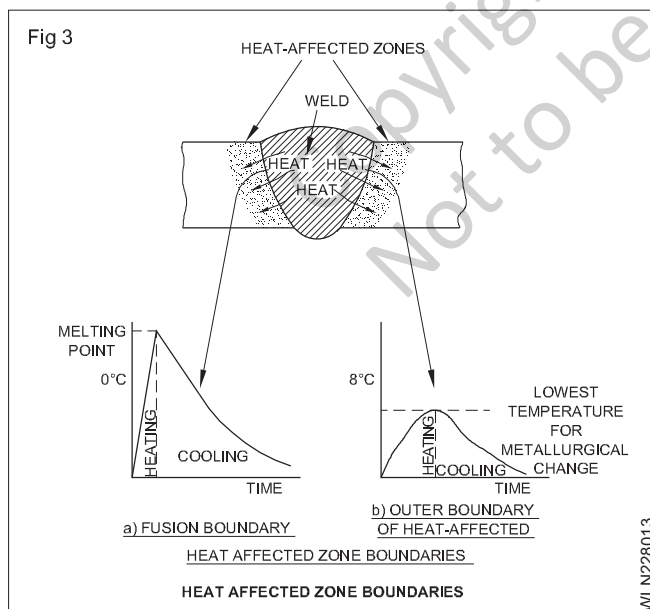
The region of the HAZ where extensive grain growth of the weld metal takes place is referred to as coarse grained HAZ (CGHAZ) 1300°C.

The region of the HAZ next to it, where peak temperature is in the range of 900-1200°C and austenite grain size remains small, is called fine grained HAZ (FGHAZ).

CGHAZ is having maximum hardness and poor toughness properties compared to the rest of the HAZ. So the preheat temperature used to reduce the cooling rate.

Heat affected zone and how to avoid risk of cracking

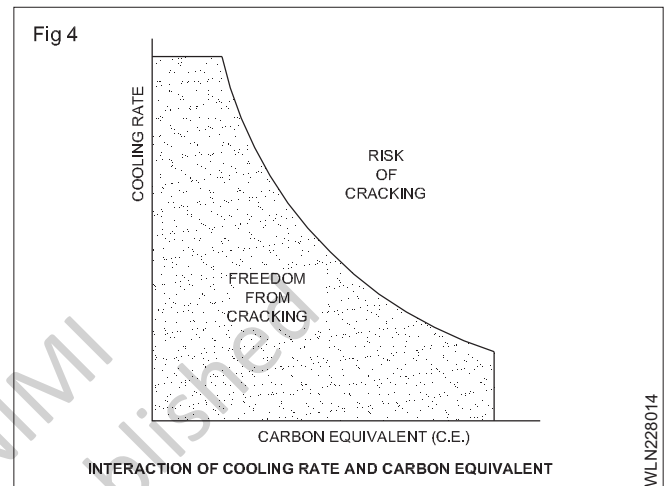
The region of the parent metal, which undergoes a metallurgical change as a result of the thermal cycle is called heat affected zone. A typical HAZ is shown in Fig 3.



If the carbon equivalent (CE) exceeds 0.4, the welding situation changes due to the possibility of cracking in the heat affected zone and due to increase in volume of martensite, cracks will usually develop the phenomenon called underbead cracking.

The normal structural steel has a hardness of 190-200 BHN. In HAZ, depending upon thickness, carbon content, hardness of 350-450 BHN may be reached. The level of hardness depends upon cooling rate. The risk of cracking is higher when hardness exceeds a certain level corresponding to higher rate of cooling.

The interaction of cooling rate and carbon equivalent is illustrated in Fig 4. At low levels of carbon equivalent fast rates can be tolerated before there is risk of cracking; except in thick section, HAZ cracking is rarely experienced with CE values below 0.39%. At high levels of CE, say around 0.48%, there is high risk of cracking even at slower cooling rates.



However, appropriate preheating of the parent metal and or low levels of hydrogen in the weld metal can eliminate this problem.

Higher level of hydrogen is harmful. Hydrogen is absorbed in the molten weld pool from a variety of sources, moisture in the flux covering of an electrode or in the shielding gas, grease on the joint faces and so on. Hydrogen can flow (diffuse) readily through hot steel and pass from the weld pool in to the HAZ causing a major risk of cracking.

Gas shielded processes such as MAG and TIG are inherently low in hydrogen with levels 5-10 ml/100 gram and are thus effective in avoiding cracking.

Heat input and the thickness of the metal in the joint affect the cooling rate in the unit.

In thick sections cooling rate is faster than in thin. Preheating temperature slows down the cooling rate through the temperature range within which a hardened structure is formed i.e., 300-200°C. Preheat also helps to reduce the risk of cracking by allowing any hydrogen in the heat affected zone to flow into the parent metal where hardening has not taken place.

The interdependence of principal factors i.e., CE, cooling rate (heat input, joint type and thickness), hydrogen content and preheat (temperature of parent metal during welding) governing the risk of HAZ cracking is complex.

The problem of underbead cracking can easily be overcome by preheating the weld joint just prior to welding or by choosing a proper low hydrogen electrode.

Purpose of preheat: There are four reasons why preheat is useful in weld fabrication. They are

- a The use of preheat lowers the cooling rates in the weld metal and in the heat affected zone. This results in a more ductile metallurgical structure, one that will resist weld cracking.

The slower the cooling rate permits hydrogen to diffuse out harmlessly, without causing cracking.

Preheat reduces shrinkage.

It also brings some steels above the temperature where brittle fracture might occur during welding.

No steel is immune to hydrogen-induced cracking. Additionally, preheat can be used to help ensure specific mechanical properties, such as notch toughness.

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Heat distribution and effects of faster cooling

Objective: At the end of this lesson you shall be able to

- **explain the necessists of heat distribution in welding.**
-

Heat input is increased with increasing wire feeding speed but increasing welding speed decreases the welding heat input. When heat input increases, the cooling rate decreases for weld metal and increases the volume fraction of tempered martensite and coarsening of the microstructure of weld zone.

The outcome of microstructural examination and mechanical tests should that fast cooling, immediately after submerged welding can reduce the width of heat affected and coarse grained zones, as well as improving the low temperature impact toughness.

Heat input is increased with increasing wire feeding speed but increasing welding speed decreases the welding heat input. When heat input increases, the cooling rates decreses for weld metal and increases the volume of fraction of tempered, marking and coarsening of the microstructure of weld zone.

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Preheating and post heating treatment

Objectives: At the end of this lesson you shall be able to

- explain the necessity of heat treatment in welding
- describe different methods of heat treatment applied in welding
- state the purpose of preheating
- state the purpose of post heating.

Different methods of heat treatment

Direct preheating, Indirect preheating, Local preheating

Preheating and its purpose: Preheating means heating a joint to be welded before or during welding to a certain temperature as shown in tables 1 and 2.

Table 1

Preheating of various metals

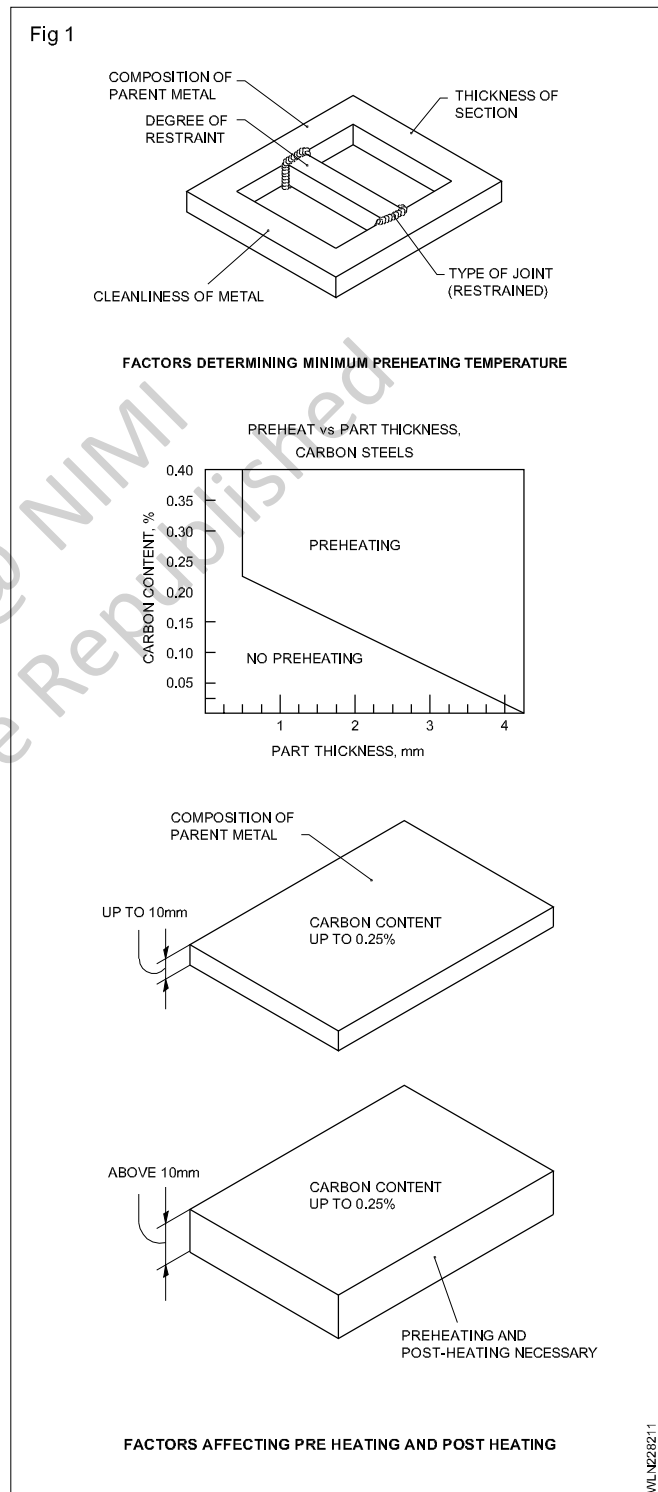
Metal	Temperature °C
Nickel alloys (wrought)	Warm it below 16°
Nickel alloys (cast)	90° - 200°
Copper and copper alloys	200° maximum
Silicon bronze	90°
Brass low zinc	200° - 260°
Brass high zinc	260° - 370°
Phosphor bronze	150° - 200°

The preheating reduces the rate of cooling after welding. This is necessary to prevent the weld metal from cracking in restrained/rigid joints. Also some of the non-ferrous metals like copper, brass, aluminium, etc. expand more due to heating and ferrous metals like cast iron, medium and high carbon steels require preheating as they are too brittle. These materials are necessarily to be preheated to avoid cracking or distortion. In some cases, it is also necessary to preheat during welding between each layer of deposition.

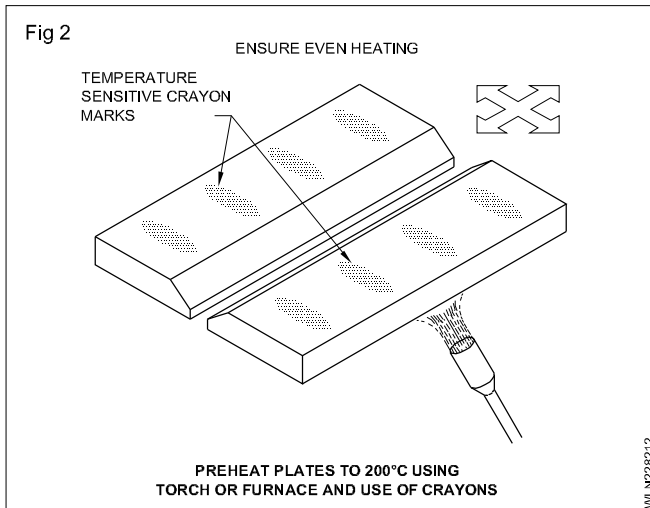
The minimum preheating temperature for satisfactory welds of different grades of steel, cast iron, non-ferrous metals will depend upon the: (Fig 1)

- type of metal
- composition and properties of the parent metal
- thickness of the plate
- type of joint
- degree of restraint of the joint
- rate of heat input.

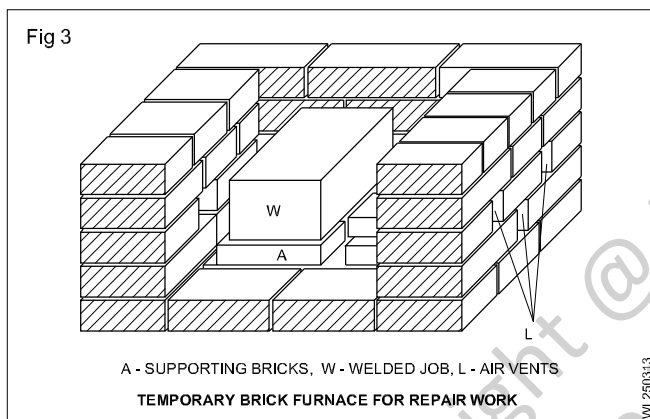
Do not allow the temperature to drop below the minimum preheating temperature between each weld run.



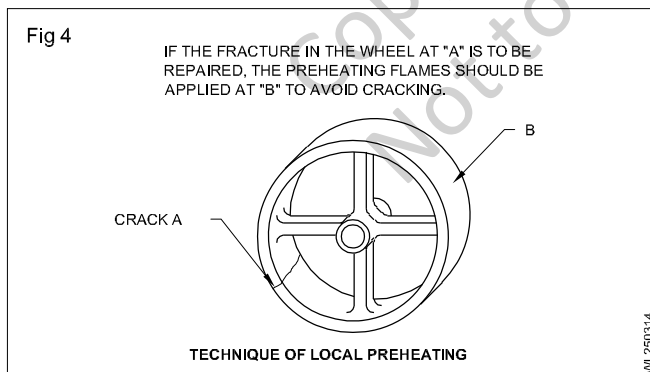
The preheating temperature can be checked by temperature indicating crayons. (Fig 2)



If the job and area to be preheated are large, then it is done in a preheating furnace (Fig 3).



If it is small localised preheating is applied to the joint area only. This is called local preheating. (Fig 4)

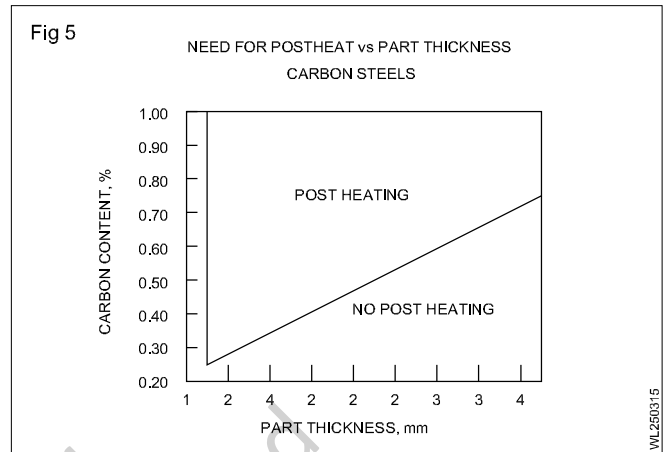


Post heating: Post heating means that the part is heated immediately after welding. The reasons for post heating are to prevent hard and brittle spots from forming in the weldment. It also relieves the residual stresses caused by the welding heat and due to welding of a rigid joint.

The important aspects to be considered while post-heating are:

- the rate of heating
- temperature to which the part is to be post-heated
- holding time in the furnace
- the rate of cooling.

Post heating of carbon steels depends on the thickness of the base metal and its carbon content. (Fig.5)



Post heating retards the rate of cooling of a welded joint.

For plain carbon steels the joint is heated from 100°C to 300° C for general post heating. This treatment will reduce the cracking tendency of carbon steel and cast iron. If they are not post heated, cracks may develop.

Also the welding heat can develop hardness and brittleness in some areas of the joint. In addition the grains of the base metal in the heat affected zone and fusion zone will grow in size which will change the property of the welded joint.

In the case of joints which are not free to expand i.e., restrained joints and in joints in which there is a stress already present before welding, the residual stresses will be more after cooling of the joint. If these residual stresses are not removed after welding, then the joint will fail or distort when they are put into use or the joint is machined or the joint is subjected to dynamic loading.

To avoid the above problems a welded job is usually either normalised or annealed or stress-relieved.

TABLE 2

Preheating temperatures for plain and alloy steels

	Approximate composition (percentage)			Recommended preheating temperature	
	% Carbon			°C	°F
PLAIN CARBON STEELS	C				
Plain carbon	Below 0.20			Up to 95	Up to 200
Plain carbon	0.20 to 0.30			95 to 150	200 to 300
Plain carbon	0.30 to 0.45			150 to 280	300 to 500
Plain carbon	0.45 to 0.80			260 to 425	500 to 800
CARBON MOLYBDENUM STEELS	C	Mo			
Carbon molybdenum	0.10 to 0.20	0.50		150 to 260	300 to 500
Carbon molybdenum	0.20 to 0.30	0.50		200 to 315	400 to 600
Carbon molybdenum	0.30 to 0.35	0.50		260 to 425	500 to 800
MANGANESE STEELS	C	Mn	Si		
Silicon structural	0.35	0.80	0.25	150 to 260	300 to 500
Medium manganese	0.20 to 0.25	1.0 to 1.75		150 to 260	300 to 500
SAE T 1330	0.30	1.75		200 to 425	400 to 600
SAE T 1340	0.40	1.75		260 to 425	500 to 600
SAE T 1350	0.50	1.75		315 to 480	600 to 900
12% Manganese		1.25	12.0	Usually not required	Usually not required
NICKEL STEELS	C	Ni			
SAE 2015	0.10 to 0.20	0.50		Up to 150	Up to 300
SAE 2115	0.10 to 0.20	1.50		95 to 150	200 to 300
2% Nickel	0.10 to 0.20	2.50		95 to 200	200 to 400
SAE 2315	0.15	3.50		95 to 260	200 to 500
SAE 2320	0.20	3.50		95 to 260	200 to 500
SAE 2330	0.30	3.50		150 to 315	300 to 600
OSAW 2340	0.40	3.50		200 to 370	400 to 700
LOW CHROME MOLYBDENUM STEELS	C	Cr	Mo	°C	°F
2% Cr. % Mo	Up to .15	2.0	0.5	200 to 315	400 to 600
2% Cr. % Mo	0.15 to 0.25	2.0	0.5	260 to 425	500 to 800
2% Cr. 1% Mo	Up to 0.15	2.0	1.0	260 to 370	500 to 700
2% Cr. 1% Mo	0.15 to 0.25	2.0	1.0	315 to 425	600 to 800
MEDIUM CHROME MOLYBDENUM STEELS	C	Cr	Mo		
5% Cr. % Mo	Up to 0.15	5.0	0.5	260 to 425	500 to 800
5% Cr. % Mo	0.15 to 0.25	5.0	0.5	315 to 480	600 to 900
8% Cr. 1% Mo	0.15 Max.	8.0	1.0	315 to 480	600 to 900
PLAIN HIGH CHROMIUM STEELS	C	Cr			
12 to 14% Cr TYPE 410	0.10	13.0		150 to 260	300 to 500
16 to 18% Cr TYPE 430	0.10	17.0		150 to 260	300 to 500
23 to 30% Cr TYPE 446	0.10	26.0		150 to 260	300 to 500

Pre-heat treatment and post weld heat treatment

Objectives: At the end of this lesson you shall be able to

- explain heat treatment
- explain the different methods of heat treatment.

Heat treatments: Heat treatments are used to obtain certain desired properties. Essentially, heat-treating metals consists of heating and cooling it after it has reached the solid state. There are a number of different methods of heat treatment for various steels in today's industry.

Normalising: Normalising is very similar to annealing except that the steel is held above the critical temperature very briefly and the cooling takes place in air at normal temperature. Normalising will result in refining the grain structure of a metal. It is sometimes used after quenching.

Annealing: Annealing involves heating of metal to a temperature above the critical point and allowing it to cool slowly. The purpose of annealing may be to accomplish one or more of the following.

- To soften the metal, e.g. to improve machinability.
- To relieve internal residual stresses.
- To refine the grains.
- To improve ductility.
- Homogenizing to reduce.

Hardening: Hardening increases the strength of the pieces after they are fabricated. It is accomplished by heating the steel to a temperature above the critical point, and then cooling it rapidly in oil, water or lime. Only medium, high and very high carbon steels can be hardened by this method. The temperature at which the steel must be heated varies with the steel used.

Case hardening: It is the process of hardening the outer surface of steel. It is done by inducing additional carbon into the case of the steel. This is done in a number of different ways all of which require heating to a high temperature and rapid cooling.

Some of the methods employed are:

- to pack the steel part in a sealed metal box which contains some carbonizing material

Hardening and tempering

Objectives: At the end of this lesson you shall be able to

- explain the principle of hardening
- describe the effect of carbon content in hardening
- explain the process of hardening
- explain the tempering of steel
- describe the purpose of tempering
- explain the factors on which the mechanical properties of hardened steel depend.

Introduction: If a piece of steel is heated to a sufficiently high temperature, all the carbon will be dissolved in the solid iron to form the solid solution, austenite of the steel. When it is slowly cooled, the change in the arrangement of the iron atoms will cause a solid solution called ferrite to be produced. The solid solution can only contain up to 0.006%

- to immerse the steel part in a molten cyanide salt bath
- to dip the heated steel part in a container having powdered cyanide
- to heat the steel part and pass carbonizing gas over it
- to employ manual or machine-controlled oxy-acetylene flame process.

Tempering: Tempering (grain refining) is used to relieve some of the brittleness which occurs after a piece of steel has been fully hardened, and to make the steel tough.

It is accomplished by reheating the hardened metal to a specified temperature, depending upon the hardness to be removed, and then quenching.

Quenching: Quenching is the rapid cooling of a metal usually done by immersing it in oil or water. This will cause certain changes in the structure of the metal. For example, carbon steel that is quenched will form a martensite structure.

Stress relieving: Stress relieving is a means of removing the internal stresses which develop during the welding operation.

This process consists of heating the structure to a temperature below the critical range (approximately 590°C) and allowing it to cool slowly. Another method of relieving stresses is peening (hammering). However, peening must be undertaken with considerable care because there is always the danger of weakening the physical strength of the metal.

Stress relieving should be done only if there is a possibility that the structure will crack upon cooling and no other means can be used to eliminate the expansion and contraction forces.

carbon, and so the excess carbon will be forced to leave the solid solution, and produce cementite. This will, with ferrite, form a laminated structure called pearlite.

The principle of hardening: If steel is cooled rapidly (quenched) the excess carbon will not have sufficient time to leave the solid solution with the result that it will be

trapped in the iron, and so cause an internal distortion. This internal distortion is the cause for the increase in the hardness of steel with a corresponding reduction in its strength and ductility. This is the basis of the hardening process.

The mechanical properties produced as a result of this treatment will depend upon

- the carbon content of the steel
- the temperature to which it is heated
- the duration of heating
- the temperature of the steel at the start of quenching
- the cooling rate produced by quenching.

The effect of carbon content upon the hardness produced by the process is illustrated in Fig 1.

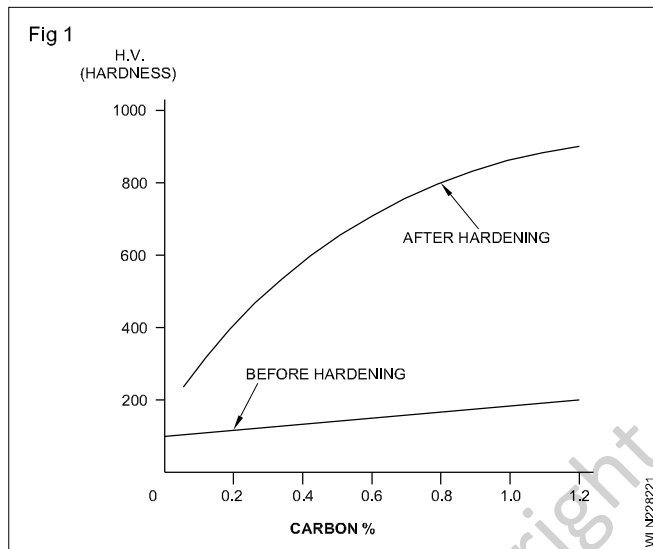
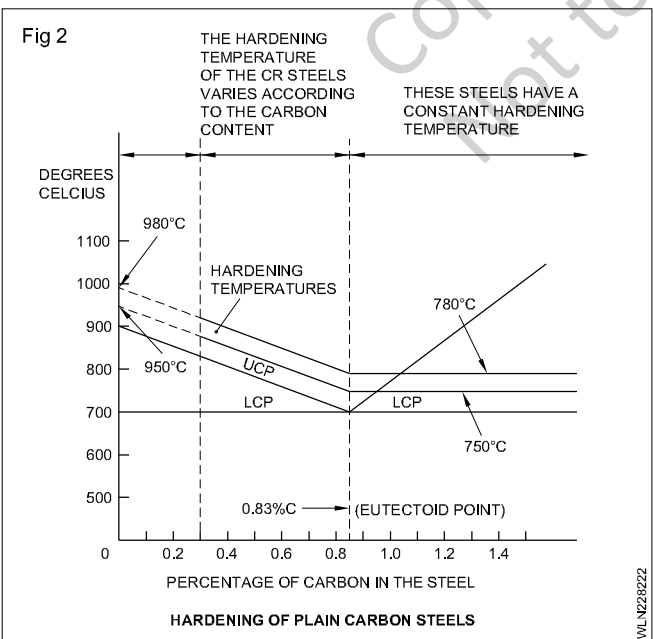
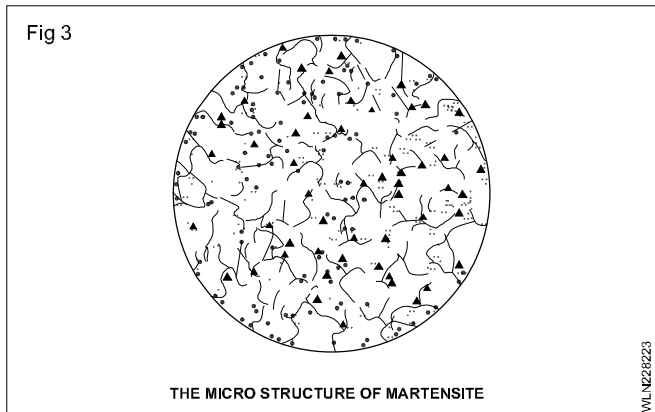


Fig 2 illustrates the temperatures to which steels are heated before quenching.



Soaking time: After heating, the steel is held at that temperature for some time. Normally 5 mts are allowed as soaking time for 10 mm thickness of steel.

Cooling: Then the steel is cooled in a suitable quenching medium at a certain minimum rate called the critical cooling rate. The critical cooling rate depends upon the composition of the steel. This cooling transforms all the austenite into a fine, needle-like structure called martensite, the appearance of which is shown in Fig 3.



The structure of steel treated this way is very hard and strong, but very brittle.

The quenching medium: The quenching medium controls the rate of cooling.

For rapid quenching a solution of salt or caustic soda in water is used.

For very slow quenching a blast of air is sufficient.

Oil gives an intermediate quenching.

Water and oil are the most common quenching media used.

Air quenching is suitable only for certain special alloy steels.

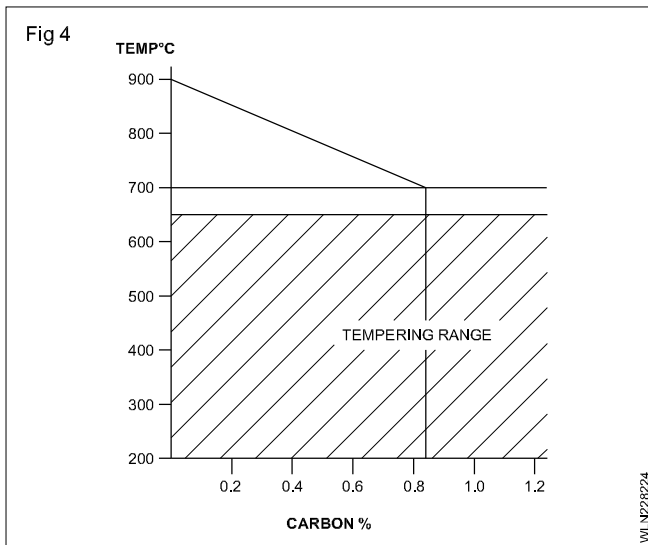
Tempering: After hardening, steel is usually reheated to a suitable temperature below the lower critical point (heating) to improve its toughness and ductility but it is done at the expense of hardness and strength. It is done in order to make the steel more suitable for service requirements.

Purpose of tempering the steel: Steel, in its hardened condition, is generally too brittle and too severely strained. In this condition, steel cannot be used, and hence it has to be tempered.

The aims of tempering are:

- to relieve the steel from internal stresses and strains
- to regulate the hardness and toughness
- to reduce the brittleness
- to restore some ductility
- to reduce shock resistance.

Process of tempering: The tempering temperature depends upon the properties required, but it is between 180°C and 650°C. (Fig 4) The duration of heating depends upon the thickness of the material. Tools are usually tempered at a low temperature. The temperature itself is judged by the colour of the oxide film produced upon heating. (Table 1)



This method is not, however, suitable for accurate temperature assessment.

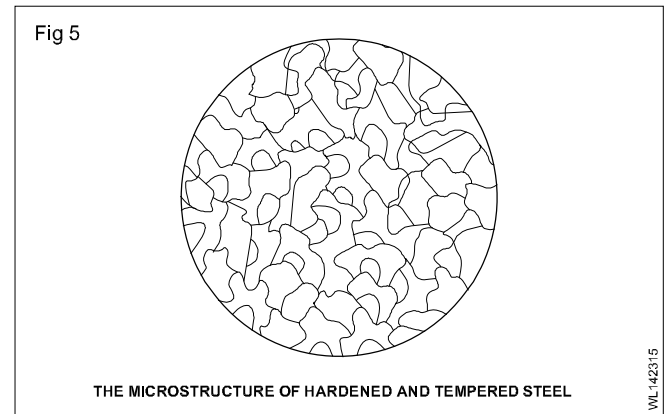
Table 1

Tempering temperature

Temper colour	Temperature in °C
Pale straw	230
Dark straw	240
Brown	250
Brownish purple	260
Purple	270
Dark purple	280
Blue	300

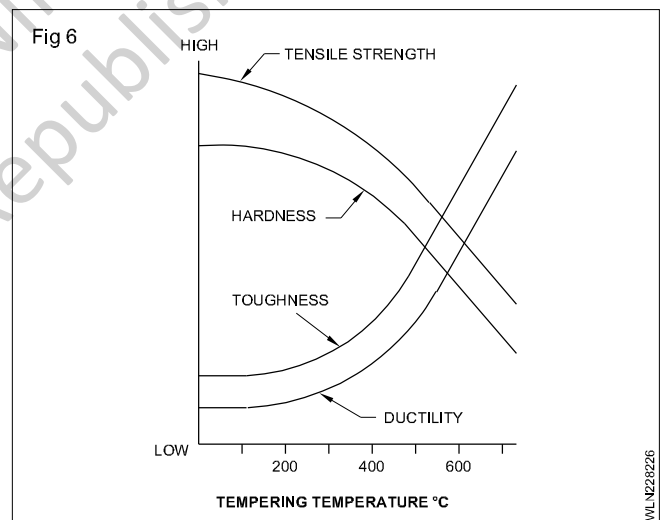
In a manufacturing plant, when heat-treating is done on a production basis, modern methods are used. Tempering is done in controlled atmosphere furnaces with the temperatures controlled by modern instruments. Under such conditions, it is possible to obtain accurate and uniform results in any number of pieces.

Fig 5 illustrates the appearance of the microstructure of hardened and tempered steel.



Generally, tempering in the lower temperature range for an increased time provides greater control in securing the desirable mechanical properties. Such heat treatment may not be feasible under all conditions. For precision work, where results justify the method, and for certain combination of mechanical properties, tempering for long periods of time in a lower temperature range provides a reliable method of getting the desired results.

Fig 6 illustrates how the mechanical properties of hardened steel can be modified by tempering.



Heat treatment of steels (Annealing and normalising)

Objectives: At the end of this lesson you shall be able to

- explain the purpose of heat treatment
- explain the purpose of annealing
- distinguish between the processes of annealing and normalising.

The properties of steel depend upon its composition and its structure. The properties of steel and its structure can be changed by heating it to a particular temperature and then, allowing it to cool at a definite rate. The process of heating and cooling for changing the structure of steel, and thus obtaining the required properties is called 'Heat treatment of steel'.

If the steel is heated to a suitable temperature, and then, slowly cooled, the steel will be soft, weak and ductile.

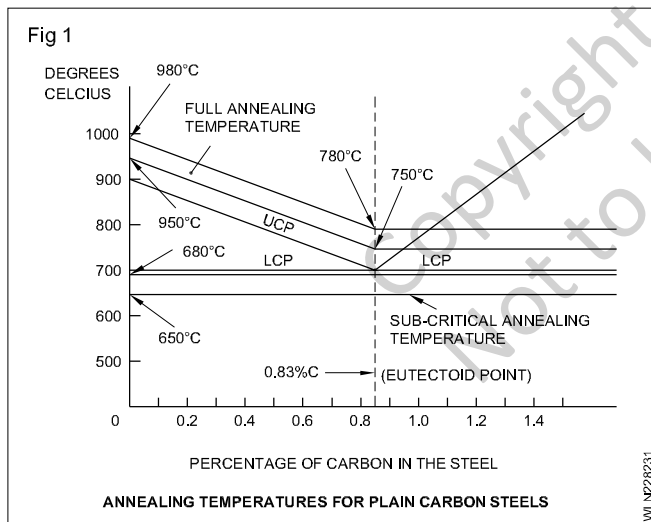
If the steel is heated to a suitable temperature, and then, rapidly cooled (quenched) the steel will be hard and brittle.

Classification of heat treatments

The treatments that produce equilibrium conditions are annealing and normalising.

Treatments that produce non-equilibrium conditions are hardening and tempering (usually done in conjunction with each other).

Annealing: In this process, steel is heated to a suitable temperature depending upon its carbon content (Fig 1), and is held at that temperature for sufficient time, and then slowly cooled to room temperature.



The heating, soaking (holding the temperature) and slow cooling cause the grains to become large, and so, produce softness and ductility. For annealing, hypoeutectoid steel is heated to 30° to 50°C above the upper critical temperature, and it is 50°C above the lower critical temperature for hypereutectoid steel. (Fig 1)

Soaking time at this temperature is 5 mts/10 mm of thickness for carbon steel.

The cooling rate for carbon steel is 100 to 150°C/hour.

The cooling is done in the furnace itself by switching off the furnace or the steel is covered either with sand or dry lime and dry ash.

Annealing temperature

Carbon content %	Temperature °C
<0.12	875 to 925
0.12 to 0.25	840 to 970
0.25 to 0.50	815 to 840
0.50 to 0.90	780 to 810
0.90 to 1.3	760 to 780

Purpose of annealing

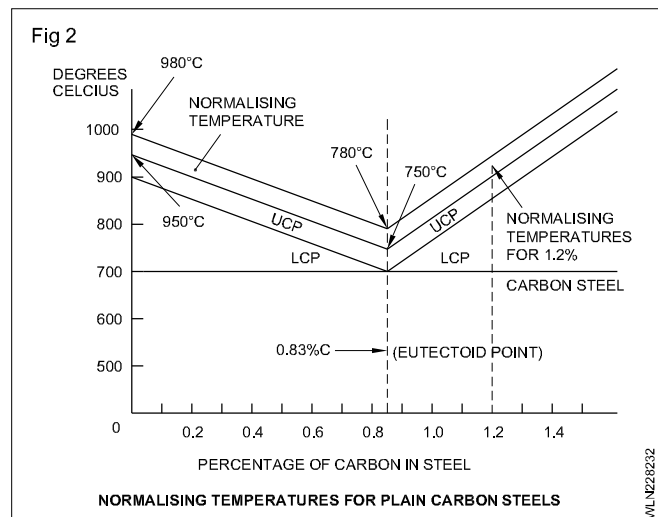
Annealing is done:

- to obtain softness
- to improve machinability
- to increase ductility
- to relieve internal stresses
- to reduce or eliminate structural inhomogeneity
- to refine grain size
- to prepare the steel for subsequent heat treatment process.

Normalising: Due to continuous hammering or uneven cooling, strains and stresses are formed in the internal structure of steel. These should be removed from forgings or castings; otherwise, they may fail at any time while in use.

Normalising is done to produce a fine grain for uniformity of structure and for improved mechanical properties.

The normalising process: In this process, steel is heated to a suitable temperature depending upon its carbon content, (Fig 2) and held at the same temperature, and then, cooled freely in air.



Normalising is usually done before machining and before hardening to put the steel in the best condition for these operations.

The steel is heated to a temperature (300 to 400C above the upper-critical temperature) at which all austenite is present even in the case of high carbon steel. This is because this process is the first step towards providing the final properties, and it is necessary to start with austenite to ensure uniformly.

The heated piece for normalising should not be kept at a wet place, in wet air or kept in forced air as they will induce some hardness.

Use of temperature indicating crayons

The temperature of the preheated job can be checked by wax crayons. Marks are made on the cold job pieces by these crayons before preheating and after the job pieces reach the preheating temperature the marks will disappear.

This indicates that the job has been heated to the required preheating temperature. Different wax crayons are available for checking different temperatures. The temperature which is checked by the crayon will be marked on it.

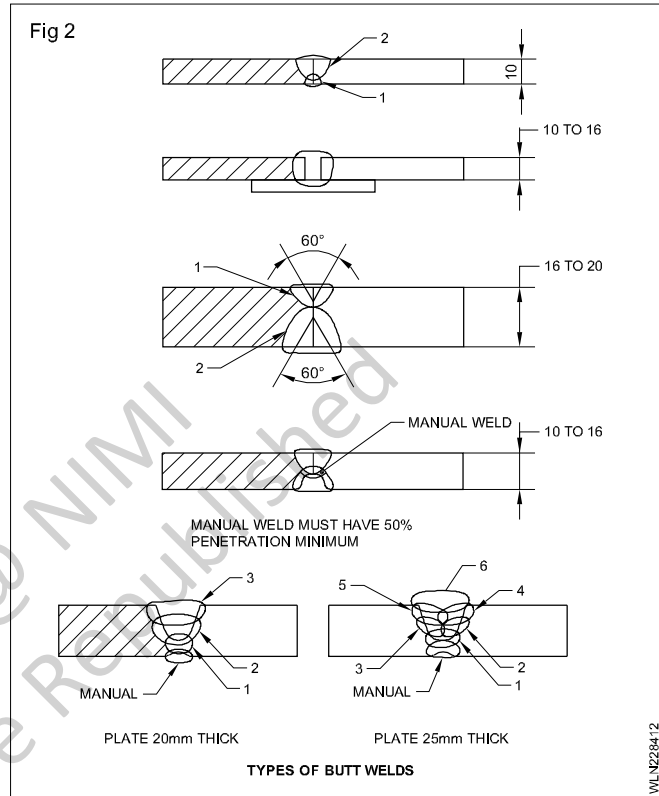
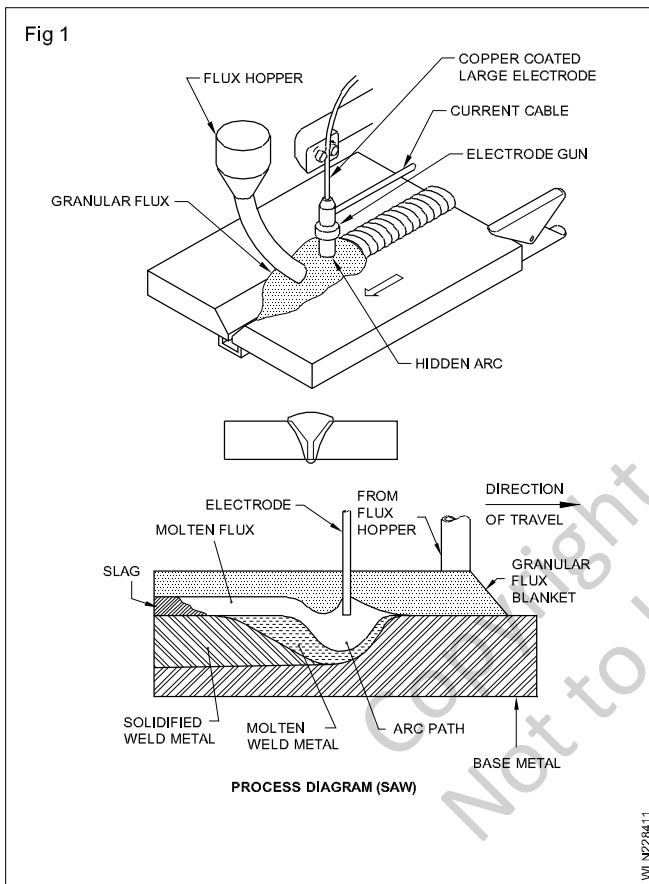
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Submerged arc welding process principles

Objectives: At the end of this lesson you shall be able to

- explain the principles and applications of submerged arc welding
- explain the SAW
- describe the welding procedure of the above processes
- state the advantages and limitations of the above processes.

Principles of submerged arc welding: Submerged arc welding is an arc welding process that uses an arc between a bare metal electrode and the weld pool. The arc and the molten metal are hidden by a blanket of granular flux on the workpieces. (Fig 1)



For plate thicknesses higher than 25mm a double Vee or single U or double "U" edge preparation is done Fig.3 shows fillet welds done by submerged arc welding.

The "T" and Lap joints shown in Fig.3 are tilted to 45° to weld them in flat position. If the thickness of plates are more than 16mm in T fillet joint then the edge of the vertical plate is bevelled by 45° and the joint is welded without a root gap.

Types of submerged arc welding process

There are two types of SAW.

- Automatic
- Semi-automatic

Automatic SAW: In this type the arc voltage, arc length, speed of travel and electrode feed are automatically controlled.

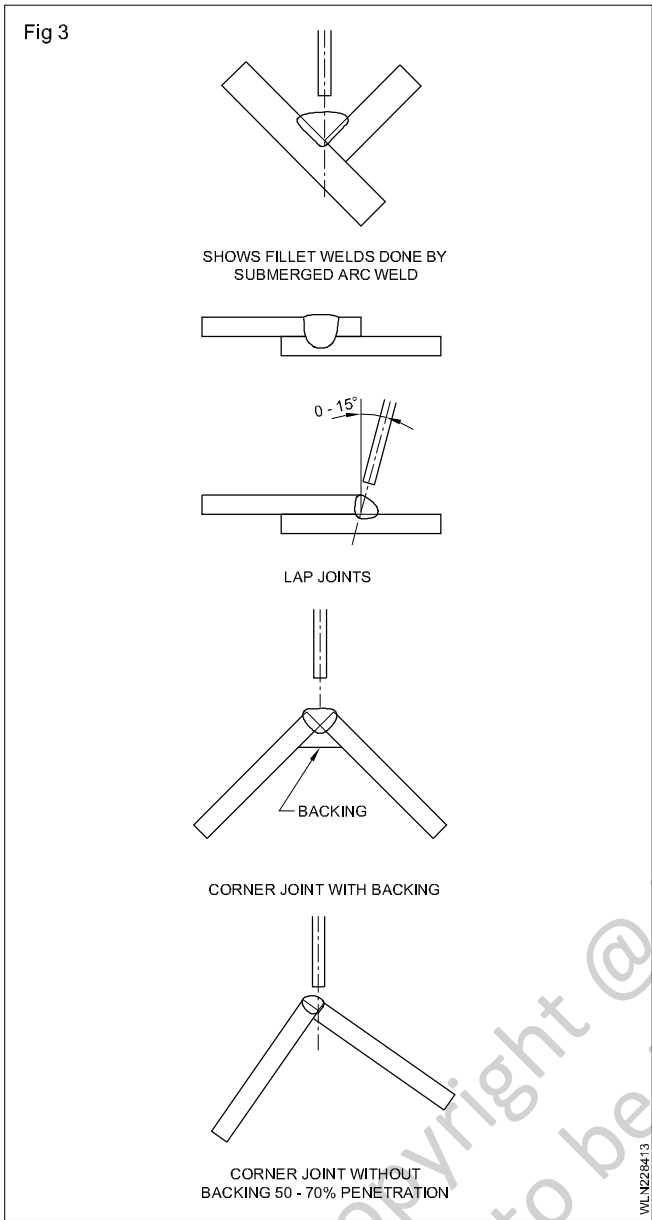
Semi-automatic SAW: The arc length, flux feeding and electrode feed are automatic but the speed of travel is controlled by the operator.

Metals which can be welded by SAW: In submerged arc welding, low and medium carbon steels, low alloy steels, high strength steels, quenched and tempered steel and stainless steel can be welded.

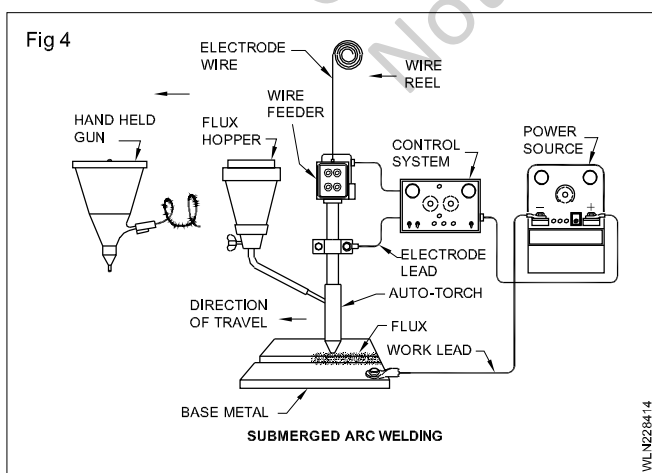
Metals weldable by saw

Base metal	Weldability
Wrought iron	Weldable
Low carbon steel	Weldable
Low alloy steel	Weldable
High and medium carbon	Possible but not popular
High alloy steel	Possible but not popular
Stainless steel	Weldable

Edge preparation in SAW process: The edge preparation for Butt welds are as shown in Fig.2.



Parts of a SAW machine and their functions (Fig 4)



A wire feeder to drive the electrode to the work through the contact tube of the welding gun or welding head.

A welding power source to supply welding current to the electrode at the contact tube.

Arrangement for holding the flux and feeding it on the head of the arc.

A means of traversing the joint.

Fluxes: Fluxes used with submerged arc welding are granulated fusible mineral materials which are free from substances capable of producing large amount of gas during welding.

Flux when cool is non-conductive, but when molten it is highly conductive and allows high current.

The flux protects the weld pool from atmospheric contamination and influences deep penetration.

Electrode: Bare or lightly copper coated rods or wires are used as electrodes in SAW. These electrodes are available in coil or reel form.

Standard reels with diameters 2 to 8 mm are available.

Welding procedure (for striking the arc): The electrode momentarily contacts the work and is withdrawn slightly.

Arc start: Arc starting is difficult in submerged arc welding because of the flux cover. It is important to start the weld at a specific point on the joint.

Method of starting arc by using steel wool or iron powder: A rolled ball of steel wool 10 mm in dia. is placed at the required spot on the joint and the electrode wire is lowered on to it till it is lightly compressed. The flux is then applied and when the welding is commenced the steel wool or iron powder conducts the current from the wire to the workpiece, while at the same time it melts away rapidly as the arc is formed.

Clean the prepared workpiece and place it in position with provision for backing up. Fill the hopper with flux and insert the electrode ends into the welding head.

Adjust the voltage, the current and the welding speed as indicated in Table 1 and 2.

Start welding by striking an arc beneath the flux on the work.

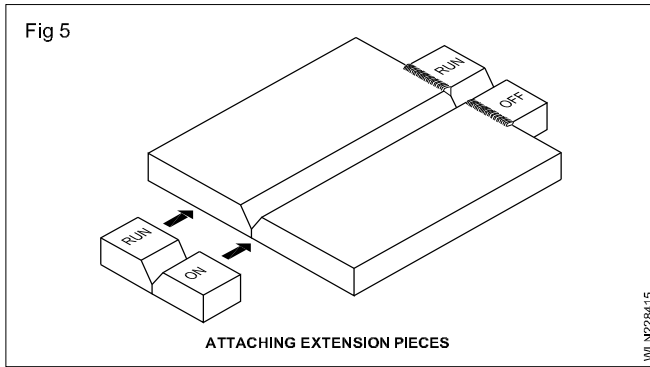
The entire welding zone is buried under a blanket of flux and longitudinally it travels along the seam.

Use 'run on' and 'run off' pieces for starting and ending to avoid formation of crater and beginning and ending faults. (Fig 5)

Advantages of SAW

- High quality weld metal
- High deposition rate and speed
- Smooth, uniform finished weld
- No spatter
- Little or no smoke
- No arc flash
- High utilization of electrode wire
- No need for protective clothing

Fig 5



Limitations: The submerged arc welding process is limited to flat position and horizontal fillet position.

Table 1
Submerged arc welding parameters for single electrode
(For fillet welds by automatic welding)

Weld size (mm)	5	6	8	10	12	16	20
Plate thickness (mm)	6	8	10	12	16	20	25
Electrode size (mm)	3.2	4	5	5	5	5	5
Current (amp) DC	520	620	720	800	870	920	970
Volts	30	32	34	36	38	39	40
Welding speed (m/min.)	1.4	1	0.7	0.56	0.36	0.25	0.20
Electrode req'd (Kg/m)	0.10	0.18	0.28	0.40	0.70	1.1	1.6
Flux req'd (Kg/m)	0.05 - 0.09	0.75 - 0.12	0.14 - 0.18	0.18 - 0.27	0.33 - 0.45	0.53 - 0.75	0.83 - 1.2
Total time (hr/m of weld)	0.012	0.016	0.0024	0.03	0.047	0.67	0.09

Table 2
Submerged arc welding parameters for single electrode
(For Butt welds by Automatic welding)

Plate thickness (mm)	6		10		12		16		20	
Pass	1	2	1	2	1	2	1	2	1	2
Electrode size (mm)	5		5		5		5		5	
Current (amp) DC+	600	750	650	800	750	850	750	850	800	900
Volts	31	33	33	35	35	36	35	36	36	37
Welding speed (m/min)	1.8	1.8	1.2	1.2	0.9	0.9	0.6	0.6	0.5	0.5
Electrode consumed (Kg/m)	0.13		0.23		0.35		0.56		0.63	
Flux consumed (Kg/m)	0.14 - 0.16		0.19 - 0.25		0.3 - 0.4		0.5 - 0.65		0.55 - 0.72	
Total time (hr/m of weld)	0.019		0.028		0.038		0.059		0.06	

Welder - Gas metal arc welding

Electro slag welding and electro gas welding

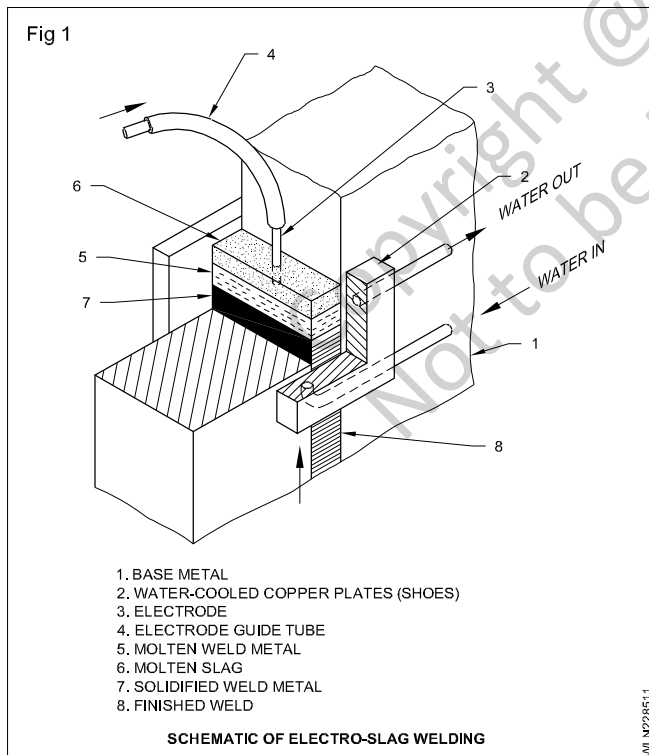
Objectives: At the end of this lesson you shall be able to

- state the principle of electro slag welding & electro gas welding
- explain the procedure
- state the advantages of electro slag welding
- state application and limitations.

Introduction

Electro slag welding process is considered as a further development of submerged arc welding and developed for the welding of thick plates with a single pass. With this process, plates of 25mm or more can be joined without multiple passes and without edge preparations such as bevel joints, 'V' joints and 'J' joints and 'U' joints and reduced the twice in the fabrication.

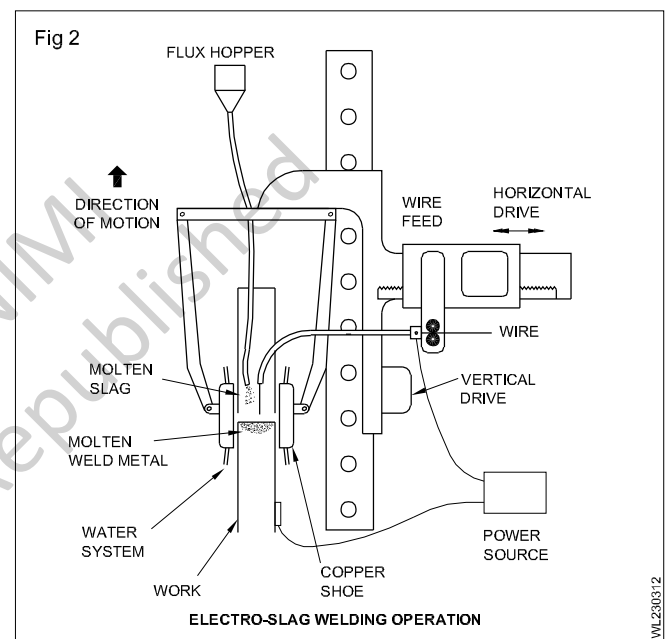
Principle: The electro-slag process is fully automatic. The plates to be joined are kept in vertical position. (The axis of the weld joint is vertical) The flux is continuously fed into the area being welded where it forms a cover of molten slag over the weld metal. This covering of molten slag serves as a major source of heat for the electro-slag welding process. The welding takes place in the flat or down hand position with vertical upward travel of the weld pool. (Fig 1)



Operation: An electric arc is struck between the electrode and the joint bottom with the help of a piece of steel wool.

Welding flux is added which melts by the heat of the arc. When a thick layer of hot flux or molten slag is formed, the arc action stops and the electric current passes from the electrode to the workpieces through the conductive slag pool.

The conductive slag pool remains molten because of its resistance to the electric current passing between the electrode and the work through it. The temperature of this molten slag pool is 1650°C at the surface and 1930°C inside under the surface. The heat fuses the edges of the workpiece and the welding electrode. Fig 2 shows an electro-slag welding process in progress.



The function of welding flux: The welding flux shields the molten metal and reduces oxidation. It cleans impurities from the molten metal. The flux is added in small quantities periodically.

Copper dams or shoes

Water-cooled copper shoes contain and confine the molten slag and molten welding metal until it solidifies. The copper shoes accelerate solidification of the weld metal.

Advantages

- Less edge preparation.
- Thicker steels can be welded in a single pass.
- High deposition rate.
- Residual stresses and distortion low.
- Less flux consumption.
- No spatter.

Application

- Forging and castings of heavy thickness can be welded.
- Some alloys such as low carbon and medium carbon steels can be welded.
- High strength structural steels can be welded.
- High strength alloy steel such as stainless steel and nickel alloy can be welded.

Limitations: This process can be used only for welding of very heavy plates.

Equipments

- 1 AC Power Source
- 2 Wire Feeder
- 3 Electrode Guide Tube
- 4 Control Panel
- 5 Travel Carriage
- 6 Water cooled Copper Shoes

1 AC power source

Electro Slag Welding requires a Power Source, capable of delivering the AC welding current, recommended for the process. The Power Source is stationary.

2 Wire feeder

The function of the wire feeder is to deliver the electrode wire through the guide tube to the molten flux.

3 Electrode guide tube

The tube is insulated materials to avoid short circuiting. It is made of beryllium copper alloys because this alloy can withstand high temperature and retains its strength.

4 Control panel

It consists a mounting near the welding head which as the following components

- a Ammeter, Voltmeter and a remote control for each of the Power Source.
- b A speed control for each wire drive motors.
- c Alarm Systems for equipment mall functions.

5 Travel carriage

All functions of the machine are controlled from a Panel located at the vertical transport carriage assembly.

6 Water cooled copper shoes

The Copper Shoes accelerate solidification of the weld metal. The functions of the Copper Shoes are to maintain the molten metal and molten slag until it solidifies.

Electro gas welding

Electro Gas Welding is an automatic welding Process that uses a Carbon Di-oxide (CO₂) or a mixture of CO₂ and Argon Shielding Gas to protect the Arc and molten weld metal from Atmospheric Contaminants. A Consumable Flux cored or Solid electrode wire is continuously and mechanically led into the arc and molten pool. Edge Preparation is not necessary. This process may be carried out by two methods

- 1 Solid Electrode Process
- 2 Flux Cored Electrode Process

Solid electrode process

In this Process, generally single electrode is fed into the joint. Two electrodes can be used for welding of thick plates. The Shield is done by the CO₂ gas and no extra flux is required.

Flux cored electrode process

In this Process, electrode with flux is fed into the joint and a thin layer of Slag on the top of molten pool. The Shielding is done by Flux.

Electro gas welding equipment and supplies

The Equipments of Electro Gas Welding are similar to Electro Slag Welding but the difference is Shielding Gas.

- 1 AC power source
- 2 Water cooled copper shoes
- 3 Welding gun
- 4 Wire feeder
- 5 Shielding gas and
- 6 Control panel

Applications

It is used for welding of thick plates in vertical position. It can be applied on Carbon Steel and Alloy Steels.

Advantages

- 1 Welder can see the welding pool easily.
- 2 Restarting the weld is easier.

Disadvantages

It is not suitable economical for welding metal lesser than 25 mm. thick.

Thermit welding

Objectives: At the end of this lesson you shall be able to

- **state the principle of thermit welding**
 - **describe the parts of thermit welding equipment**
 - **explain the sequence of operation for completing the weld**
 - **state the application of thermit welding.**
-

Thermit welding

Thermit is a trade name for a mixture of finely divided metal oxide (usually iron oxide) and a metal reducing agent. (almost always aluminium). The thermit mixture may consist of about five parts of aluminium and eight parts of iron oxide, and the weight of thermit used will depend on the size of the parts of to be welded. The ignition powder usually consists of powdered magnesium or a mixture of Aluminium and Barium Peroxide.

Principle of thermit welding

The heat necessary for joining in the thermit welding process is obtained from a chemical reaction that takes place between a metal oxide (Iron oxide) and a metal reducing agent. (Aluminium) When ignited by using a burning magnesium ribbon in one spot of thermit mixture. The reaction spreads throughout the mixture. The tremendous heat released approximately 2760°C (5000°F) causes the iron to change to a liquid state within 25 to 30 seconds. As the aluminium in the mixture combines with the oxygen from the iron oxide, it forms Alumina oxide, which serves as slag and float to the top. Thermit reaction is an exothermic process. There are two types of Thermit Welding:

- 1 Plastic or Pressure Thermit Welding
- 2 Fusion of Non-pressure Thermit Welding

Plastic or Pressure thermit welding

This type is used mainly for butt welding of thick pipes of rails. In this weld, pressure is used to join the metal. The work pieces are clamped into C.I moulds and are forced together when the desired temperature is achieved. The thermit is heated in a crucible above the work. While heating, the lighter aluminium oxide slag rises to the top. When pouring temperature is reached, the thermit solution is poured into the mould. When the thermit mixture has heated the work pieces sufficiently, the work pieces are forced together forming a pressure butt weld. The whole welding process takes 45 to 90 seconds for welding of thick walled pipe.

Fusion of non-pressure thermit welding

In this process, the work pieces are lined up, leaving a space between the ends to be welded. Wax is placed between the joint. The whole frame is suspended in a mould, and then the molten metal is poured. The first step in preparing a non-pressure thermit weld is the cleaning of the joint.

Equipments, materials and supplies

The thermit welding process requires an adequate supply of

- 1 Thermit mixture
- 2 Thermit Ignition powder and a
- 3 Device (Flint Gun, Hot Iron Rod etc...)

Thermit mixture

The most commonly used types of thermit for welding the various ferrous metals are:

- 1 Plain Thermit
- 2 MS Thermit or Forging Thermit
- 3 Cast Iron Thermit
- 4 Steel Mill Wabblers
- 5 Rail welding Thermit
- 6 Thermit for welding electric connections

Plain thermit

A mixture of finely divided Aluminium and Iron Oxide. This is the basic of most thermit mixtures and yields maximum temperature.

MS thermit

This is a plain thermit with the addition of manganese and mild steel punching, and is used in welding steel. Manganese is added to adjust the chemistry of thermit mixture (Carbon may also be added, the mild steel punching are used to augment the metal content)

Cast iron thermit

Cast iron Thermit consists of plain thermit with addition of Ferro-silicon and Mild Steel punching and is used for welding cast iron. The mild steel punching augments the total metal content. Unless the weld area is post heat treated, this weld metal is generally not machinable and, because of the different contraction between it and the cast iron parent metal. It is limited to use where the maximum weld dimension is less than 8 times its width.

Thermit for steel mill wabblers

This consists of plain thermit with additions of manganese and carbon to provide a hard, wear resistant, machinable steel especially adopted to the building up of worn wabblers ends of steel mill rolls.

Thermit for welding rail

These mixtures usually consist of plain thermit with additions of carbon and manganese to adjust hardness of the deposited metal to the hardness of the rail being welded. Alloys are also added for controlling resistance to abrasion and to act as grain refiners.

Thermit for welding electric connections

This consists of Copper Oxide and Aluminium.

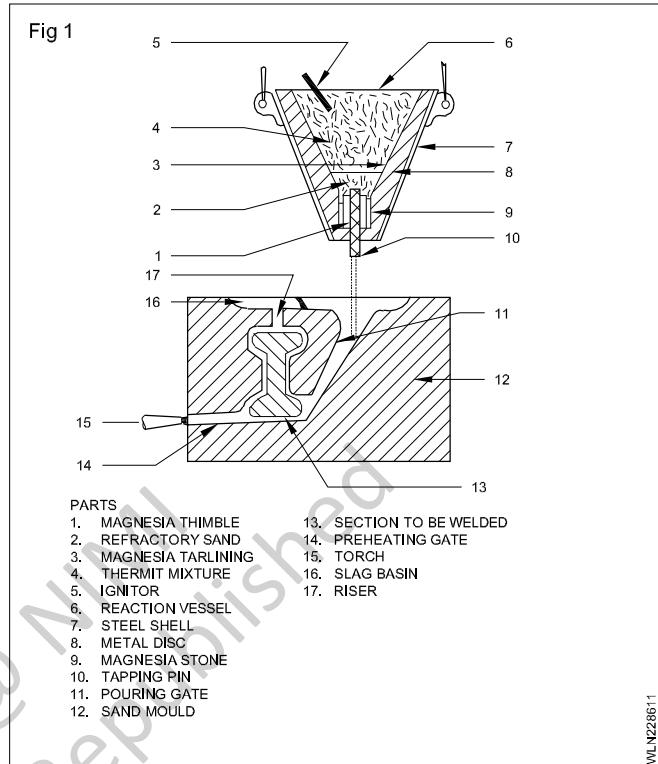
Thermit ignition powder

There are a number of different ignition powders available. Barium per oxide is frequently used. The thermit ignition powder is ignited directly with a match. This should be done by partly burying the match head in the mixture and igniting the match with a thin red hot rod. This avoids the danger of burns injuries to the finger or hand due to the sudden flare in igniting. The thermit ignition powder can also be ignited with a spark from a flint gun or by using a burning magnesium ribbon.

Thermit welding procedure

The ends are to be welded are thoroughly cleaned of scale and rust. After cleaning, the parts to be welded are to be lined up with a gap of 1.5 to 6mm depending upon the size of parts. This gap compensates the contraction of thermit steel and the shrinkage of the base metal. The next stage is making wax pattern of the weld. A refractory sand mould is rammed up around the wax joint and necessary gates and risers provided. Ramming should be light between the moulding sand and the wax. When ramming is completed, the pattern may be drawn and loose sand may be wiped out. Then, the heat is given to the wax pattern through the heating gate to melt and burn out wax. The heating is continued until the ends to be welded are at a red heat. This prevents the thermit steel being chilled, as it would be if it came into contact with cold metal. The preheating gate is now sealed off with sand. Now, charge the thermit in the crucible. The approximate weight of thermit is 12 to 14 kgs against one kg. of wax. The outside shell of crucible is made by steel and is lined with manganese tar lining. At the bottom, a magnesia stone and a thimble is provided through which the tapping pin works. The thimble is inserted in the stone which provides a channel through which the molten metal is poured for each reaction a new thimble is used. The thimble is plugged by suspending the tapping pin and placing a metal disc above pin. The metal disc is lined with refractory sand. At the top of the thermit, low ignition temperature thermit is placed in the crucible. When ignited in one spot of thermit mixture, the

reaction spreads throughout the mixture. The reacted can be heard, as soon as the noise of reaction stops, the crucible should be tapped. The intense heat of thermit melts the preheated ends of the parts to be welded and the fusion welding takes place. Then the mould is allowed to cool overnight. If possible or at least for 12 hours and cut away the gates and risers with a cutting torch and finish the weld. (Fig 1)



Application

Thermit welding is mainly used in rail welding, concrete reinforcement rod welding, building up of steel mill wobbler ends and for electrical connections.

1 Rail welding

Rails are welded to create long railways for electrified and other fast tracks. This increases the passenger comfort and keeps the maintenance cost down. Spillage of goods (like coal) is minimised in mining industry.

2 Reinforcement steel rod welding

In big building projects, a massive number of joints are to be carried out for joining of reinforcement steel at a short time. Thermit welding is applied by using prefabricated moulds with reaction chambers.

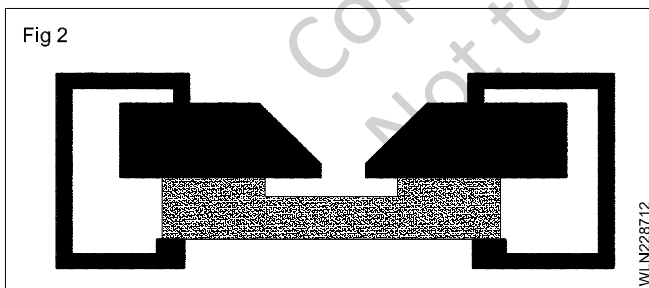
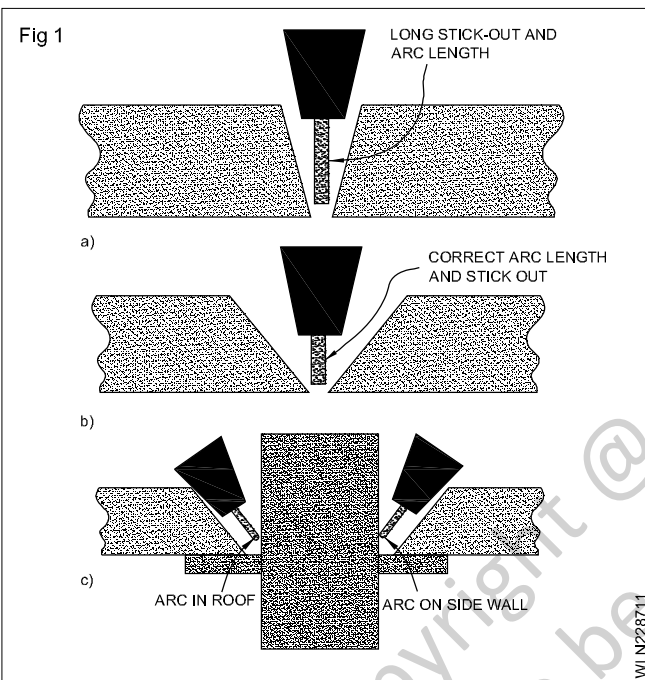
Backing strips and backing bars

Objective: At the end of this lesson you shall be able to
 • understand the principle of backing strips and backing bars.

Definition

While welding the product supported and control the distortion of the concened jobs/product. To minimise the distortion and contraction we can use backing strips and backing bars.

The following sketches are to be used.



The temperature and fast cooling is applied on fully heat treated samples.

The microstructure results due to cooling at the maximum holding temperature as well as independant of the applied pressure value.

The effect of heat treatment and cooling rate on the properties of fast cooling from the upper limit and proesize distruction do not change significantly throughout the sample sarees.

In the experiments the effect of fast and slow cooling the bathing prior to heating these was a heat distribution of intervals.

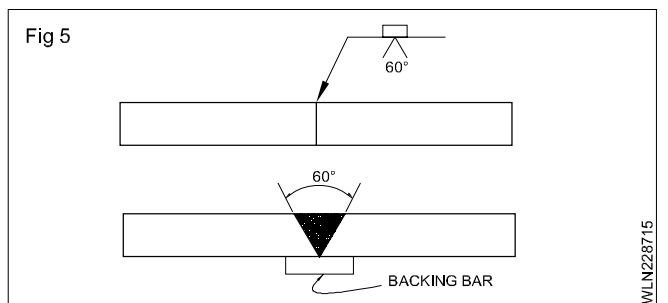
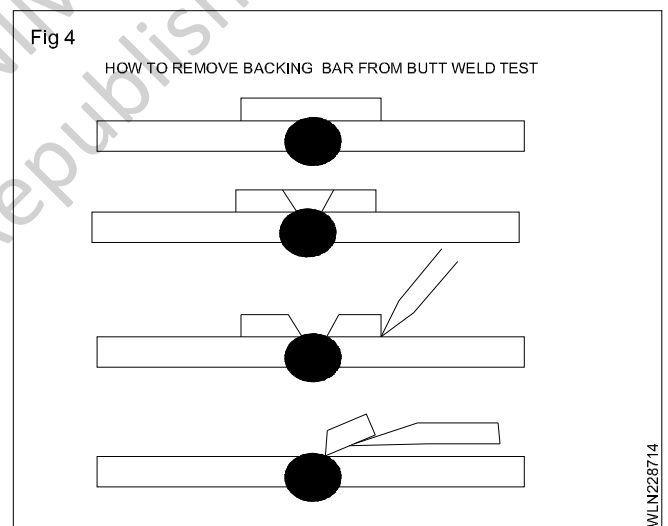
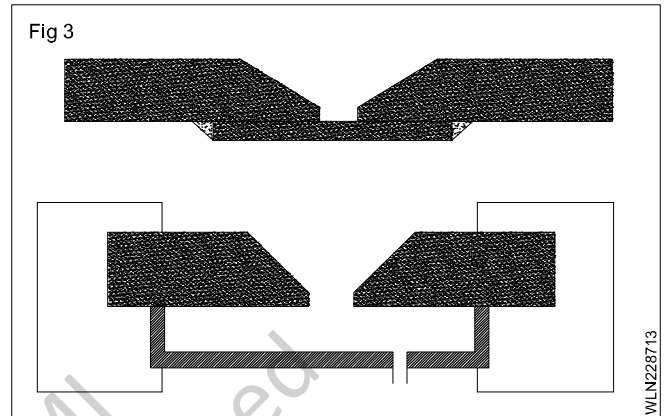
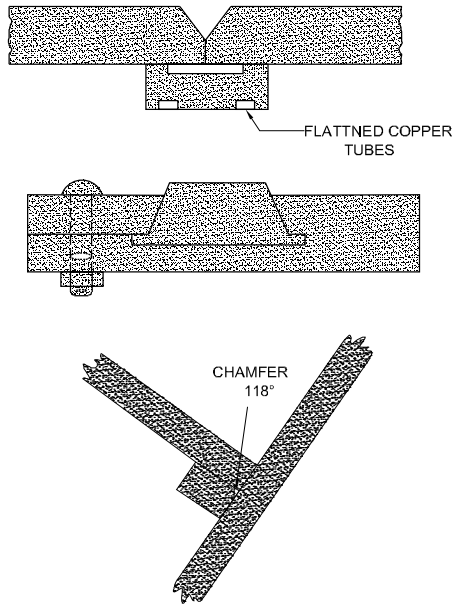
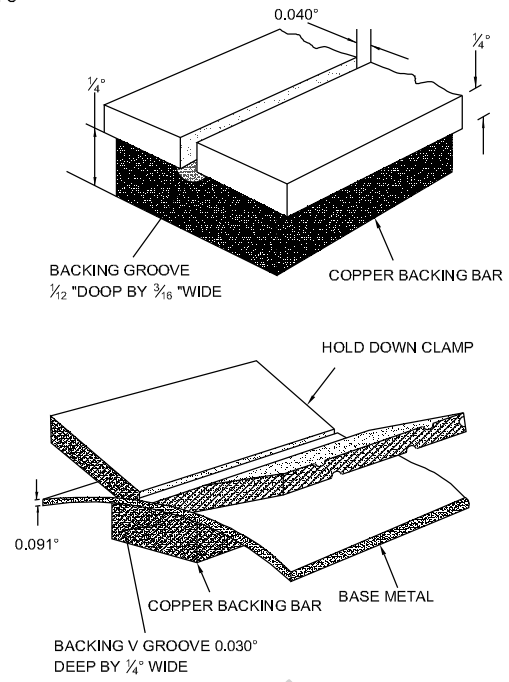


Fig 6



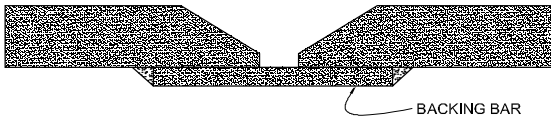
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Fig 9



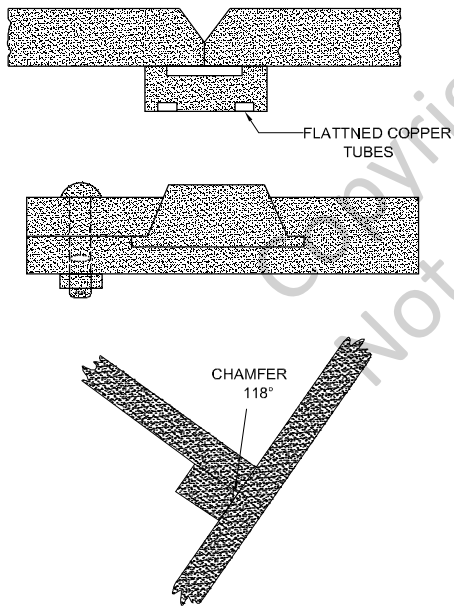
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Fig 7



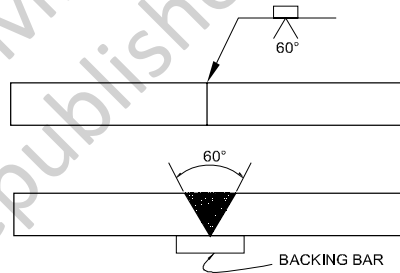
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Fig 8



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Fig 10



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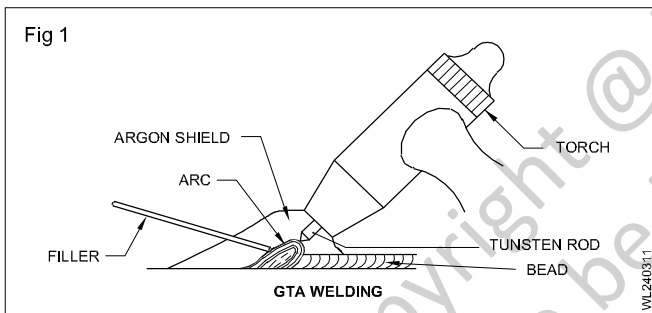
Principles of Gas Tungsten Arc Welding (GTAW), advantages & limitations

Objectives: At the end of this lesson you shall be able to

- state the principle of GTAW process
- state its application
- state the advantages and disadvantages of GTAW.

Process description (Fig.1)

Gas Tungsten Arc Welding (GTAW), also known as tungsten inert gas (TIG) welding is a process that produces an electric arc maintained between a nonconsumable tungsten electrode and the part to be welded. The heat-affected zone, the molten metal, and the tungsten electrode are all shielded from atmospheric contamination by a blanket of inert gas fed through the GTAW torch. Inert gas (usually Argon) is inactive or deficient in active chemical properties. The shielding gas serves to blanket the weld and exclude the active properties in the surrounding air. Inert gases, such as Argon and Helium, do not chemically react or combine with other gases. They pose no odor and are transparent, permitting the the welder maximum visibility of the arc. In some instances Hydrogen gas may be added to enhance travel speeds.



The GTAW process can produce temperatures of up to 3000° F. The torch contributes heat only to the workpiece. If filler metal is required to make the weld, it may be added manually in the same manner as it is added in the oxyacetylene welding process, or in other situations may be added using a cold wire feeder.

GTAW is used to weld steel, stainless steel, nickel alloys, titanium, aluminum, magnesium, copper, brass, bronze, and even gold. GTAW can also weld dissimilar metals to one another such as copper to brass and stainless steel to mild steel.

Advantages of GTA welding

- Concentrated Arc - Permits pinpoint control of heat input to the workpiece resulting in a narrow heat-affected zone.

- No Slag - No requirement for flux with this process; therefore no slag to obscure the welder's vision of the molten weld pool.
- No Sparks or Spatter - No transfer of metal across the arc. No molten globules of spatter to contend with and no sparks produced if material being welded is free of contaminants.
- Little Smoke or Fumes - Compared to other arc-welding processes like stick or flux cored welding, few fumes are produced. However, the base metals being welded may contain coatings or elements such as lead, zinc, copper, and nickel that may produce hazardous fumes. Keep your head and helmet out of any fumes rising off the workpiece. Be sure that proper ventilation is supplied, especially in a confined space.
- Welds more metals and metal alloys than any other arc welding process.
- Good for welding thin material.
- Good for welding dissimilar metals together.

Disadvantages of GTA welding

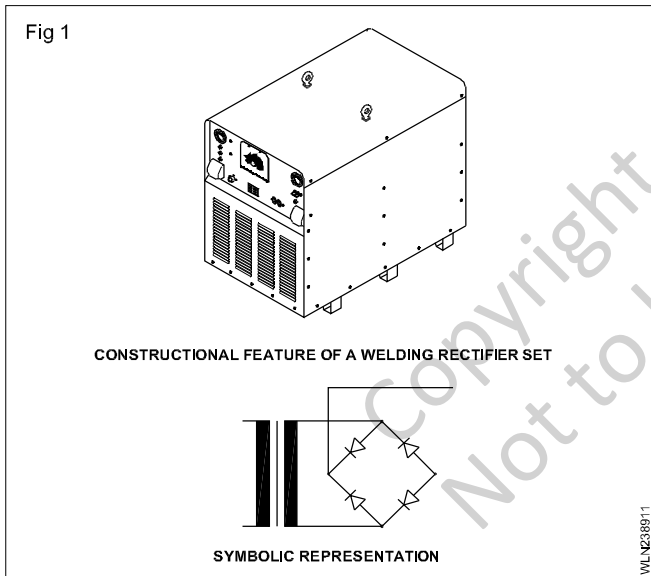
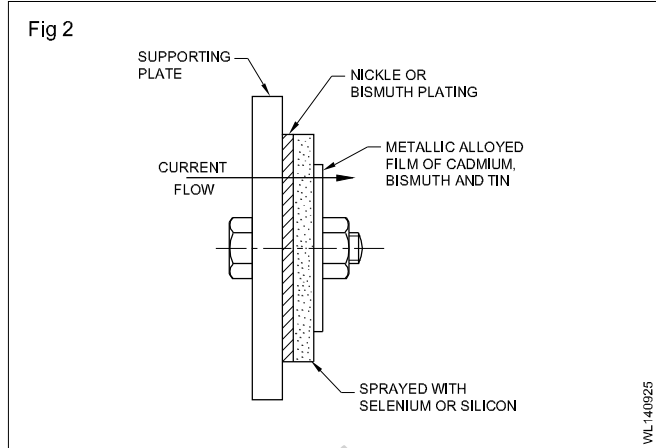
- Slower travel speeds than other processes.
- Lower filler metal deposition rates.
- Hand-eye coordination is a required skill.
- Brighter UV rays than other processes.
- Equipment costs can be higher than with other processes.
- Concentrations of shielding gas may build up and displace oxygen when welding in confined areas - ventilate the area and/or use local forced ventilation at the arc to remove welding fumes and gases. If ventilation is poor, wear an approved air-supplied respirator.

GTAW process brief description

Objective: At the end of this lesson you shall be able to
 • **difference between equipments polarities and applications.**

Constructional features of AC/DC welding rectifier: A welding rectifier set is used to convert AC welding supply into DC welding supply. It consists of a step down transformer and a welding current rectifier cell with a cooling fan. (Fig.1) The rectifier cell consists of a supporting plate made of steel or aluminium (Fig.2) which is plated with a thin layer of nickel or bismuth, sprayed with SELENIUM or SILICON. It is finally covered with an alloyed film of CADMIUM, BISMITH and TIN.

The coating of nickel or bismuth over the supporting plate serves as one electrode (ANODE) of the rectifying cell. The alloyed film (of cadmium, bismuth and tin) serves as another electrode (CATHODE) of the rectifying cell. The rectifier acts as a non-return valve and allows current to flow on one side of it as it offers very little resistance and on the other side it offers very high resistance to the flow of the current. Hence the current can flow in one direction only.



Working principle: The output of the step down transformer is connected to the rectifier unit, which converts AC to DC. The DC output is connected to positive and negative terminals, from where it is taken for welding purposes through welding cables. It can be designed to provide either AC or DC welding supply by operating a switch provided on the machine.

Care and maintenance of rectifier welding set

- Keep all the connections in tight condition.
- Lubricate the fan shaft once in 3 months.
- Do not adjust the current or operate the AC/DC switch when the welding arc is 'on'.
- Keep the rectifier plates clean.

Check and clean the set atleast once in a month.
Keep the air ventilation system in good order.
Never run the machine without the fan.

Advantages and disadvantages of AC and DC welding

Objectives: At the end of this lesson you shall be able to
 • **compare the advantages and disadvantages of AC welding**
 • **compare the advantages and disadvantages of DC welding.**

Advantages of AC welding

- A welding transformer has
- a low initial cost due to simple and easy construction
 - a low operating cost due to less power consumption
 - no effect of arc blow during welding due to AC
 - low maintenance cost due to the absence of rotating parts
 - higher working efficiency
 - noiseless operation.

Disadvantages of AC welding

- It is not suitable for bare and light coated electrodes.
- It has more possibility for electrical shock because of higher open circuit voltage.
- Welding of thin gauge sheets, cast iron and non-ferrous metals (in certain cases) will be difficult.
- It can only be used where electrical mains supply is available.

Advantages of DC welding

Required heat distribution is possible between the electrode and the base metal due to the change of polarity (positive 2/3 and negative 1/3).

It can be used successfully to weld both ferrous and non-ferrous metals.

Bare wires and light coated electrodes can be easily used.

Positional welding is easy due to polarity advantage.

It can be run with the help of diesel or petrol engine where electrical mains supply is not available.

It can be used for welding thin sheet metal, cast iron and non-ferrous metals successfully due to polarity advantage.

It has less possibility for electrical shock because of less open circuit voltage.

It is easy to strike and maintain a stable arc.

Remote control of current adjustment is possible.

Disadvantages of DC welding

DC welding power source has:

- a higher initial cost
- a higher operating cost
- a higher maintenance cost
- trouble of arc blow during welding
- a lower working efficiency
- noisy operation in the case of a welding generator
- occupies more space.

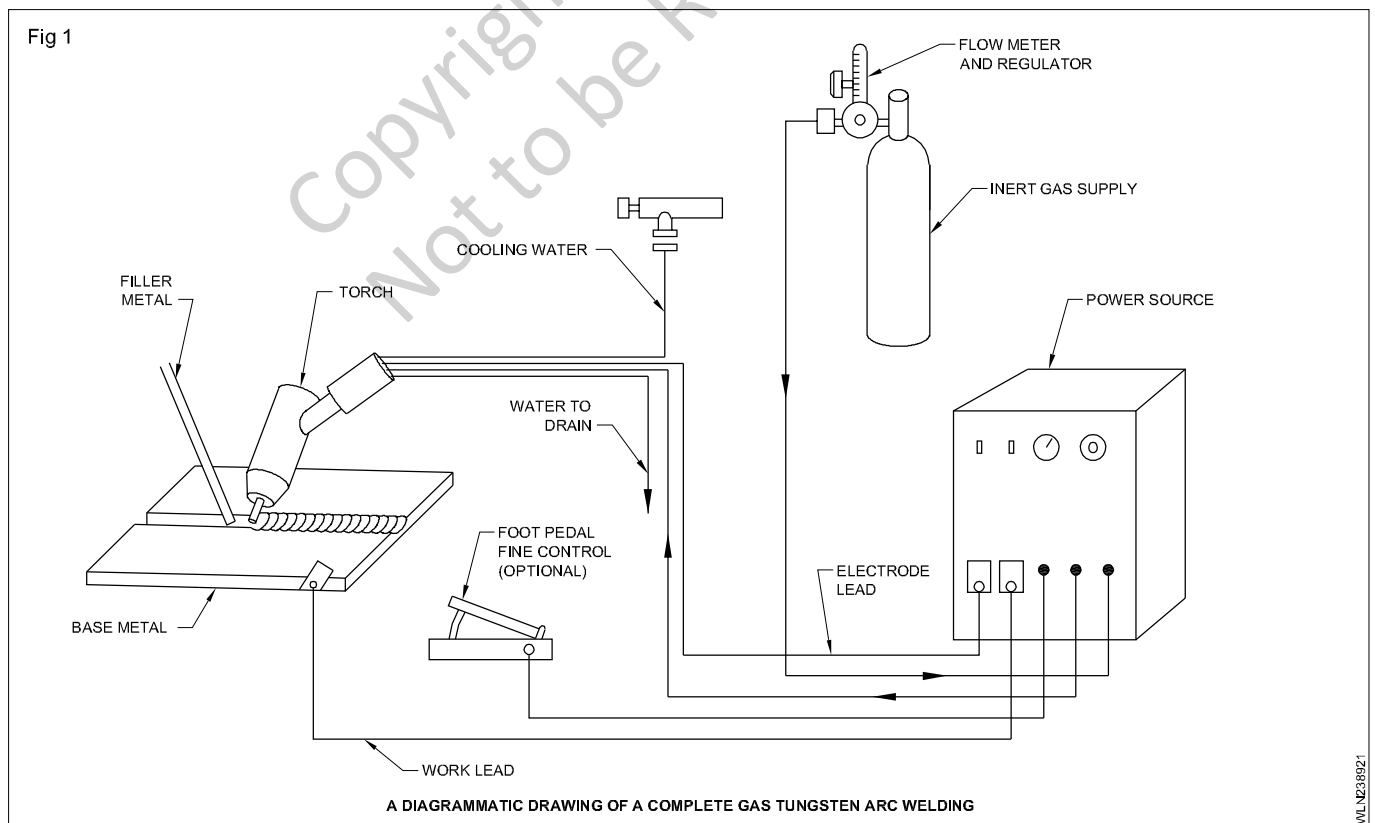
GTAW process and equipment

Objectives: At the end of this lesson you shall be able to

- identify the GTAW equipment
- name the parts of a GTAW equipment

TIG welding equipment (Fig 1)

- An AC or DC arc welding machine.
- Shielding gas cylinders or facilities to handle liquid gases
- A shielding gas regulator
- A gas flowmeter
- Shielding gas hoses and fittings
- A welding torch (electrode holder)
- Tungsten electrodes
- Welding filler rods
- Optional accessories
- A water cooling system with hoses for heavy duty welding operations
- Foot rheostat (switch)



Various other name of the process (Tig organic)

Objectives: At the end of this lesson you shall be able to

- understand the history and overview of GTAW
 - state the advantages and applications of GTAW
-

History of Gas Tungsten Arc Welding (GTAW)

GTAW welding was, like GMAW developed during 1940 at the start of the Second World War.

GMAW's development came about to help in the welding of difficult types of material, eg aluminium and magnesium. The use of GMAW today has spread to a variety of metals like stainless mild and high tensile steels.

GTAW is most commonly called TIG (Tungsten Inert Gas welding).

The development of TIG welding has added a lot in the ability to make products, that before the 1940's were only thought of.

Like other forms of welding, TIG power sources have, over the years, gone from basic transformer types to the highly electronic power source of the world today.

Overview

TIG welding is a welding process that uses a power source, a shielding gas and a TIG torches. The power is fed out of the power source, down the TIG torches and is delivered to a tungsten electrode which is fitted into the torches. An electric arc is then created between the tungsten electrode and the workpiece. The tungsten and the welding zone is protected from the surrounding air by a gas shield (inert gas). The electric arc can produce temperatures of up to 3000°C and this heat can be very focused local heat.

GTAW power sources

Objectives: At the end of this lesson you shall be able to

- state the necessity of a suitable power sources
 - state the different types of power sources used
 - state the application of different power sources
 - state the care and maintainance of GTAW machine.
-

Power sources

TIG welding power sources have come a long way from the basic transformer types of power sources which were used with add-on units to enable the power source to be used as a TIG unit, eg high frequency unit and/or DC rectifying units.

The basics of TIG welding has almost remained the same, but the advent of technology TIG welding power sources have made the TIG processes more controllable and more portable.

The one thing that all TIGs have in common is that they are CC (Constant Current) type power sources. This means only output adjustment will control the power source amps. The voltage will be up or down depending on the resistance of the welding arc.

The weldpool can be used to join the base metal with or without filler material.

The TIG process has the advantages of -

- 1 Narrow concentrated arc
- 2 Able to weld ferrous and non-ferrous metals
- 3 Does not use flux or leave a slag
- 4 Uses a shielding gas to protect the weldpool and tungsten
- 5 A TIG weld should no spatter
- 6 TIG produces no fumes but can produce ozone

The TIG process is a highly controllable process that leaves a clean weld which usually needs little or no finishing. TIG welding can be used for both manual and automatic operations.

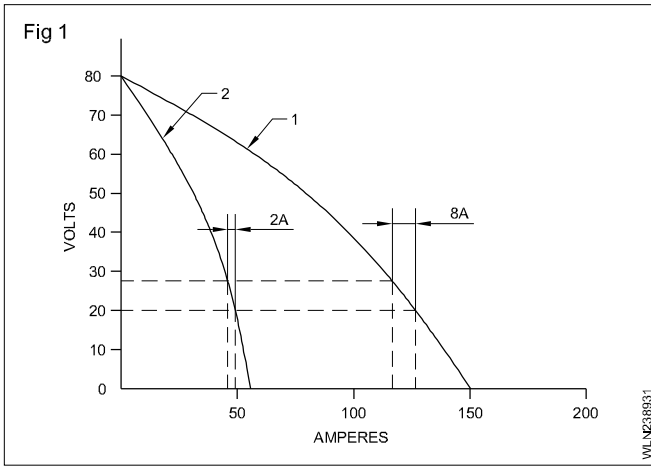
The TIG welding process is so good that it is wisely used in the so-called high-tech industry applications such as

- 1 Nuclear industry
- 2 Aircraft
- 3 Food industry
- 4 Maintenance and repair work
- 5 Some manufacturing areas
- 6 The off shore industry
- 7 Combined heat and power plants
- 8 Petro chemical industry.
- 9 Chemical industry.

Characteristics of power source : The output slope or voltampere curve A, a change from 20 volts to 25 volts will result in a decrease in amperage from 135 amps to 126 amps. With a change of 25 percent in voltage, only a 6.7 percent change occurs in the welding current in curve A. Thus if the welder varies the length of the arc, causing a change in voltage, there will be very little change in the current and the weld quality will be maintained. The current in this machine, even though it varies slightly is considered constant (Fig 1).

This is called drooping characteristic power source. Also called Constant Current (CC) power source.

This type of power source is used in SMAW & GTAW process.

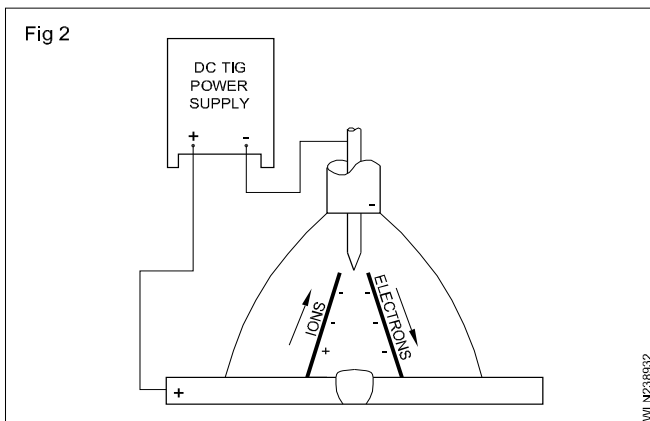


Types of welding current used for GTAW

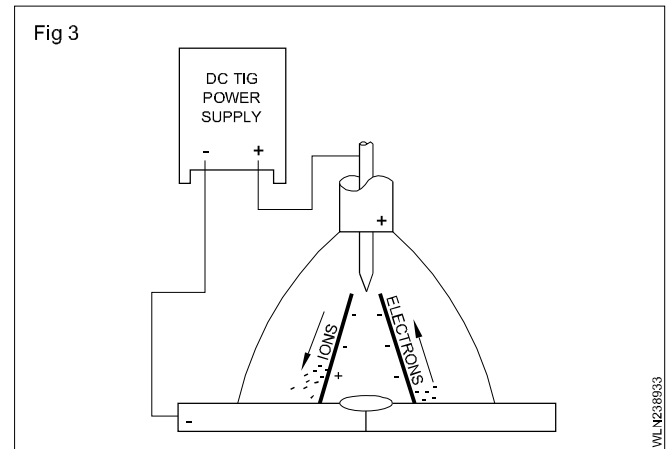
When TIG welding, there are three choices of welding current. They are: Direct Current Straight Polarity, Direct Current Reverse Polarity, and Alternating Current with High Frequency stabilisation. Each of these has its applications, advantages, and disadvantages. A look at each type and its uses will help the operator select the best current type for the job. The type of current used will have a great effect on the penetration pattern as well as the bead configuration. The diagrams below, show arc characteristics of each current polarity type.

DCSP - Direct Current Straight Polarity (Fig 2): (The tungsten electrode is connected to the negative terminal). This type of connection is the most widely used in the DC type welding current connections. With the tungsten being connected to the negative terminal it will only receive 30% of the welding energy (heat). This means the tungsten will run a lot cooler than DCRP. The resulting weld will have good penetration and a narrow profile.

Current type	DCSP
Electrode Polarity	Electrode Negative
Oxide Cleaning Action	No
Heat Balance in the Arc	70% at work end 30% at electrode end
Penetration Profile	Deep, narrow
Electrode Capacity	Excellent



DCRP - Direct Current Reverse Polarity (Fig 3): (the tungsten electrode is connected to the positive terminal). This type of connection is used very rarely because most heat is on the tungsten, thus the tungsten can easily overheat and burn away. DCRP produces a shallow, wide profile and is mainly used on very light material at low amps.

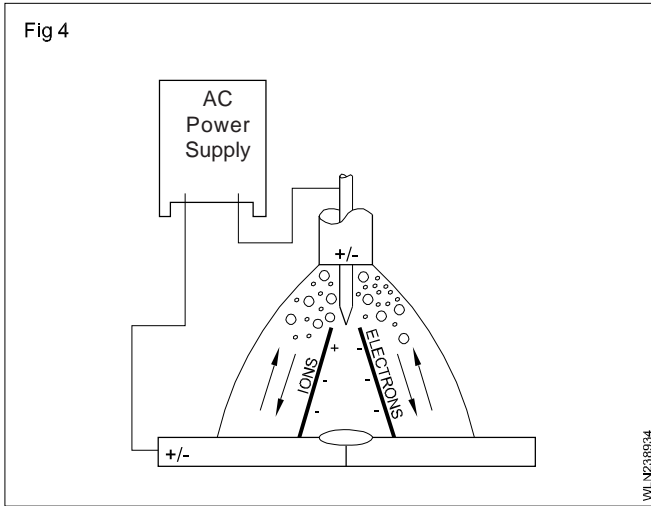


Current type	DCRP
Electrode Polarity	Electrode Positive
Oxide Cleaning Action	Yes
Heat Balance in the Arc	30% at work end 70% at electrode end
Penetration Profile	Shallow, wide
Electrode Capacity	Poor

Current type	ACHF
Electrode Polarity	Alternating
Oxide Cleaning Action	Yes (once every half cycle)
Heat Balance in the Arc	50% at work end 50% at electrode end
Penetration Profile	Medium
Electrode Capacity	Good

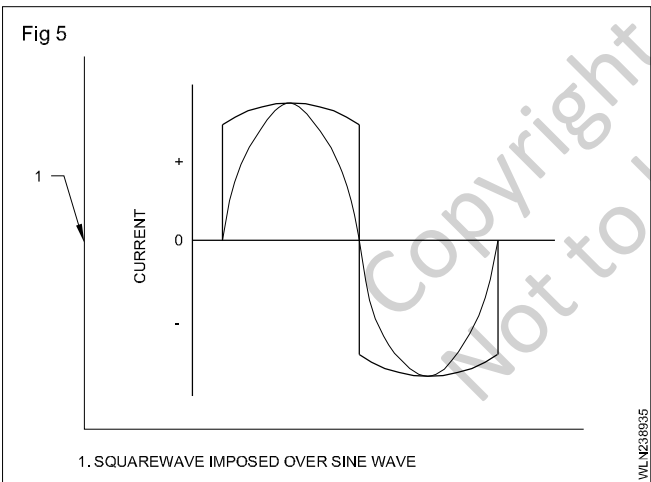
AC - Alternating Current (Fig 4) is the preferred welding current for most white metals, eg aluminium and magnesium. The heat input to the tungsten is averaged out as the AC wave passes from one side of the wave to the other.

On the half cycle, where the tungsten is positive electron welding current will flow from base material to the tungsten. This will result in the lifting of any oxide skin on the base material. This side of the wave form is called the cleaning half. As the wave moves to the point where the tungsten becomes negative the electrons (welding current) will flow from the welding tungsten to the base material. This side of the cycle is called the penetration half of the AC wave form.



Because the AC cycle passes through a zero point the arc goes out. This can be seen with fast film photography. At this point the arc would stay out if it wasn't for the introduction of HF (high frequency). High frequency has very little to do with the welding process; its job is the re-ignition of the welding current as it passes through zero. HF is also often used for starting the welding arc initially without the tungsten touching the workpiece. This helps on materials that are sensitive to impurities. HF start can also be used on DC welding current to initially start the welding current without the tungsten touching the workpiece.

AC - Alternating Current - Square Wave (Fig 5)



With the advent of modern electricity AC welding machines can now be produced with a wave form called Square Wave. The square wave has the benefit of a lot more control and each side of the wave can be, in some cases, controlled to give a more cleaning half of the welding cycle, or more penetration.

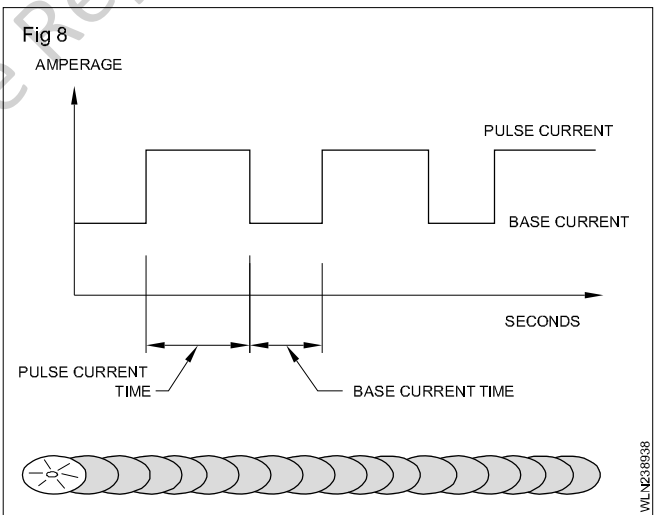
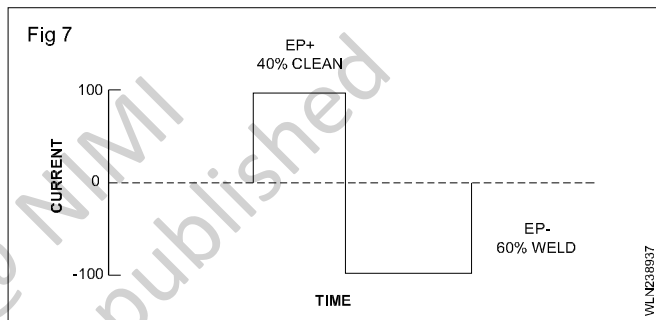
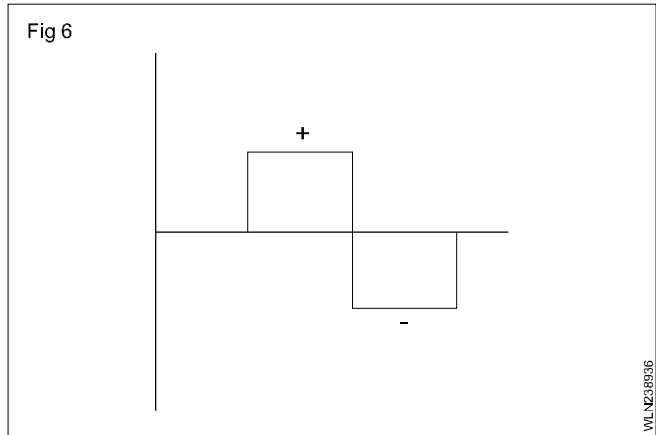
Once the welding current gets above a certain amperage (often depends on the machine) the HF can be turned off, allowing the welding to be carried on with the HF interfering with anything in the surrounding area.

Extended Balance Control (Fig 5 ,6 & 7)

AC balance control allows the operator to adjust the balance between the penetration (EN) and cleaning action

(EP) portions of the cycle. Some inverters have adjustable EN as great as 30 percent to 99 percent for control and fine-tuning of the cleaning action.

For instance, if the operator sets EN at 60 percent, it means that 70 percent of the AC cycle is putting energy into the work, while 40 percent of the cycle is cleaning.



Pulsed TIG (Fig 8)

In this type of power source, the supply current is not constant and it is being fluctuated from low level to high level. This causes low heat input to the metal and hence distortion effect will be less.

Pulsed TIG has the advantages of

- 1 better penetration with less heat
- 2 less distortion
- 3 better control when welding out of position
- 4 easy to use on thin materials

The down side is - more set-up cost and more operator training.

Pulsed TIG consists of

Peak current - This is set up higher than for non-pulsed TIG.

Background current - This is set lower than peak current and is the bottom current the pulse will drop to, but must be enough to keep the arc alive.

Pulses per second - This is the number of times per second that weld current reaches peak current.

% on Time - This is the pulse peak duration as a percentage of the total time, which controls how long the peak current is on for before dropping to the background current.

The pulse and base current periods are also controllable.

When welding is done with pulsing welding mode the weld is in principle a row of spot welds overlapping to a larger or smaller extent depending on the welding speed.

Many double-current machines are equipped with a control function which makes it possible to modify the curve of the alternating current in balance between the positive and the negative semi-periods.

Current Type	DCEN	DCEP	AC (Balanced)
Electrode Polarity	Negative	Positive	
Electron and ion flow			
Penetration Characteristics			
Oxide Cleaning Action	No	Yes	Yes-once every Half Cycle
Heat Balance in the arc (approx.)	70% at work end 30% at electrode end	30% at work end 70% at electrode end	50% at work end 50% at electrode end
Penetration	Deep Narrow	Shallow Wide	Medium
Electrode Capacity	Excellent e.g., 1/8 in. (3.2 mm) 400 A	Poor e.g. 1/4 in. (6.4 mm) 120 A	Good e.g. 1/8 in. (3.2 mm) 225 A

GTAW electrodes

Objectives: At the end of this lesson you shall be able to

- state the types of electrodes
- state the colour codification.

Electrodes for TIG welding

For TIG welding the applied electrode is mainly made of tungsten.

Pure tungsten is a very heat resistance material with a fusion point of approximately 3,380°C.

By alloying tungsten with a few per cent of a metal oxide the conductivity of the electrode can be increased which has the advantage that it can thereby resist a higher current load.

The alloyed tungsten electrodes therefore have a longer lifetime and better ignition properties than electrodes of pure tungsten.

The most frequently used metal oxides used for alloying of tungsten are:

- Thorium oxide ThO_2
- Zirconium oxide ZrO_2
- Lanthanum oxide LaO_2
- Cerium oxide CeO_2

Colour code and alloying elements for various tungsten electrode alloys

AWS classifications	Colour*	Alloying element	Alloying oxide	Current type
EWP	Green	Pure	-	AC/DC
EWCe-2	Orange	Cerium	CeO_2	AC/DC
EWL-1	Black	Lanthanum	La_2O_3	AC/DC
EWTh-1	Yellow	Thorium	ThO_2	DC
EWTh-2	Red	Thorium	ThO_2	DC
EWZr-1	Brown	Zirconium	ZrO_2	AC

- Colour may be applied in the form of bands, dots, etc, at any point on the surface of the electrode.

Electrode dimensions

Tungsten electrodes are available in different diameters from 0.5 to 8 mm. The most frequently used dimensions for TIG welding electrodes are 1.6 - 2.4 - 3.2 and 4 mm.

The diameter of the electrode is chosen on basis of the current intensity, which type of electrode that is preferred and whether it is alternating or direct current.

Colour indications on tungsten electrodes

As the pure tungsten electrodes and the different alloyed ones look the same, it is impossible to tell the difference between them. Therefore a standard colour indication on the electrodes has been agreed.

The electrodes are marked with a particular colour on the last 10 mm.

The most commonly used types of tungsten electrodes are:

- Pure tungsten is marked with green colour. This electrode is especially used for AC welding in aluminium and aluminium alloys.
- Tungsten with 2% thorium is marked with red colour. This electrode is mostly used for welding of non-alloyed and low-alloyed steels as well as stainless steels.
- Tungsten with 1% lanthanum is marked with black colour. This electrode is equally suited for welding of all TIG weldable metals.

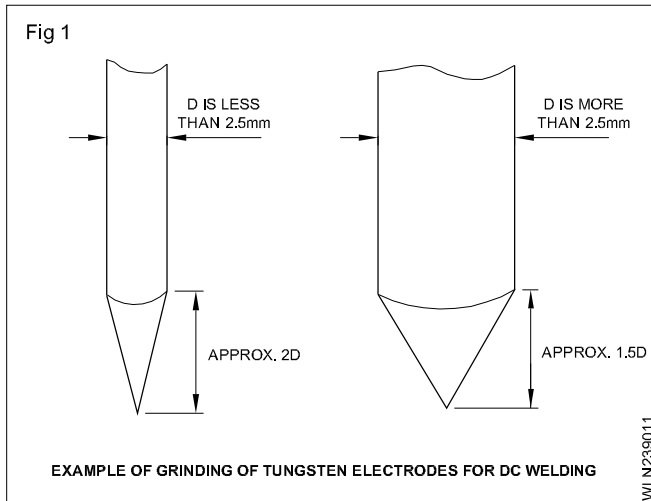
Grinding angle

An important condition for obtaining a good result of TIG welding is that the point of the tungsten electrode must be ground correctly.

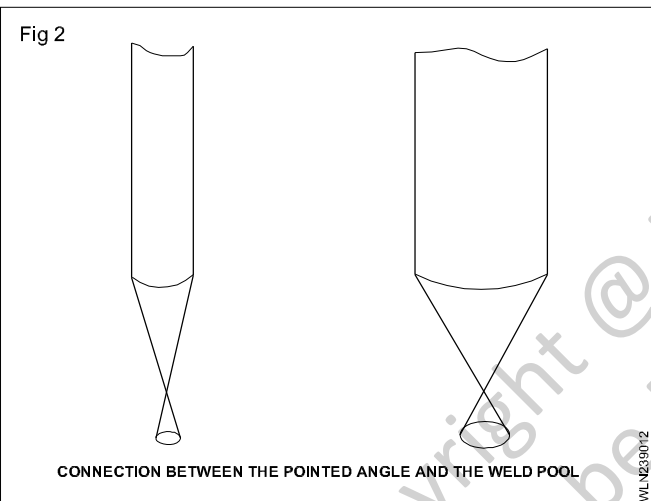
When welding is done with direct current and negative polarity, the electrode point should be conical in order to obtain a concentrated arc that will provide a narrow and deep penetration profile.

The following thumb rule indicates the relation between the diameter of the tungsten electrode and the length of its ground point.

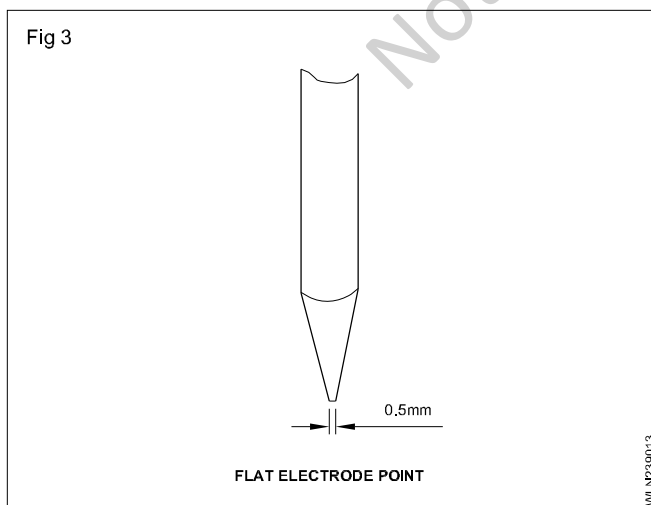
A small pointed angle gives a narrow weld pool and the larger the pointed angle the wider the weld pool (Fig 1).



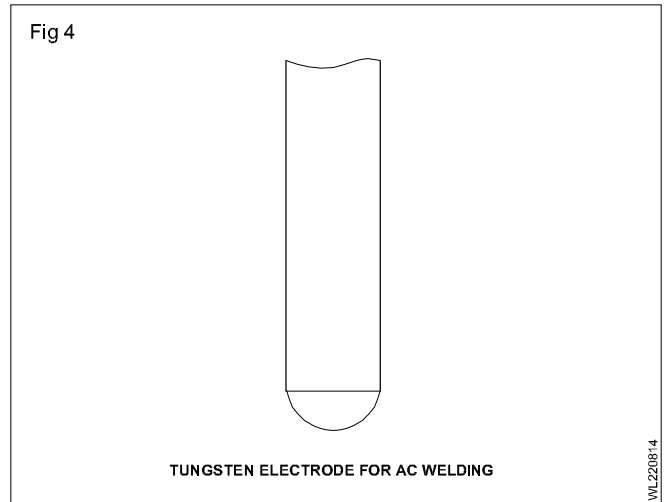
The pointed angle also has an influence of the penetration depth of the weld (Fig 2).



Blunting the electrode point to make a flat area with a diameter of about 0.5 mm can increase the lifetime of the tungsten electrode (Fig 3).

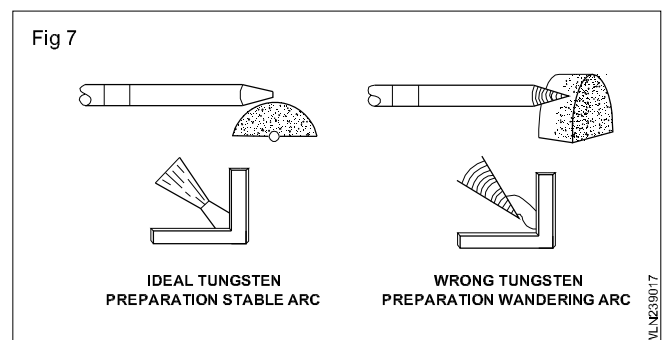
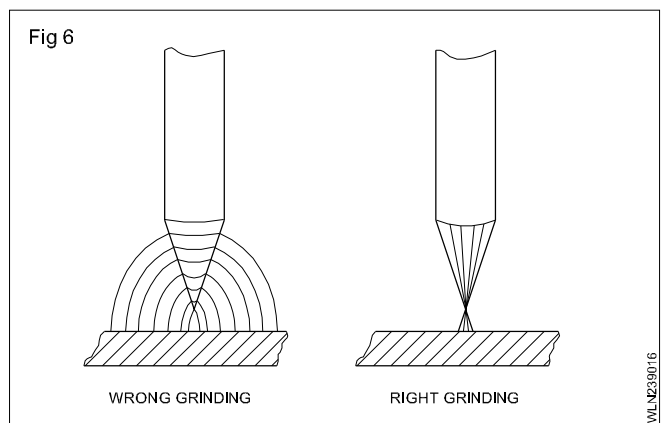
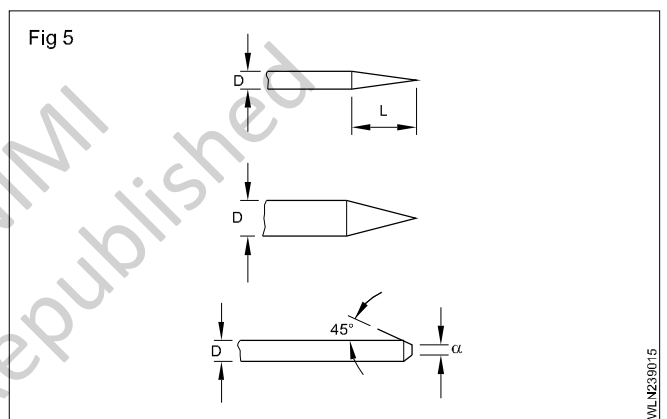


For AC TIG welding the tungsten electrode is rounded as during the welding process it is so heavily loaded that it is melted into a half globular form (Fig 4).

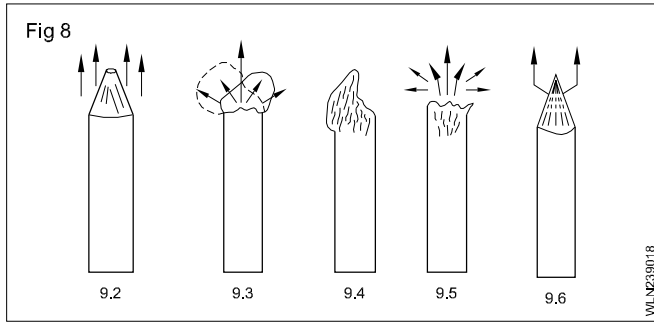


Grinding of the tungsten electrode

When grinding the electrode its point must point in the direction of the rotation of the grinding disc so the grinding traces will lie lengthways the electrode (Fig 5, 6, 7).



Electrode condition: Fig. 8 shows tungsten electrode conditions associated with TIG welding.



Comments

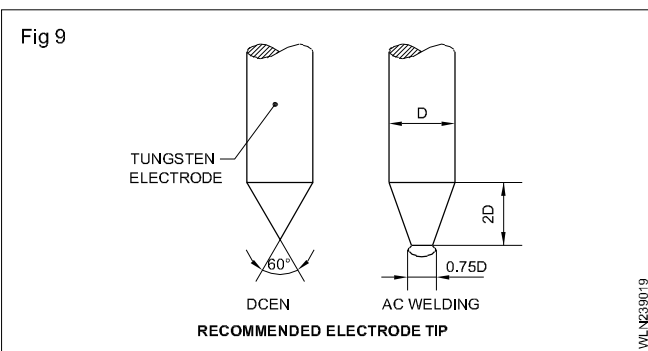
a Well sharpened and healthy electrode (color 'silver white') and used with normal current. Sharpening to a cone (without a point) allows a rapidly forming and stable arc, centered in relation to the electrode.

- b The point of the electrode has melted under the action of too great a current. The point is deformed, the arc is erratic and poorly directed because the ball 'vibrates' during welding. Welding is therefore difficult, if not impossible.
- c The electrode has been used without protection of argon shielding gas. The flow has been cut off too soon. The electrode has turned blue, is contaminated with oxygen and disintegrates rapidly. It is necessary to reshape it.
- d This fault occurs mostly in the welding of light alloys with an electrode of thoriated tungsten and a low current. The current must be increased to form a ball shape at the electrode tip. If this is not done the arc will remain 'erratic'.
- e Electrode point too sharp. Rapid wear occurs since the point carries current densities which are too high. This leads to systematic inclusions of tungsten in the weld which are highly visible on radiographs.

Tungsten selection and preparation

Base metal type	Welding current	Electrode type	Shield gas
Aluminium alloys and Magnesium alloys	AC/HF	Pure (EW-P)	Argon
		Zirconiated(EW-Zr)	Argon
Copper Alloys, Cu-Ni alloys and nickel alloys	DCSP	2% Thoriated (EW-Th2)	Argon
		2% Ceriated(EW-Ce2)	Argon, Helium mixture
Mild steels, Carbon steels, alloy steels and Titanium alloys	DCSP	2% Thoriated (EW-Th2)	Argon
		2% Ceriated(EW-Ce2)	Argon, Helium mixture
		2% Lanthanated (EWG-Th2)	Argon

GTAW electrodes: The electrode is made of tungsten or an alloy of it and this provides easy arc starting and steady arcing. The Fig.9 show the recommended tip shape for DC EN polarity and AC polarity for TIG welding.



The common varieties of the tungsten electrodes are

- pure tungsten
- 1% or 2% thorium oxide and tungsten

Tungsten with thorium oxide is used welding with DC. An addition of 1% or 2% thorium oxide increases the maximum current carrying capacity by approx. 45-50% for a given electrode and does not form hemispherical blobs as does the pure tungsten.

Thoriated tungsten electrodes are however preferred for DC as the arc wanders when used on AC. Red and yellow colour bands are used widely to indicate 2% and 1% alloyed thoriated tungsten electrodes. The current carrying capacity depends upon the type of shielding gas (whether argon or helium).

GTAW torches - types, parts and their functions

Objectives: At the end of this lesson you shall be able to

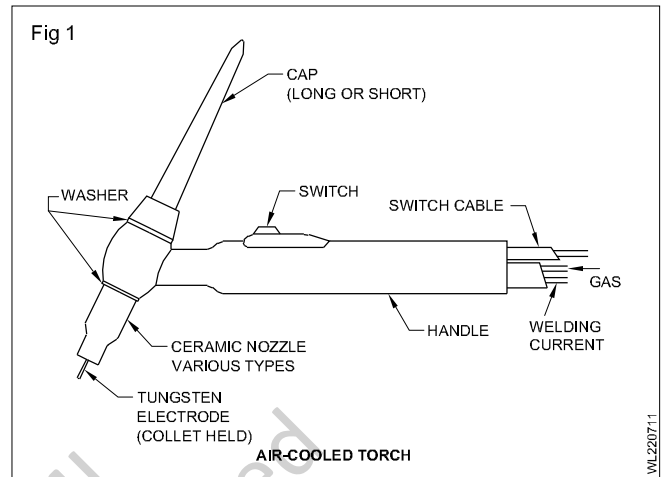
- state the purpose of the torch and its parts
- state the care and maintenance of torches.

GTAW torch

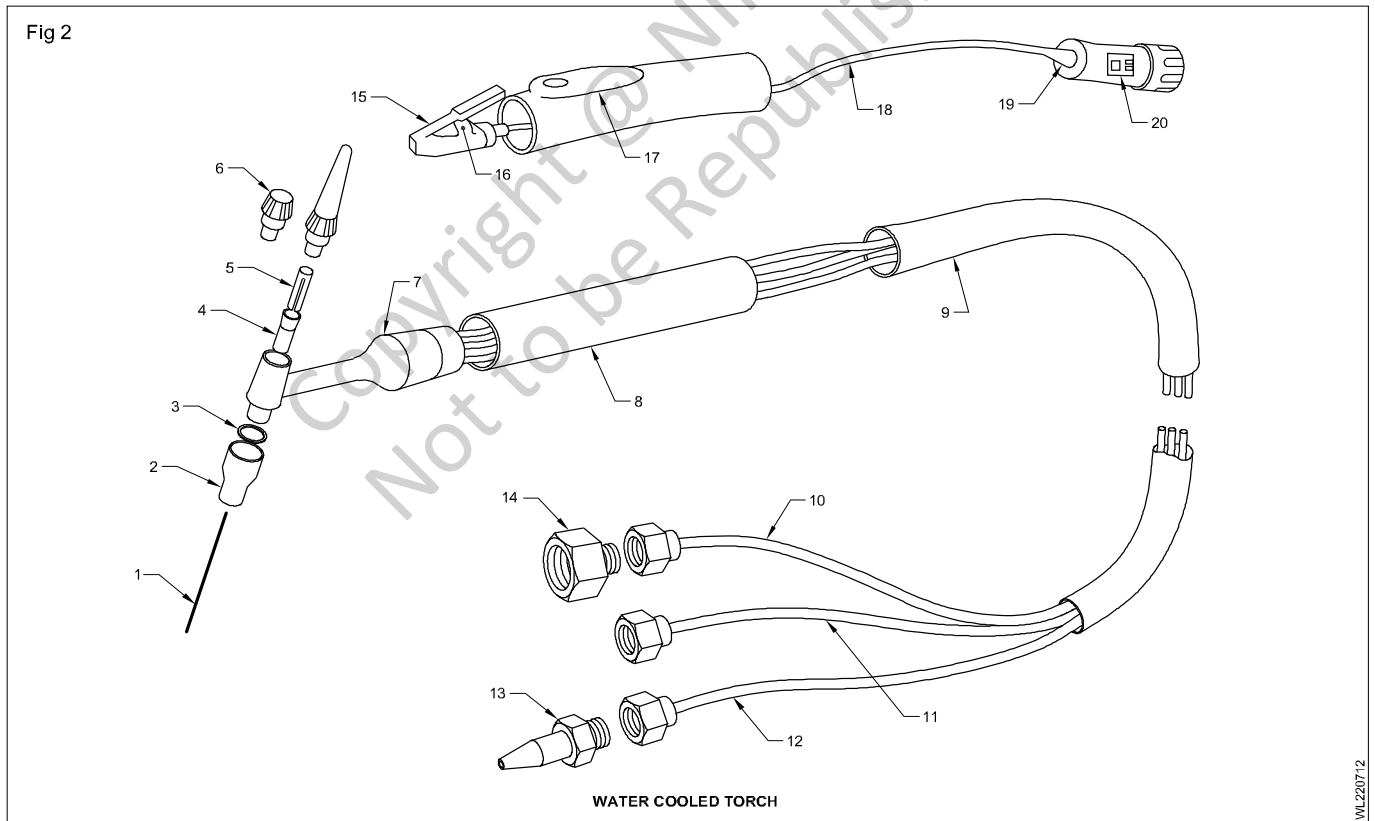
Torch: There is a variety of torches available varying from light weight air cooled to heavy duty water cooled types. Figs 1 & 2. The main factors to be considered in choosing a torch are:

- Current carrying capacity for the work in hand
- Weight, balance and accessibility of the torch head to the work in hand.

The torch body holds a top loading compression-type collet assembly which accommodates electrodes of various diameters. They are securely gripped, yet the collet is easily slackedened for removal or reposition of the electrode. As the thickness of plate to be welded increases, size of torch and electrode diameter must increase to deal with the larger welding currents required.



W/L220711



W/L220712

Parts of water cooled torch Fig.2

- | | | | |
|---|--------------------------------|-------------|--------------------------|
| 1 Thoriated or Zirconiated tungsten electrode | 2 Ceramic shield/nozzle | 3. "O" ring | 4 Collet holder |
| 5 Collet | 6 Electrode cap (short & long) | | 7 Body assembly |
| 8 Sheath | 9 Hose assembly cover | | 10 Argon hose assembly |
| 11 Water hose assembly | 12 Power cable assembly | | 13 Adaptor (power cable) |
| 14 Adaptor (argon gas hose) | 15 Switch actuator | | 16 Switch |
| 17 Switch retaining sheath | 18 Cable (2 core) | | 19 Insulating sleeve |
| 20 Plug | | | |

The function of the TIG torch is to

- 1 hold the electrode tungsten
- 2 deliver welding current to the tungsten via a welding power cable
- 3 deliver shielding gas to the TIG torch nozzle. The nozzle then directs the shielding gas to cover the weldpool protecting it from contamination from the surrounding air.
- 4 often will be the way of getting the welder control circuit to the operation, eg on/off and/or amperage control.
- 5 the TIG torch can be watercooled. Hoses in the TIG lead will supply cooling water to the TIG torch head assembly.
- 6 the TIG torch length will allow a distance from the TIG power source and workpiece.

TIG torches come in different styles depending on the brand being selected. But they all have things in common -

- 1 aircooled or watercooled
- 2 current rating. The operator must select the correct amperage rating TIG torch.

Cooling of the TIG torch

Some torches are constructed in such a way that it is the flowing shielding gas that cools the torch. However, the torch also gives off heat to the surrounding air.

Other torches are constructed with cooling tubes. Water-cooled torches are mainly used for welding with larger current intensities and AC-welding.

Usually a water-cooled TIG torch is smaller than an air-cooled torch designed to the same maximum current intensities

Using a TIG torch that is not sufficiently rated for the machine may result in the TIG torch overheating. A TIG torch with an excessive rating may be larger and heavier than a lower amperage TIG torch.

The TIG torch is made up of

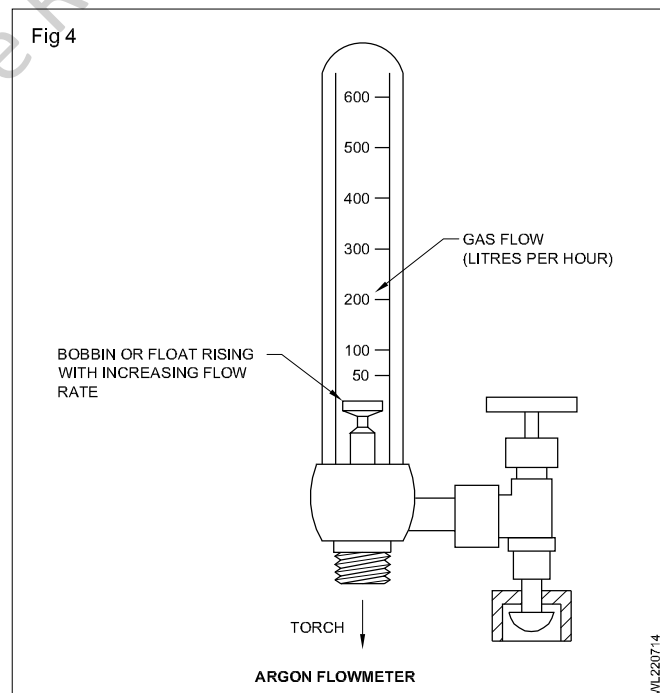
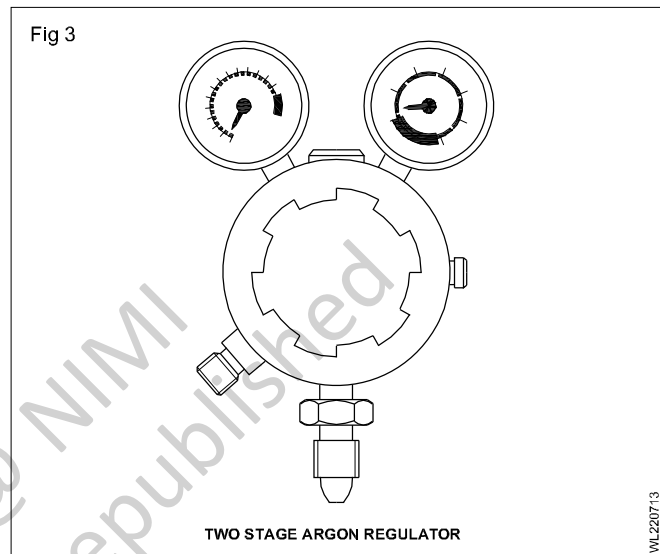
- 1 **Leads** - The lead will be set up for either aircooled or watercooled. It will be at a length suitable to do the job, eg 4 metre, 8 metre, etc. The lead will be made up of a power cable, gas hose and water leads in and out if the TIG torch is watercooled. The lead may also include a control lead.
- 2 **Collet** - To hold the tungsten rods. Collet may vary with different brands of TIG torches.
- 3 **Ceramic Nozzles** - The nozzle's job is to direct the correct gas flow over the weldpool.
- 4 **Back Caps** - The back cap is the storage area for excess tungsten. They can come in different lengths depending on the space the torch may have to get into (eg. long, medium and short caps).

Please make sure when ordering a TIG torch to tell the supplier the amperage rating, whether water- or air-cooled, and the fitting that is to go on the end of the TIG torch lead suitable to fit the TIG power source it will be used from. This may include power cable fit up, gas fittings and control plug fittings.

Gas regulator & flowmeter

Gas regulator, flowmeter (Fig 3 & 4): The gas regulator reduces the pressure in the argon cylinder from 175 or 200 bar down to 0-3.5 bar for supply to the torch.

The flowmeter which has a manually operated needle valve, controls the argon flow from 0-600 litres/hour to 0-2100 litres/hour according to type.



GTAW filler rods and selection methods (criteria)

Objective: At the end of this lesson you shall be able to
 • state the mandatory classification designators.

In the welding process (GTAW or gas tungsten) is an arc welding process that operates the filler rods.

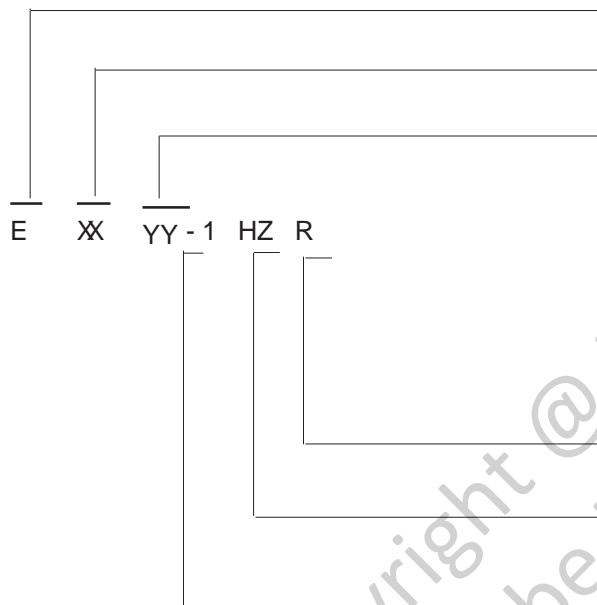
The TIG torch may be cooled by air or water and the process uses a filler metal in rod form. The tungsten electrode selection and parameters for welds are guided them.

Gas tungsten arc welding also known as tungsten inert gas (TIG) welding, is an arc development within the GTAW process.

Now always the filler rods is withdrawn from the weld pool each time the electrode can be changed.

Welding filler metal designators

1 Carbon steel electrodes



Mandatory classification designators

Designates an electrode

Designates minimum tensile strength, in Ksi, of the as-deposited weld metal.

Designates the welding position, the type of covering and the type of welding current for which the electrodes are suitable (See table below)

Optional supplemental designators

Designates that the electrode meets the requirements of absorbed moisture.

Designates that the electrode meets the requirements of the diffusible hydrogen test - with an average value not exceeding "Z" mL of H₂ per 100gms of deposited metal.

Designates that the electrode meets the requirements for improved toughness and ductility.

Optional supplemental designators			
AWS Classification	Type of covering	Welding position	Type of current ^b
E6010	High cellulose, sodium	F,V,OH, H	dcep
E 6011	High cellulose, potassium	F,V,OH,H	as or dcep
E 7018	Low hydrogen, Potassium, Powder	F,V,OH,H	ac or dcep
E7024	Iron Powder, Titania	H-Fillets, F	ac, dcep or dcen

Note

a The abbreviations indicate the welding positions

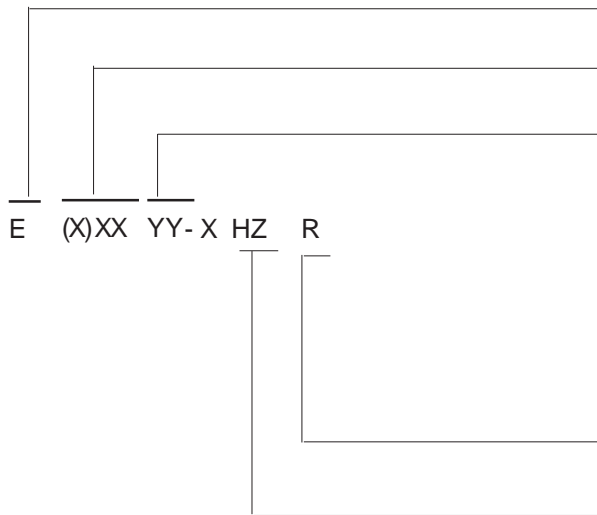
F=Flat; V=Vertical, OH=overhead, H=Horizontal, H=Fillets = Horizontal fillets.

b The term dcep refers to direct current electrode positive (dc, straight polarity)

Also note that the above electrode classifications are the most widely used and does not include all of the available classifications. **Refer to AWS A 5.1 for complete listing.**

2 Alloy steel electrodes

Mandatory classification designators



Designates and electrode

Designates minimum tensile strength, in Ksi, of the as-deposited weld metal

Designates the welding position, the type of covering and the type of welding current for which the electrodes are suitable.

Designates the chemical composition of the undiluted weld metal produced by the electrode using SMAW process.

Optional supplemental designators

Designates that the electrode meets the requirements of absorbed moisture.

Designates that the electrode meets the requirements of the diffusible hydrogen test - with an average value not exceeding "Z" mL of H₂ per 100gms of deposited metal, where "Z" is 4,8 or 16.

Refer to AWS A 5.5 for complete listing of mechanical properties, chemical composition of as deposited weld metal and testing procedures for SMAW process.

3 Stainless steel filler metal

Usability classification

Types of welding current and position of welding		
AWS classification	Welding current	Welding position
EXXX (X) - 15	dcep	All
EXXX (X) - 16	dcep or ac	All
EXXX (X) - 17	dcep or ac	All
EXXX(X) - 25	dcep	H,F
EXXX (X) - 26	dcep or ac	H,F

For more details on the usability classifications, refer to AWS A 5.4

Table 1: Carbon and low - alloy steel welding consumables for SMAW process

Types of welding current and position of welding						
Base material	Types of welding current and position of welding					
	Carbon steel	Carbon-molybdenum steel	1 and 1 1/4 Cr-1/2 Mo steel	2 1/4 Cr-1 Mo steel	5 Cr-1/2 Mo Steel	9 Cr - 1 Mo steel
Carbon steel	AB	AC	AD	AE	AF	AG
Carbon-Molybdenum steel		C	CD	CE	CF	CH
1 and 1 1/4 Cr-1/2 Mo steel			D	DE	DF	DH
2 1/4 Cr-1 Mo steel				E	EF	EH
5 Cr - 1/2 Mo steel					F	FH
9 Cr-1 Mo steel						H

Legend

- A AWS A 5.1 classification E 70XX low hydrogen (E7018 preferred)
- B AWS A 5.1 classification E 70XX low hydrogen (E7018 preferred)
- C AWS A 5.5 classification E70XX - A1, low hydrogen
- D AWS A 5.5 classification E70XX - B2L or E80XX-B2, low hydrogen
- E AWS A 5.5 classification E80XX-B3L or E80XX-B6L, low hydrogen
- F AWS A 5.5 classification E80XX-B6 or E80XX-B6L, low hydrogen

- G AWS A 5.5 classification E80XX-B7 or E80XX-B7L, low hydrogen
- H AWS A 5.5 classification E90XX-B8 or E80XX-B8L, low hydrogen
- 1 Table 1 refers to coated electrodes (SMAW process) only. For bare wire welding (SAW, GMAW, GTAW and FCAW), use equivalent electrode classifications (AWS A 5.14, A 5.17, A 5.18, A 5.20, A 5.23, At 28)
- 2 Higher allow electrode specified in the table should normally be used to meet the required tensile and toughness after post weld heat treatment (PWHT). If no PWHT is required, the lower alloy electrode specified may be required to meet the hardness requirements.

Table 2: Austenitic, super-austenitic and duplex stainless steel alloys

Types of welding current and position of welding										
Base Material	304L SS	304H SS	316L SS	317L SS	904L SS	6% Mo SS	7% Mo SS	Alloy 20Cb-3	2304 Duplex SS	2205 Duplex SS
Carbon and low alloy steel	ABC	ABC	ABC	ABC	ABC	ABC	ABC	ABC	N	N
Type 304L stainless steel	D	DE	DF	DG	DC	C	C	DCH	NL	NL
Type 304H stainless steel		E	EF	EG	*	*	*	ECH	*	*
Type 316L stainless steel			FG	FG	FC	FC	FC	FCH	NL	NL
Type 317L stainless steel				GC	GC	GC	GC	GC	L	L
Type 904L stainless steel					C	C	C	C	L	L
Type 6% Mo stainless steel						CJK	CJK	*	*	*
Eg: 254 SMO, AL 6XN							CJK	*	*	*
Type Alloy 20Cb-3								H	*	*
Type 2304 Duplex SS									LM	LM
Type 2205 Duplex SS										LM

Legend

- A-AWS A 5.4 classification E309L-XX
- B-AWS A 5.11 classification ENiCrFe-2 or -3 (-2 is alloy 718 and -3 is Inconel 182)
- C-AWS A 5.11 classification ENiCrMo-3 (Inconel 625)
- D-AWS A 5.4 classification E308L-XX
- E-AWS A 5.4 classification E308H-XX
- F-AWS A 5.4 classification E316L-XX
- G-AWS A 5.4 Classification E317L-XX
- H-AWS 5.4 classification E320LR-XX
- J-AWS A5.11 classification ENiCrMo-4 (Hastelloy C-276)

- K-AWS A 5.11 classification ENiCrMo-11 (Hastelloy G-30)
- L-AWS A 5.4 classification E2209-XX
- M-AWS A 5.4 classification E2553-XX
- N-AWS A 5.4 classification E309MoL-XX

Table 2 refers to coated electrodes only. For wire welding (GMAW & GTAW) use equivalent electrode classification (AWS A5.14)

There are many proprietary alloys available in the market and material combinations you might encounter. Consult the manufacturer or the DFD for proper filler metal selection.

Edge preparations and GTAW parameters for different type of metals

Objective: At the end of this lesson you shall be able to
 • state the welding method of MS pipe using TIG welding process.

GTAW/TIG welding is generally recommended for pipe to pipe or tube to tube joints. TIG welding with inert gas shielding produces the joints without any defect like gas porosity, oxide slag inclusions and hence the joints are of superior quality.

For MS/Carbon steel pipes and tubes, when welding is done with TIG process, the weld metal is free from hydrogen entrapment which usually occurs in normal oxy acetylene gas welding or manual metal arc welding processes. The hydrogen gas dissolved in the weld causes embrittlement during service. Hence TIG welding for MS pipes is always preferred for all pipe lines viz., gas pipe lines/liquid lines in all petroleum and power plant to convey high temperature and high pressure fluids (liquids & gases, steam etc.).

There are various pipe jointings like straight butt welds, fillet tee joints and pipe elbow joints to suit the piping layout of any process plant say petroleum or power generating plant.

Therefore it is mandatory to take utmost care in development of members of pipe joints so that the geometry will provide appropriate clearances for the joint fit up and the TIG welds so produced will be free from any defect and will offer highest joint efficiency as per the design standards.

Various configuration of the joints are well shown in practical Exercise book.

Low alloy steel (DCSP)

Metal Gauge	Joint Type	Tungsten size	Filler Rod Size	Cup Size	Shield Gas Flow			Welding Amperes	Travel Speed
					Type	CFH (L/Min)	PSI		
1.6 mm	Butt Fillet	1.6 mm	1.6 mm	4, 5, 6	Argon	15 (7)	20	95-135	400 mm
3.2 mm	Butt Fillet	1.6 mm 2.4 mm	2.4 mm	4, 5, 6	Argon	15 (7)	20	145-205	300 mm
4.8 mm	Butt Fillet	2.4 mm	3.2 mm	7, 8	Argon	16 (6.5)	20	210-260	250 mm
6.4 mm	Butt Fillet(2)	3.2 mm	4.0 mm	8, 10	Argon	18 (8.5)	20	240-300	250 mm

Welding low alloy steel

Mild and low carbon steels with less than 0.30% carbon and less than 25 mm thick, generally do not require pre-heat. Low alloy steels such as the chromium-molybdenum steels will have hard heat affected zones after welding, if the preheat temperature is too low. This is caused by rapid cooling of the base material and the formation of martensitic grain structures. A 90° to 200°C preheat temperature will slow the cooling rate and prevent the martensitic structure.

Typical manual GTA (TIG) welding parameters

Aluminium (ACHF)

Metal Thickness	Joint Type	Tungsten size	Filler Rod Size	Cup Size	Shield Gas Flow			Welding Amperes	Travel Speed mm/min
					Type	CFH (L/Min)	PSI		
1.6 mm	Butt Fillet	1.6 mm	1.6 mm	4, 5, 6	Argon	15 (7)	20	60-80	300
								70-90	250
3.2 mm	Butt Fillet	2.4 mm	2.4 mm	6, 8	Argon	17 (8)	20	125-145	300
			3.2 mm					140-160	250
4.8 mm	Butt Fillet	3.2 mm	3.2 mm	6, 8	Argon/ Helium	21 (10)	20	190-220	250
								210-240	230
6.4 mm	Butt Fillet	4.8 mm	3.2 mm	8, 10	Argon/ Helium	25 (12)	20	260-300	250
								280-320	200

CFH - Cubic Feet per hour ACHF - Alternative current with high frequency L/Min - Litre per minute

Welding aluminium

The use of TIG welding for aluminium has many advantages for both manual and automatic processes. Filler metal can be either wire or rod and should be compatible with the base alloy.

Filler metal must be dry, free of oxides, grease, or other foreign matter.

Magnesium (ACHF)

Metal Gauge	Joint Type	Tungsten size	Filler Rod Size	Cup Size	Shield Gas Flow			Welding Amperes	Travel Speed mm/min
					Type	CFH (L/Min)	PSI		
1.6 mm	Butt Fillet	1.6 mm	2.4 mm	5, 6	Argon	13 (5)	15	60	500
			3.2 mm					60	
3.2 mm	Butt Fillet	2.4 mm	3.2 mm	7, 8	Argon	19 (9)	15	115	450
			4.0 mm					115	
6.4 mm	Butt Butt(2)	4.8mm	4.0 mm	8	Argon	25 (12)	15	100-130	550
								110-135	500
12.8 mm	Butt(2)	6.4 mm	4.8 mm	10	Argon	35 (17)	15	260	250

Welding magnesium

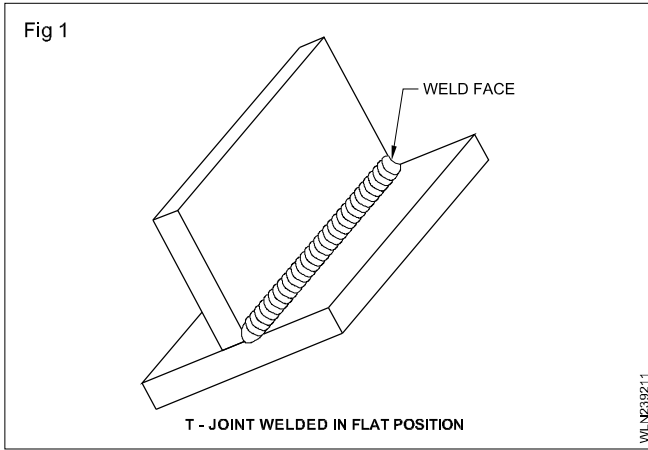
Magnesium alloys are in three groups, they are (1) aluminium-zinc-magnesium, (2) aluminium-magnesium, and (3) magnesium-magnesium. Since magnesium absorbs a number of harmful ingredients and oxidize rapidly when subjected to welding heat, TIG welding in an inert gas atmosphere is distinctly advantageous, the welding of magnesium is similar, in many respects, to the welding of aluminium. Magnesium was one of the first metals to be welded commercially by TIG. Magnesium requires a positive pressure of argon as a backup on the root side of the weld.

Types of welding joints

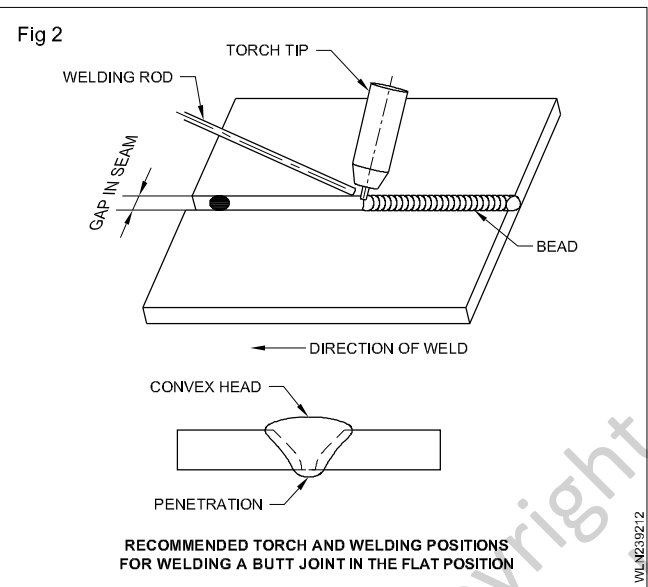
There are five basic joint designs mentioned below.

- 1 Butt joint
- 2 Lap joint
- 3 corner joint
- 4 T joint (Fillet joint)
- 5 Edge joint

The Fig. 1 below shows, filler T joint welded in flat position, When the weld axis and weld face are horizontal.



Square butt joint on aluminium: The Fig. 2 shows the recommended torch and welding filler rod positions for welding a butt joint in flat position.



Outside corner joint on aluminium: Fig.3 on the next page shows a typical corner joint welded from outside.

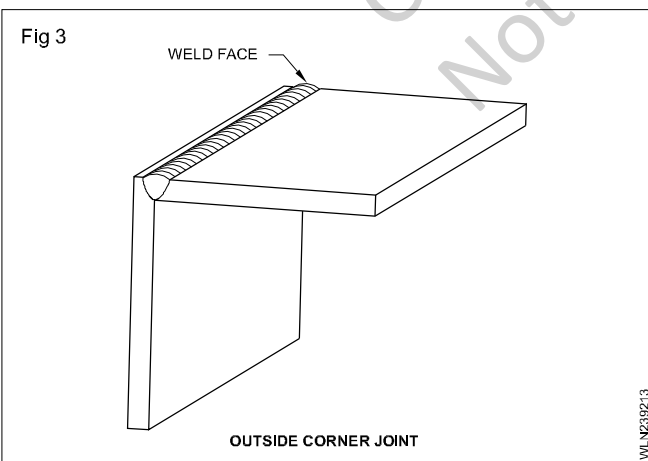


Fig.4 shows the setup for fillet tee joint on stainless steel sheets, welded by (TIG) GTAW process. Satisfactory weld, should be free from undercut at the toes and of equal leg lengths.

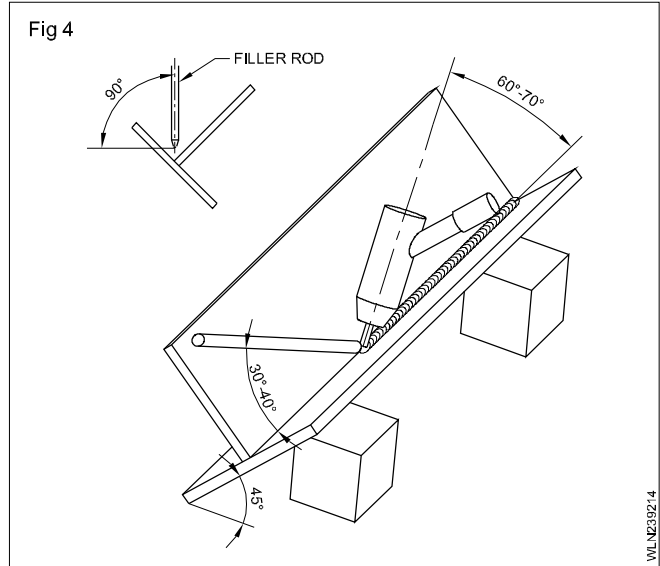


Fig. 5 shows the corner joint welded by TIG process. It also gives the set up for making the outside corner joint in flat position.

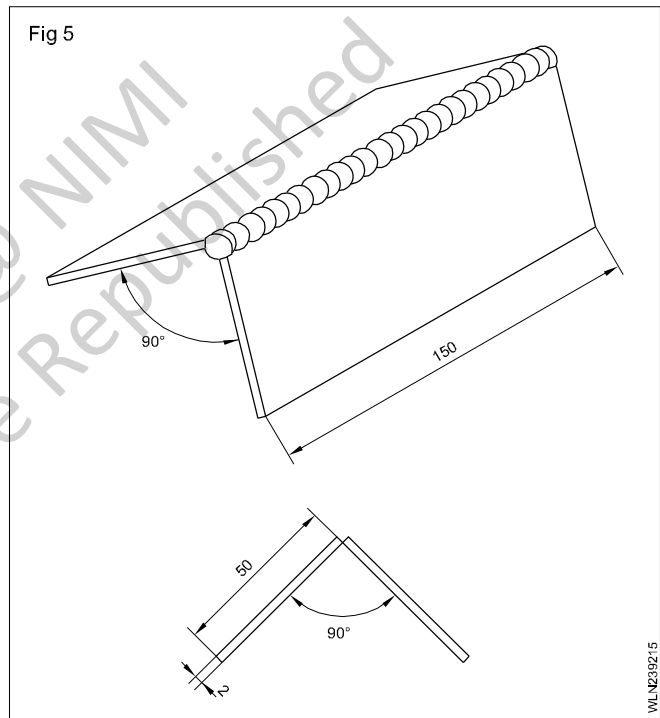
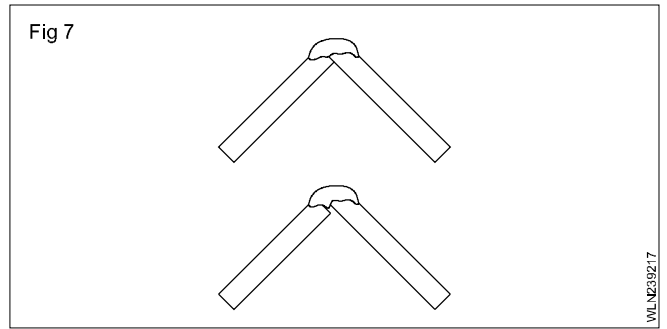
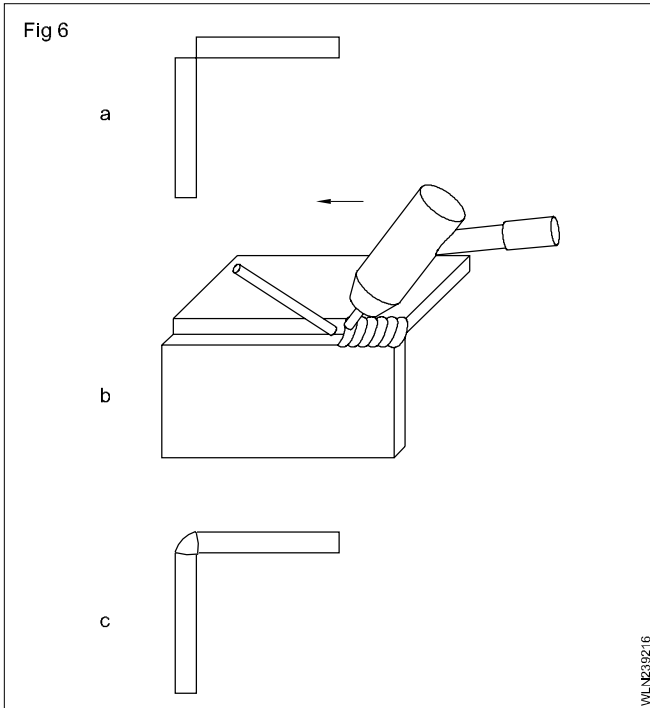


Fig. 6a,b&c elaborates the recommended steps by GTAW process using filler rod.

In this method, the two pieces of metal do not overlap. While welding the outside corner joint, watch the outside edges of the metal. When the puddle touches the outside edges of the metal, the welding rod should be placed in the puddle. Enough filler metal should be melted into the puddle to form a convex bead. The torch is moved forward and the welding rod is again placed in the puddle when the puddle touches the outside edges of the joint. This operation is repeated until the joint is completely welded. The keyhole welding technique may be used on this joint. Fig.7 shows a macrograph of a completed outside corner joint made with proper and improper assembly of a corner joint.



Welding stainless steel

In TIG welding of stainless steel, welding rods having the AWS-ASTM prefixes of E or ER can be used as filler rods. However, only bare uncoated rods should be used. Stainless steel can be welded using ACHF, however, recommendations for DCSP must be increased 25%. Light gauge metals less than 1.6 mm thick should always be welded with DCSP using argon gas. Follow the normal precautions for welding stainless such as: Clean surfaces; dry electrodes; use only stainless steel tools and brushes, carefully remove soap from welds after pressure testing; keep stainless from coming in contact with other metals.

Stainless steel (DCSP) Welding parameters

Metal Gauge	Joint Type	Tungsten size	Filler Rod Size	Cup Size	Shield Gas Flow			Welding Amperes	Travel Speed mm/min
					Type	CFH (L/Min)	PSI		
1.6 mm	Butt Fillet	1.6 mm	1.6 mm	4, 5, 6	Argon	11 (5.5)	20	80-100	300
								90-100	250
3.2 mm	Butt Fillet	1.6 mm	2.4 mm	4, 5, 6	Argon	11 (5.5)	20	120-140	300
								130-150	250
4.8 mm	Butt Fillet	2.4 mm 2.4 mm 3.2 mm	3.2 mm	5, 6, 7	Argon	13 (6)	20	200-250	300
								225-275	250
6.4 mm	Butt Fillet	3.2 mm	4.8 mm	8, 10	Argon	13 (6)	20	275-350	250
								300-375	200

Pulsed TIG welding and description of pulse parameters

In this type of power source, the supply current is not constant and it is being fluctuated from low level to high level. This causes low heat input to the metal and hence distortion effect will be less.

Pulsed TIG has the advantages of

- 1 better penetration with less heat
- 2 less distortion
- 3 better control when welding out of position
- 4 Easy to use on thin materials

The down side is - more set-up cost and more operator training.

Pulsed TIG consists of

Peak current - This is set up higher than for non-pulsed TIG.

Background current - This is set lower than peak current and is the bottom current the pulse will drop to, but must be enough to keep the arc alive.

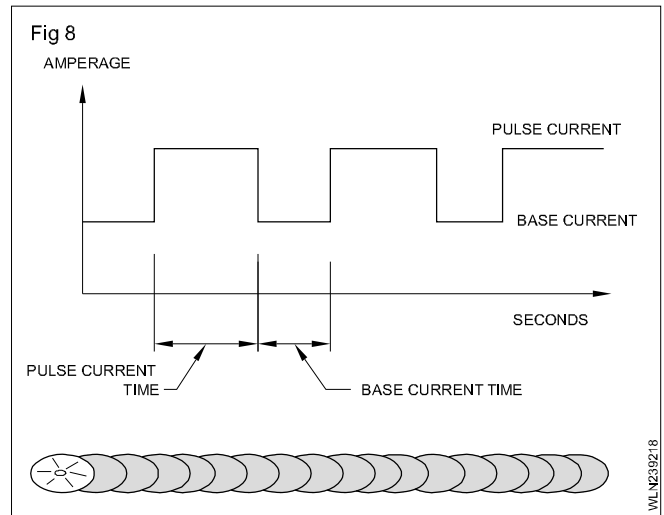
Pulses per second - This is the number of times per second that weld current reaches peak current.

% on time - This is the pulse peak duration as a percentage of the total time, which controls how long the peak current is on for before dropping to the background current.

The pulse and base current periods are also controllable.

When welding is done with pulsing welding mode the weld is in principle a row of spot welds overlapping to a larger or smaller extent depending on the welding speed. (Fig.8)

Many double-current machines are equipped with a control function which makes it possible to modify the curve of the alternating current in balance between the positive and the negative semi-periods.



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Argon/Helium gas properties and uses

Objectives: At the end of this lesson you shall be able to

- state the properties of argon gas
- compare the performance characteristics of argon and helium gas for TIG welding
- identify an argon gas cylinder and ceramic nozzles
- state the uses of argon and helium gas.

Shielding gases

Chemical activity of shielding gases: The behaviour of gases in welding is related to their chemical activity so it is convenient to group them according to this activity.

Inert gases: These are argon and helium. Other inert gases such as krypton, Radon, xenon and neon have been tried, but their low availability results in them being expensive. Also their characteristics do not, at present, give them any particular advantage.

Argon and helium are monatomic (their molecule contains only one atom) and do not react with other bodies (in the arc plasma) and hence the designation 'inert'. This precious property allows them to protect the electrode and molten metal against the atmospheric gases. However they are not suitable in every case. Pure argon for example does not allow a smooth droplet transfer when welding carbon steels. To obtain the desired transfer mode it is necessary to add a certain proportion of oxygen or carbon di oxide.

The different ionisation potential of argon and helium cause them to behave differently.

Properties of argon and helium gas

These gases are colourless, odourless.

Argon is heavier than air and helium is lighter than air.

They do not chemically react with any metals in hot or cold conditions.

They give a good shielding action for molten metal from the atmosphere.

Gases for TIG welding of aluminium

Argon gas

An argon cylinder is identified by the peacock blue colour painted on it.

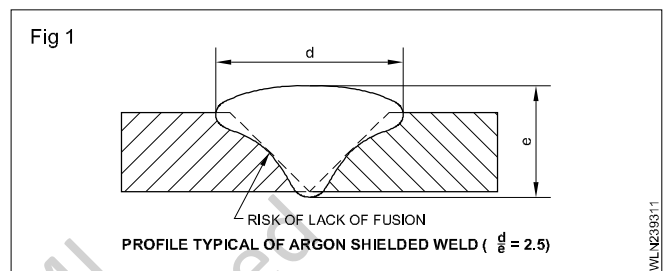
Quality : Argon gas of welding quality should be used.

The rate of flow of argon should be adequate to obtain a clean weld. This depends on several factors such as type of parent metal, current used, shape and size of nozzle, type of joint and whether the work is done indoors or outdoors. Generally a higher rate of flow is required with higher welding currents, for outside corner joints, edge welds and work outdoors. Generally flow rates 2 to 7 litres per minute will be found sufficient to weld all thicknesses.

If tungsten inert gas welding has to be done outdoors during inclement weather, especially during period of high wind, the welding area should be effectively protected. Draughts

tend to break the gas shielding, resulting in porous and oxide contaminated welds.

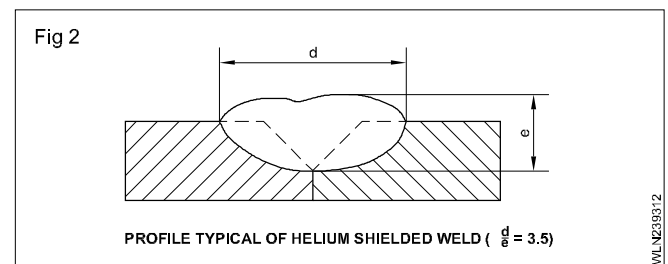
The penetration profile of argon shielded welds has a characteristic shape in the form of a finger. Fig.1



Helium: Helium is used mainly in TIG welding and is normally used with direct current whatever the metal being welded (light alloys, copper, etc.)

The main advantages of helium shielding are:

- Increase in welding speeds
- More intense local heating, important with metals which are good conductors of heat
- Fig.2 shows the penetration, profile typical of a helium shielded weld



Argon gas gives more penetration than helium gas.

Characteristics and comparative performance of argon and helium as shielding gases

Argon

Low arc voltage : Results in less heat; thus argon is used almost exclusively for manual welding of metals less than 1.6mm thick.

Good cleaning action: Preferred for metals with refractory oxide skins, such as aluminium alloys or ferrous alloys containing a high percentage of aluminium.

Easy arc starting: Particularly important in welding of thin metal.

Arc stability is greater than with helium

Low gas volume: Being heavier than air, argon provides good coverage with low gas flows and it is less affected by air drafts than helium

Vertical and overhead welding: Sometimes preferred because of better weld puddle control but gives less coverage than helium.

Automatic welding: May cause porosity and undercutting with welding speeds of more than 60cm per min. Problem varies with different metals and thicknesses and can be corrected by changing to helium or a mixture of argon and helium.

Thick work metal: For welding metal thicker than 5mm a mixture of argon and helium may be beneficial

Welding dissimilar metals: Argon is normally superior to helium

Helium

High arc voltage: Results in a hotter arc, which is more favorable for welding thick metal (over 5mm) and metals with high heat conductivity.

Small heat affected zone:With high heat input and greater speeds, the heat affected zone can be kept narrow. This results in less distortion and often in higher mechanical properties.

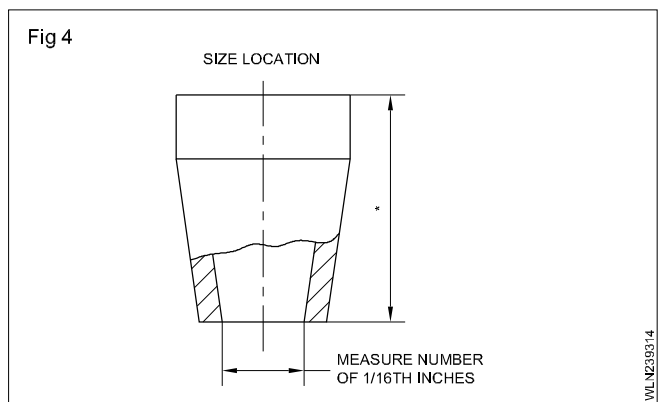
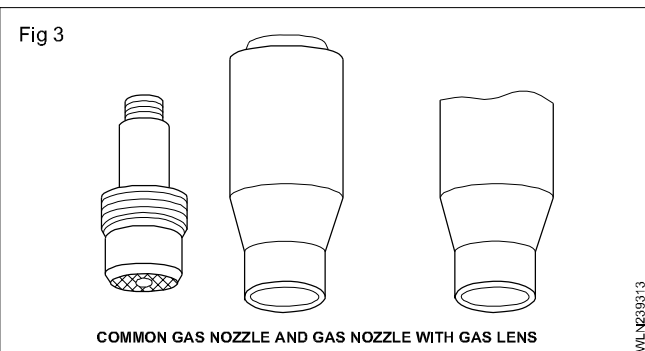
High gas volume: Helium being lighter than air, gas flow is normally 1 1/2 to 3 times greater than with argon. Being lighter, helium is more sensitive to small air drafts, but it gives better coverage for overhead welding and often for vertical position welding.

Automatic welding: With welding speeds of more than 60cm per min. welds with less porosity and undercutting may be attained (depending on work metal and thickness).

Comparison between argon and helium shielding	
Argon	Helium
1 Smoother arc.	1 Smaller heat affected zone.
2 Easy starting.	2 Best for thicker metal welding due to higher arc voltage.
3 Best for thinner metal welding due to lower arc voltage.	3 Better for welding at higher speed.
4 Good cleaning action while welding Al.	4 Gives better coverage in vertical and overhead positions.
5 Heavier than air - Lower flow rates.	5 When used in back shieldings flattens the root face.
6 Low cost, more availability.	
7 Better for welding dissimilar metals.	
8 Better control of puddle on positional joints.	

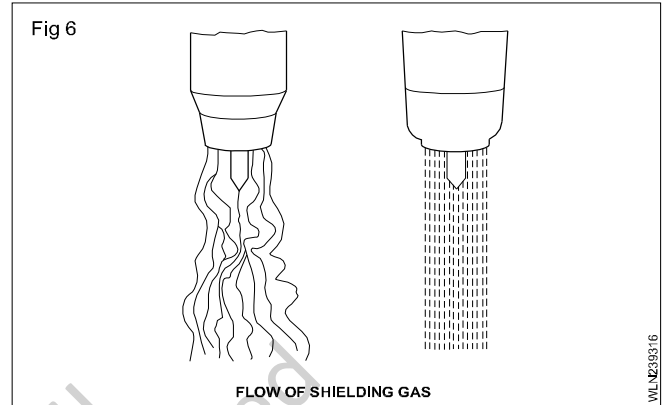
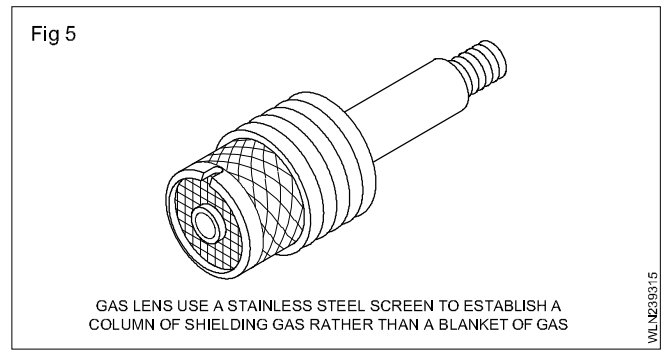
Ceramic shields/nozzles: Gas nozzles are usually designed for installation into a particular type of torch and generally do not adapt to another make or model. They come in all sizes, shapes and materials. Gas nozzles are reasonable in cost, therefore they should be replaced when they become unusable. A nozzle which has chips or cracks or a metal build up on the outlet end should be discarded. These types of defects can alter the gas flow pattern from the nozzle and cause contamination of the weld metal. Typical nozzle configuration are shown in Fig.3.

Nozzles are identified by the size of the orifice (opening) and the length of the nozzle as shown in Fig.4 Each torch manufacturer assigns part numbers to the various nozzles for individual type torches and these must be used when ordering for replacement of nozzles.



Size in mm	No.
5	No.3
6.3	No.4
8	No.5
10	No.6
11	No.7
12.5	No.8
14.5	No.9
16	No.10
18	No.11
20	No.12

Gas lens: The gas lens device allows the welder to use a longer electrode extension than with a standard nozzle. The device uses a series of stainless steel wire mesh screens to 'firm up' the argon gas column. This aids in maintaining a blanket of inert gas around the tungsten and over the weld area. This is very helpful when wind drafts are present, or the tungsten must be extended due to the location of the weld area. Use of the gas lens requires a special gas lens collet body and gas nozzle. A gas lens device is shown in Fig. 5 & 6.



Defects causes and remedy

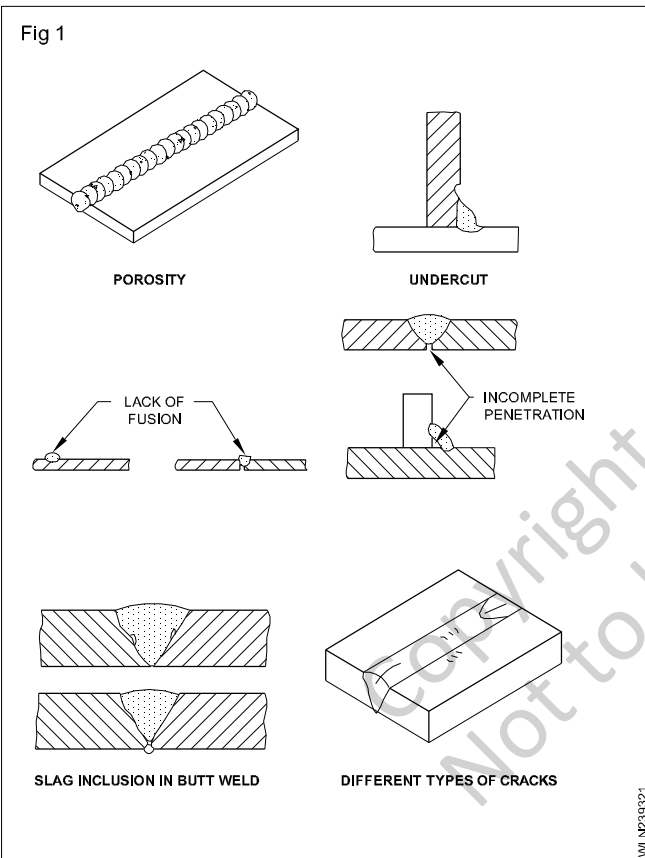
Objectives: At the end of this lesson you shall be able to

- state the different type of defects in GTAW
- state the causes and remedies of GTAW defects.

The following table relates to the cause and prevention of the more common defects encountered in welds made by the TIG welding process. (Fig. 1)

Defect	Appearance	Cause	Remedy
Porosity	Pin holes in the weld.	Insufficient shielding gas. Bore of gas nozzle too small arc length too long. Surplus degreasing agent.	Satisfactory supply gas. Correct ceramic shield. Remove all degreasing agents and dry. Shorten arc length.
Undercut	Irregular grooves or channels	Incorrect welding technique. Current too high. Incorrect welding speed.	Correct current. Correct rod manipulation. Clear weld surface. at the toes of the weld.
Lack on fusion (side root or inter run)	Surface on to which weld is deposited has not been melted. Not always visible. Usually	Incorrect current level. Incorrect filler rod manipulation. Unclean plates surfaces. detected by bend test or by non-destructive techniques (e.g. ultrasonic flaw detection).	Correct current. Use correct rod manipulation. Clean plate surfaces.
Lack of Penetration	Notch or gap at the root of a weld.	Incorrect preparation and set up. Incorrect current level. Welding speed too fast.	Use the correct preparation and set up. Correct current. Correct weld speed.
Inclusions	Usually internally and only detected by suitable testing techniques. Normally oxide or tungsten inclusions.	Oxide inclusions. Inadequate cleaning of parent material before welding. Contamination onsurface of filler rod. Inadequate protection of underside of a weld. Loss of gas shield.	Clean all metal surfaces. Ensure a satisfactory supply of shielding gas. Exclude draughts.

Defect	Appearance	Cause	Remedy
Cracking	Cracks can occur in the weld metals and in the parent metal alongside the weld. They may not be visible on the surface and may only be detected by the use of suitable testing techniques.	The type of crack and therefore its cause will depend on the material being welded. The correct diagnosis of the cause of a crack frequently calls for expert knowledge.	<p>Use correct welding procedure. Pre-heating and post heat treatment. Use correct preparation Set up current. Use correct filler rod.</p> <p>Always adhere strictly to the procedure specified when welding materials that are susceptible to cracking.</p> <p>Always ensure the correct type of filler is used and the correct amount of filler metal is added.</p>



Friction welding process equipment and application

Objectives: At the end of this lesson you shall be able to

- state the principle of friction welding
- explain the method of welding
- state the application
- state the advantages & limitations.

Friction welding

Principle: Friction welding uses friction to create heat to fuse two pieces of metals together. This process is used mainly in butt welding of large sections round rods, very heavy tubes and pipes.

Method of welding: No external heat is supplied. One of the pieces is made to rotate. The ends of the parts to be joined are then brought together under a light pressure. The resulting friction between the stationary and rotating parts develops the heat required to form the weld. As the metal surfaces reach the plastic stage, they are forced together under a much higher pressure. The process produces a clean metal-to-metal welding surface. (Fig 1)

A 1/2" diameter low carbon steel rod with welding temperature of 1650°F can be joined with a contact pressure in the range of 5000 to 10000 pounds/inch while rotating at approximately 3000 rounds per minute for about 5 second. Medium and high alloy steels require heating pressure (Contact Pressure) ranging from 10000 to 30000 pounds/inch and forging pressure between 15000 to 60000 pounds/inch.

Applications

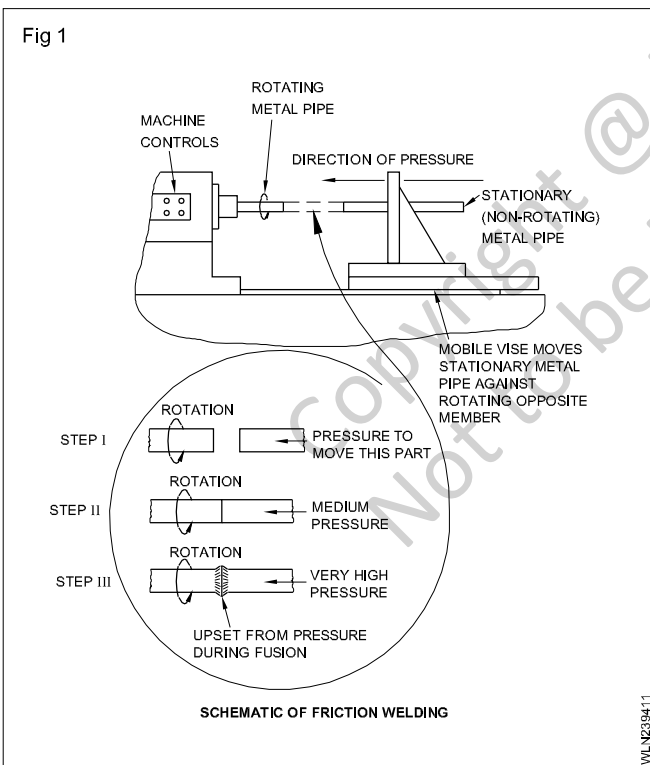
Metals that can be welded by the friction welding process include Carbon Steel, Steel Alloys, Stainless Steel, Copper, Aluminium and Titanium.

Advantages over metallic arc welding

- It is more suitable process for joining dissimilar metals.
- The process produces a clean metal-to-metal welding surface.
- A highly skilled welder is not required.
- A weld with less defects can be obtained.
- No filler rod or electrode is required.
- Power consumption is less.

Limitations

- The machine is costly.
- Plates/sections of less thickness/size cannot be welded.
- Welding can be done only inside a factory/shop and not at sites.
- Soft metals and metals with low compressive strength cannot be welded.
- Only butt joint can be done.
- There is a burr surrounding the weld area.



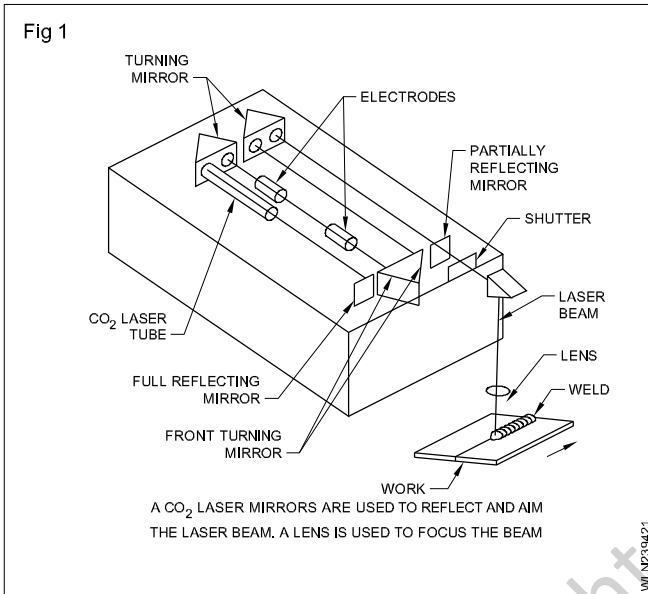
Laser Beam Welding (LBW)

Objectives: At the end of this lesson you shall be able to

- state the principle of laser beam welding
- explain the application of LBW
- explain the advantages of LBW.

Laser welding (Fig 1)

LASER is the acronym for Light Amplification by Stimulated Emission of Radiation. Laser Welding is a method in which work piece is melted and joined by narrow beam of intense Monochromatic Light. (Laser Beam) When the beam strikes the job, the heat produced melts and fuses even the hardest materials.



Process

Electrical energy stored in a capacitor bank is discharged into a flash lamp. The stimulating light source usually in a linear arc discharge lamp such as Zeon, Argon, or Krypton gas flash lamp. When the flash lamp fires, and then is a powerful burst of light that pumps electrons with the light emitted (Ruby Rod) to higher than normal energy levels. The light emitted by ruby rod is in pulse and is of single wave length travelling parallel to ruby rod. The mirrors are provided to reflect the light coming to the ends of ruby rod. So that light may pass back through the ruby rod increasing the energy level of electrons further to emit Laser Beam.

It goes through a focusing device where it is pin pointed on the work piece. Fusion takes place and the weld is accomplished. There are three basic types of Lasers.

- The solid laser
- The gas laser and,
- The semi-conductor.

The type of Laser depends upon the lasing source. The Solid Laser some type of crystal such as the Ruby or the Sapphire used for its lasing ability.

The gas laser consists of a gas (Carbon Di-oxide, Xenon) or a mixture of gases (90% Helium, 10% Neon) contained in a glass tube with highly polished mirrors at each end. One of the most widely used Gas Laser is CO₂ Laser. The radiant energy density of the CO₂ Laser is greater than that of the sun.

Equipment and setup (Fig 2)

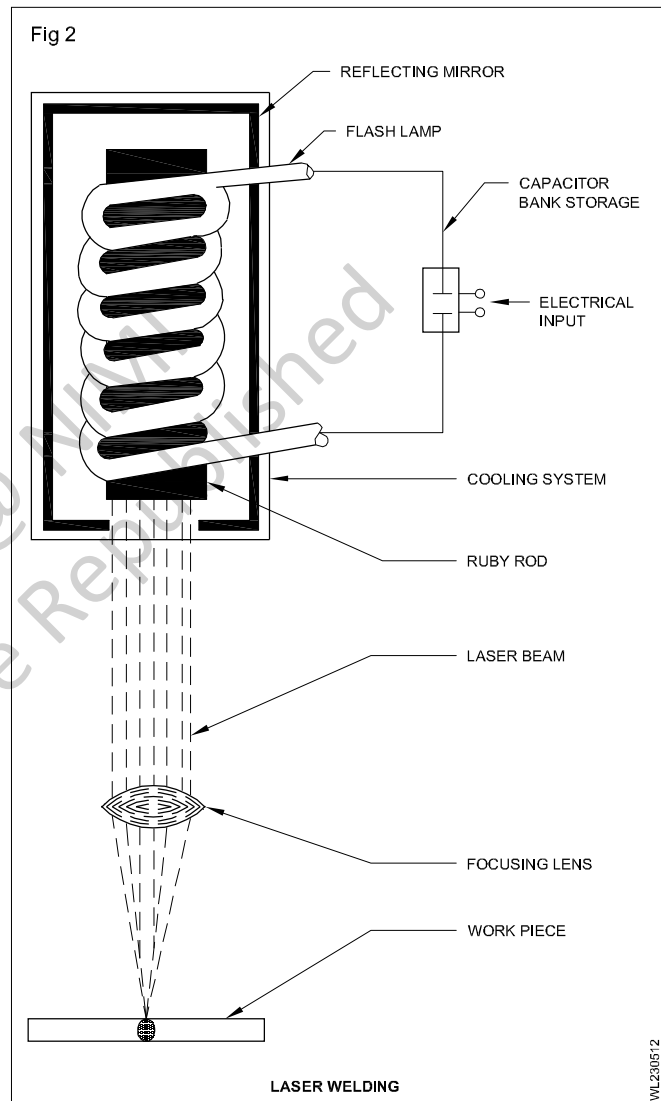


Fig 2 shows a line diagram of a laser beam welding equipment/setup. The light or heat energy is put into a single molecule of a substance (ruby or carbon-di-oxide) to create the beam. This single frequency energy of the single molecule substance in the form of a beam, when travelling between the rear and front mirrors, increases in intensity until it passes through the partially reflecting mirrors. The release of the laser beam is controlled by the operator/welder.

The heat of the laser beam which is of high intensity is conveniently directed towards the joint to be welded by different combination of mirrors. This is possible because the laser beam can be reflected like light rays. The laser beam produced can be either a continuous heat source or a pulsed beam. When the beam contacts the base metal to be welded through a lens the heat is instantaneously released. The amount of heat applied on the basemetal can be controlled by controlling the input to the laser beam source depending on the melting of the base metal being welded.

Applications

Laser Welding is used in the Space, Aircraft, Electronics industries for thinner section metals and dis-similar metals.

Advantages

- 1 Work piece does not get hot except at one point.
- 2 The heat affected zone is narrow.
- 3 No electrode / filler rod is required.
- 4 Sensitive materials can be welded.

Disadvantages

- 1 It has high capital and operating cost.
- 2 It needs a skilled operator.

Electron beam welding

Objectives: At the end of this lesson you shall be able to

- state the principle of electron beam welding
- state the welding procedure
- explain the application of electron beam welding.

Introduction

The use of the Electron Beam in industry is relatively new. The need for Electron Beam Welding developed for welding costly metals such as Titanium, Molybdenum and Tungsten as structural components.

Process

Electron Beam Welding is an automatic welding process performed in a vacuum without a shielding gas. Neither an electrode nor a filler rod is used. In the electron beam process, electrons are emitted from the heated filament called the 'Cathode' and then focused in to a beam which is directed at the welding point. When the beam strikes the welding point, the kinetic energy of the high speed electrons is converted in to heat. The heat is great enough to melt and fuse the metal. The speed of electrons in electron beam welding ranges from 48000 kms /second to 192000 kms /second, depending upon the voltage of the unit (Fig 1).

Electron beam welding equipments

An Electron Beam Welding machine consists basically of the following components:

- 1 Electron Beam Gun
 - (a. Tungsten Filament b. Anode c. Cathode and d. Focusing Coil)
- 2 A vacuum chamber
- 3 A transport system

Electron beam gun

Most electron beam guns used are the triode type. It consists of a) Tungsten Filament b) Anode c) Cathode and d) Focusing Coil. The Tungsten Filament units' electrons when it is heated in vacuum chamber to 2000°C. Electrons carry a negative charge and are repelled by the cathode electrode and are made to pass through the central hole of the anode (+). The electrons are greatly accelerated by the potential differences between anode and cathode. Then, the beam is focused by a lens. (Electromagnetic Focusing Coil) The purpose of the electron into a narrow beam.

Vacuum chamber

The vacuum chamber is operated in conjunction with pumps and a pumping system to control the vacuum environment. The size and design of the vacuum chamber used in electron beam welding will depend on the dimensions of the weldment.

Transport system

Each machine is equipped with some form of transfer system to provide movement for the gun and work. These systems are usually driven by DC motors, which control position, Location and Velocities of both the gun and the work.

Description of equipment and welding procedure

Fig.2 shows an electron beam welding equipment/setup. The machine has a chamber in which a filament is used.

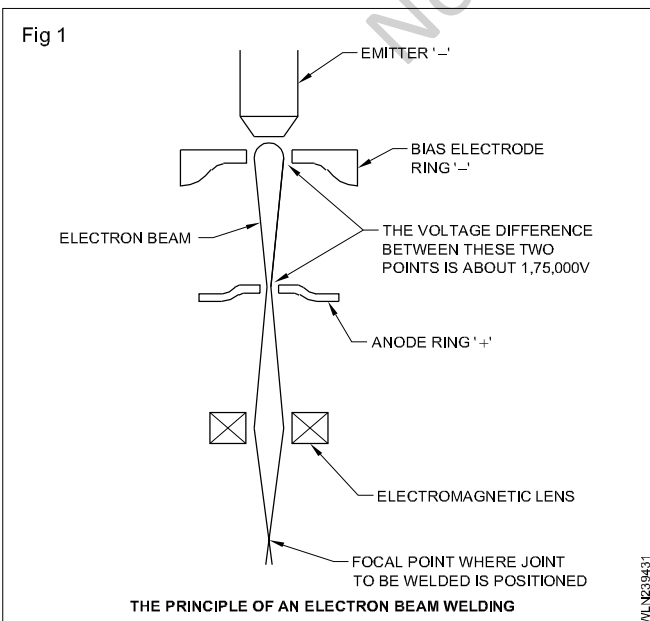
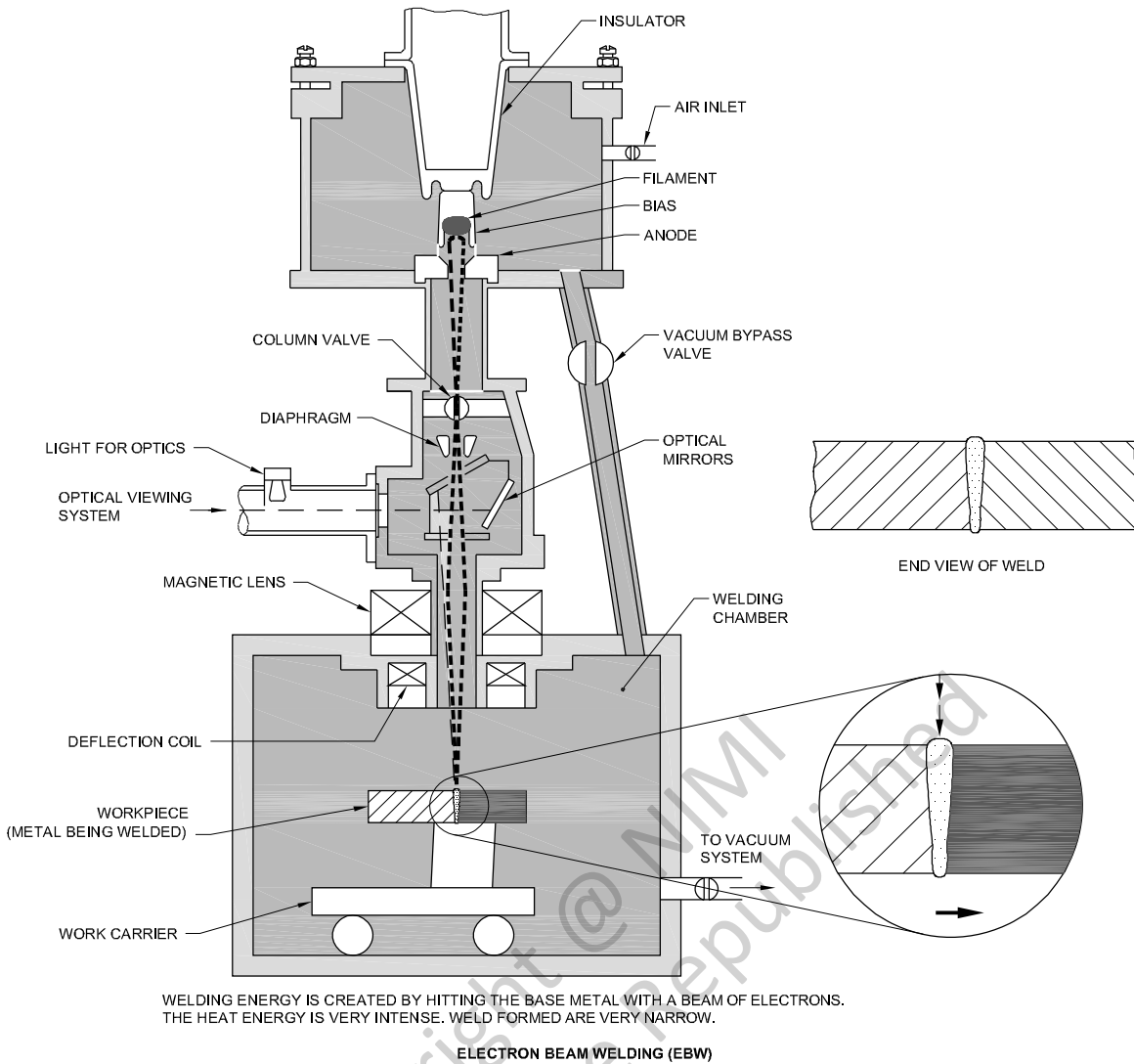


Fig 2



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This filament emits (gives off) a stream of electrons. These electrons from the emitter pass through an anode, column valve, diaphragm and then pass through an electromagnet called magnetic lens. This magnetic lens is used to focus the high energetic electron beam which also possesses a high heat intensity. The work piece to be welded is kept in a vacuum chamber below the magnetic lens. The electron beam can be directed either downwards or deflected in any other direction within the vacuum chamber by using deflection coils. The welding is done in a vacuum chamber because the air if present will interfere with the electron beam and affect the welding action. Also the vacuum acts as a shield against radiation hazards. The heat energy required to melt the base metal is controlled by the current in the electron gun filament. The operator/welder can watch the welding area on the joint through a safe optical viewing system containing optical mirrors. The surfaces to be joined should be properly cleaned before welding. The parts to be joined are to be held together very tightly and moved within the vacuum chamber using suitable trolleys.

Advantages

- 1 The weld zone and heat affected zone are relatively small in electron beam welding.
- 2 Distortion affects only a very small area.
- 3 Extremely successful in achieving deep penetration.
- 4 On steel plate 100 mm. thick welds can be made in one pass at a speed of 170 mm/minute with penetration.
- 5 Usage of current only in the milliamperage range is required, while the other electrical welding system many amperes are required.
- 6 Speed of welding is high.
- 7 No porosity and contaminations.
- 8 Very useful to weld Titanium, Zirconium, Molybdenum with same control of purity as in the original material.

Disadvantages

- 1 The cost of the equipment is high.
- 2 Obstructed joints can't be welded because electron beam travels in straight line.
- 3 Job is limited in size as per the work chamber dimensions.

Plasma arc welding

Objectives: At the end of this lesson you shall be able to

- state the types of plasma arc welding
- state the equipments
- state the applications.

Plasma Arc Welding is welding process in which plasma producing gas (Argon, Nitrogen, Helium, and Hydrogen) is ionized by the heat of an electric arc and passed through a small welding torch orifice. A shielding gas protects the plasma arc from atmospheric contamination in welding or cutting. A non-consumable Tungsten electrode is used in Plasma Arc Welding and additional metal is added to the weld with a filler rod.

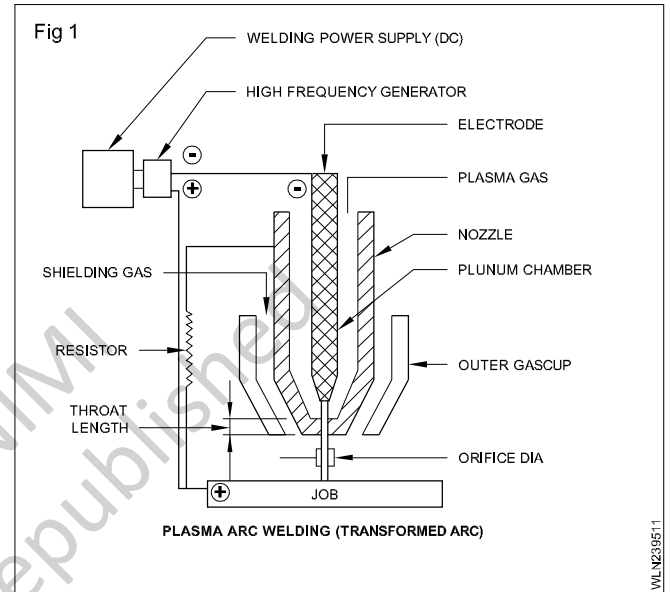
Plasma Arc welding uses the keyhole method to obtain a full penetration and can be done manually or automatically. The works of temperature obtained in this process is about 20000°C to 30,000°C.

It is divided in to two basic types. They are:

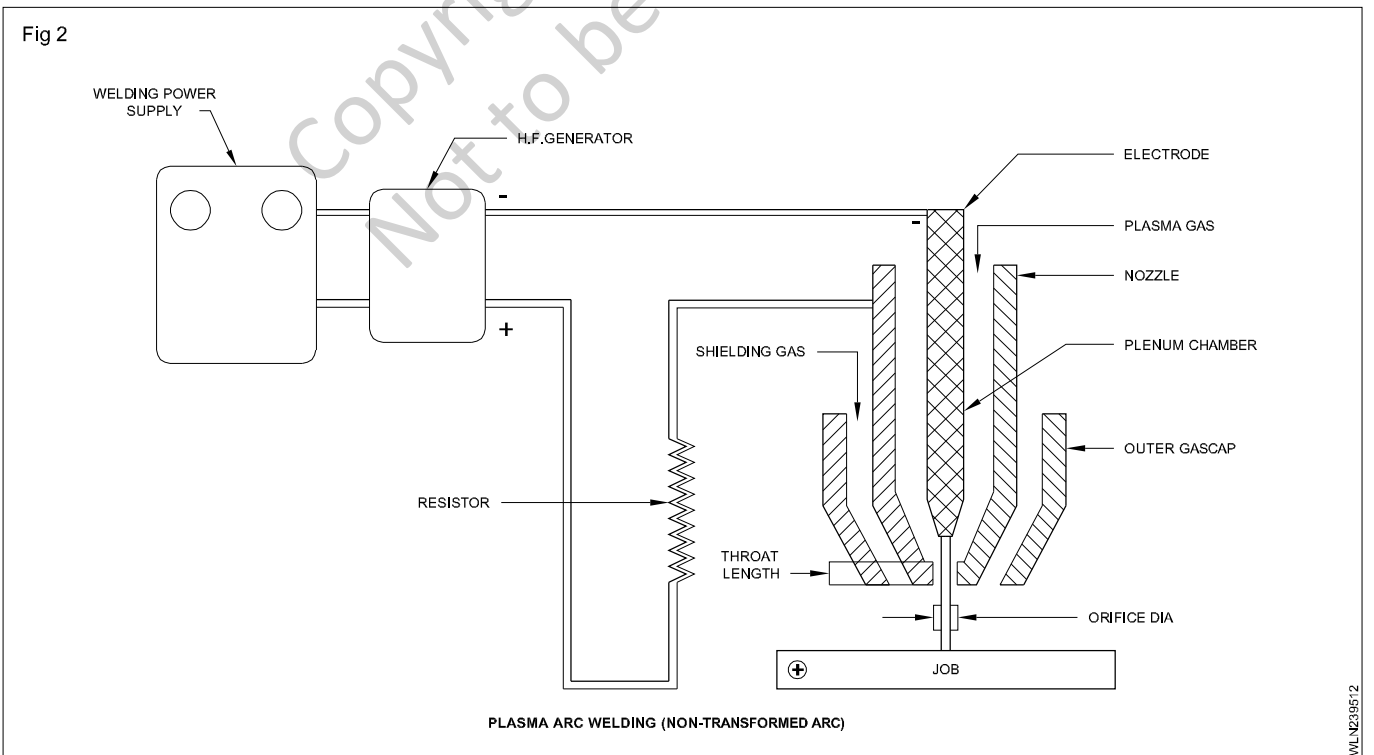
- 1 Transferred arc
- 2 Non-transferred arc

Transferred arc process (Fig 1):The arc is formed between the electrode(-) and the work piece (+). In other words, arc is transferred from the electrode to the work piece. A transferred arc possesses high energy density and plasma jet velocity. For this reason it is employed to cut and melt metals. Besides carbon steels this process

can cut stainless steel and nonferrous metals also where oxyacetylene torch does not succeed. Transferred arc can also be used for welding at high arc travel speeds.



Non-transferred arc process (Fig 2)



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The arc is formed between the electrode(-) and the water cooled constricting nozzle(+). Arc plasma comes out of the nozzle as a flame. The arc is independent of the work piece and the work piece does not form a part of the electrical circuit. Just as an arc flame, it can be moved from one place to another and can be better controlled. The non transferred arc plasma possesses comparatively less energy density as compared to a transferred arc plasma and it is employed for welding and in applications involving ceramics or metal plating (spraying).

Equipments

- 1 DC power source
- 2 Welding control console (Contain flow meter)
- 3 Recirculating water cooler
- 4 Plasma welding torch (up to 500 amps capacity)
- 5 Gas cylinders and a gas supply
- 6 Gas pressure regulator
- 7 Gas hoses and hose connections
- 8 Water cooled power cables

Gases for plasma welding

- Argon for carbon steel, titanium, zirconium, etc
- Hydrogen increase heat Argon + (5-15%) Hydrogen for stainless steel, Nickel alloys, Copper alloys

Plasma process techniques

1 Microplasma

- very low welding currents (0,1-15 Amps)
- very stable needle-like stiff arc & minimises arc wander and distortions
- for welding thin materials (down to 0,1 mm thick), wire and mesh sections

2 Medium current plasma

- higher welding currents (15-200 Amps)
- similar to TIG but arc is stiffer & deeper penetration
- more control on arc penetration.

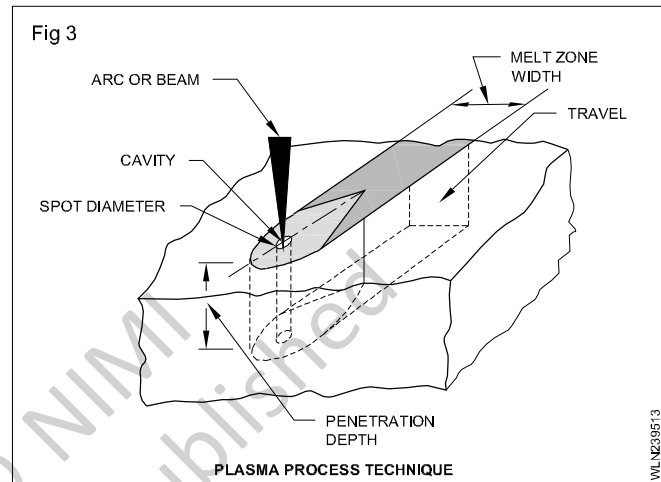
Microplasma and medium current plasma advantages

- energy concentration is greater & higher welding speed
- energy concentration is greater & lower current is needed to produce a given weld & less distortions
- improved arc stability
- arc column has greater directional stability
- narrow bead & less distortions
- less need for fixturing
- variations in torch stand-off distance have little effect on bead width or heat concentration & positional weld is much easy

- tungsten electrode is recessed & no tungsten contamination, less time for repointing, greater tolerance to surface contamination (including coatings).

Microplasma and medium current plasma limitations (Fig 3)

- narrow constricted arc & little tolerance for joint misalignment
- manual torches are heavy and bulky & difficult to manipulate
- for consistent quality, constricting nozzle must be well maintained



3 Keyhole plasma welding (Fig 5)

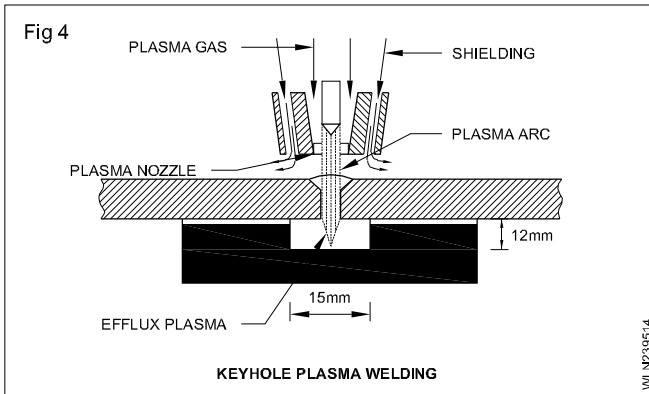
- welding currents over 100 Amps
- for welding thick materials (up to 10 mm)

Keyhole plasma welding advantage

- Plasma stream helps remove gases and impurities.
- Narrow fusion zone reduces transverse residual stresses and distortions.
- Square butt joints are generally used and reduced time preparation.
- Single pass welds and reduced weld time

Keyhole plasma welding limitations

- more process variables and narrow operating windows
- fit-up is critical
- increased operator skill, particularly on thicker materials Û high accuracy for positioning
- except for aluminium alloys, keyhole welding is restricted to downhand position
- for consistent operation, plasma torch must be well maintained



Application of the plasma process

Three operating modes possible by varying current bore diameter and gas flow rate

- **Micro plasma:** 0.05 to 15 amps – used for welding thin sheet down to 0.1mm eg SS bellows and wire mesh, welding of surgical instruments, repair of gas turbine engine blades, electronic components and micro-switches etc.

- **Medium current:** 15 to 200 amps – used as alternative to conventional TIG for improved penetration and greater tolerance to surface contamination. Generally mechanised due to bulkiness of torch.
- **Keyhole plasma:** over 100 amps – By increasing current and plasma gas flow a very powerful beam is possible which can achieve full penetration in 10 mm stainless steel. During welding the hole progressively cuts through the metal with the molten weld pool flowing behind to form the weld bead.

Limitations of plasma arc welding

- 1 PAW requires relatively expensive and complex equipment as compared to GTAW; proper torch maintenance is critical
- 2 Welding procedures tend to be more complex and less tolerant to variations in fit-up, etc.

Types of plasma arc, advantages and applications

Objectives: At the end of this lesson you shall be able to

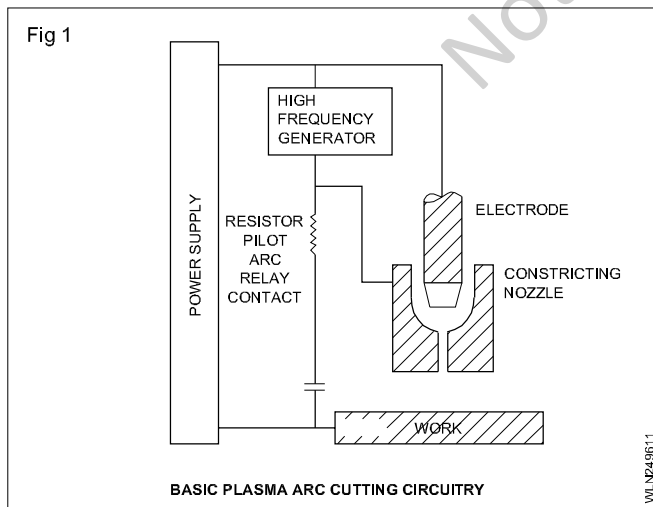
- state the principle of plasma arc cutting
- explain the process variable of plasma cutting
- state the advantages of plasma cutting.

Cutting processes - plasma arc cutting

Plasma arc cutting process, was introduced in the industry in the mid 1950s. The process is used to cut all metals and non-metals. The common oxy-fuel cutting process (based on a chemical process) is suitable for cutting carbon steel and low alloy steel cutting only. Materials such as copper, aluminium and stainless steels were earlier separated by sawing, drilling or sometimes by power flame cutting. These materials are now cut using a plasma torch, at faster rates and more economically. The Plasma cutting process is basically a thermal cutting process, free of any chemical reaction, that means, without oxidation. In plasma arc cutting an extremely high temperature and high velocity constricted arc is utilized.

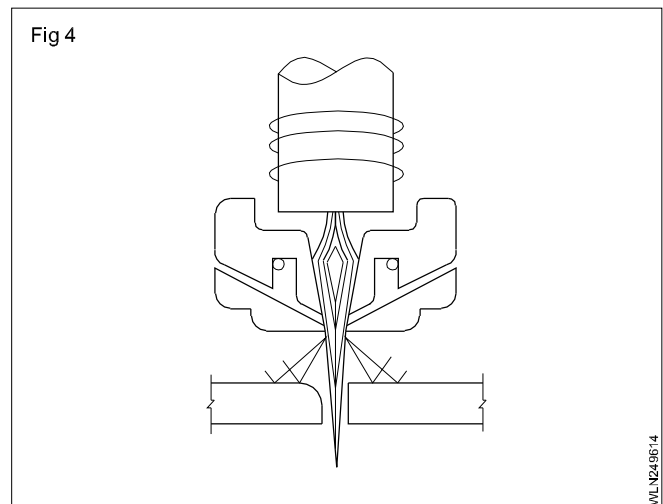
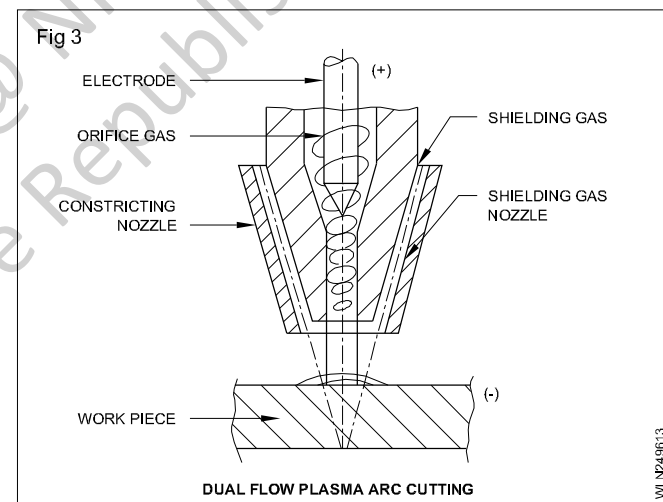
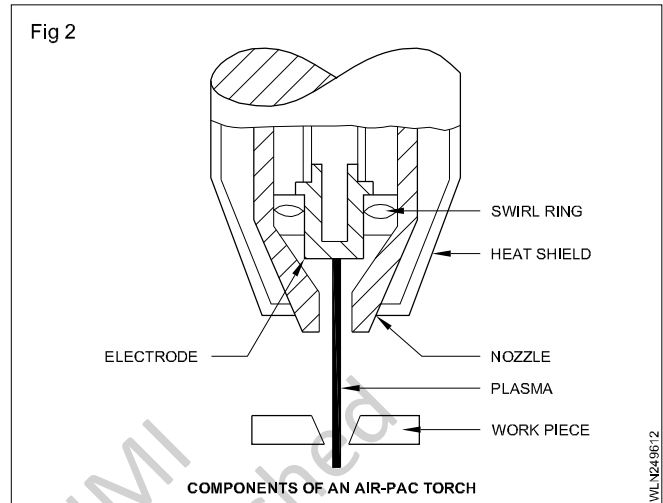
Principle of operation

Plasma arc cutting is a process resulting from ionizing a column of gas (argon, nitrogen, helium, air, hydrogen or their mixtures) with extreme heat of an electric arc. The ionized gas along with the arc is forced through a very small nozzle orifice, resulting into a plasma stream of high velocity (speed up to 600 m/sec) and high temperature (up to 20000°K). When this high speed is reached, high temperature plasma stream and electric arc strike the workpiece, and ions in the plasma recombine into gas atoms and liberate a great amount of latent heat. This heat melts the workpiece, vaporizes part of the material and the balance is blasted away in the form of molten metal through the heat (Fig 1).



Plasma cutting system (Fig 2,3,4)

Plasma cutting requires a cutting torch, a control unit, a power supply, one or more cutting gases and a supply of clean cooling water (in case water-cooled torch is used).



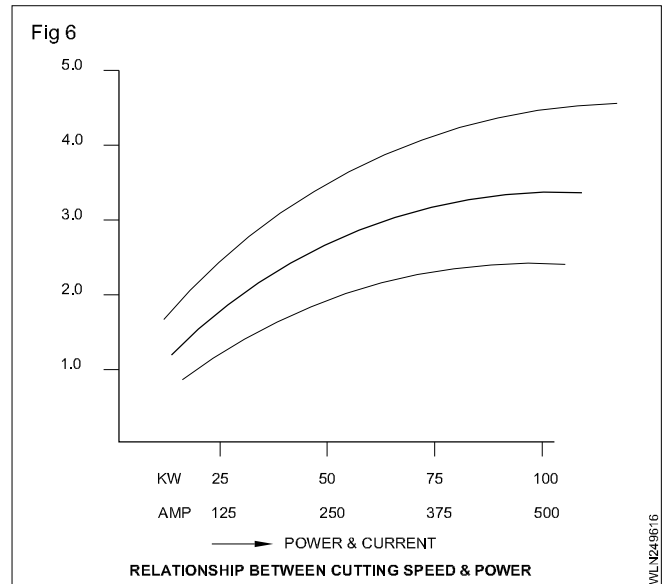
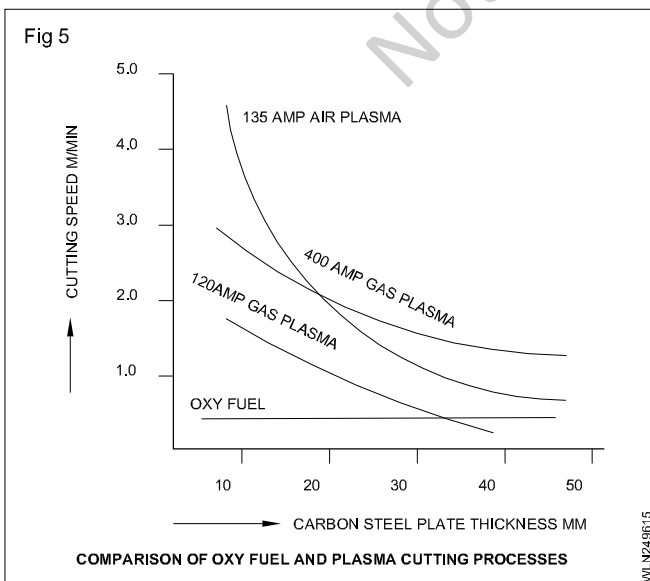
Equipment is available for both manual and mechanical cutting. A basic plasma arc cutting circuit is shown in Fig.1. It employs direct current straight polarity (DCEN). The nozzle surrounding the electrode is connected to the workpiece (positive) through a current limiting resistor and a pilot arc relay contact.

The pilot arc between the electrode and nozzle is initiated by a high frequency generator connected between the electrode and nozzle. The orifice gas ionized by the pilot arc is blown through the constricting nozzle orifice and forms a low resistance path to ignite the main transferred arc between the electrode and the workpiece when the ON/OFF switch is closed. The pilot arc relay may be opened automatically when the main arc ignites, to avoid unnecessary heating of the constricting nozzle. The constricting nozzle is of copper and normally water cooled to withstand the high plasma flame temperature (about 20000°K) and to have longer life.

In conventional gas plasma cutting, discussed above, the cutting gas can be argon, nitrogen, (argon + hydrogen), or compressed air. For all the cutting gases other than compressed air, the non-consumable electrode material is 2% thoriated tungsten. In air plasma cutting (Fig 2) where dry, clean compressed air is used as the cutting gas, the electrode of hafnium or zirconium. In used because tungsten is rapidly eroded in air. Wet and dirty compressed air reduces the useful life of consumable parts and produces poor quality.

Several process variations are used to improve the cut quality for particular applications. Auxiliary shielding in the form of gas or water is used (Fig 3) to improve the cut quality and to improve the nozzle life. Water injection plasma cutting (Fig 4) uses a symmetrical impinging water jet near the constricting nozzle orifice to further constrict the plasma flame and to increase the nozzle life. Good quality cut with sharp and clear edges with little or no dross is possible in water injection plasma cutting.

Process variables (Fig 5 & 6)



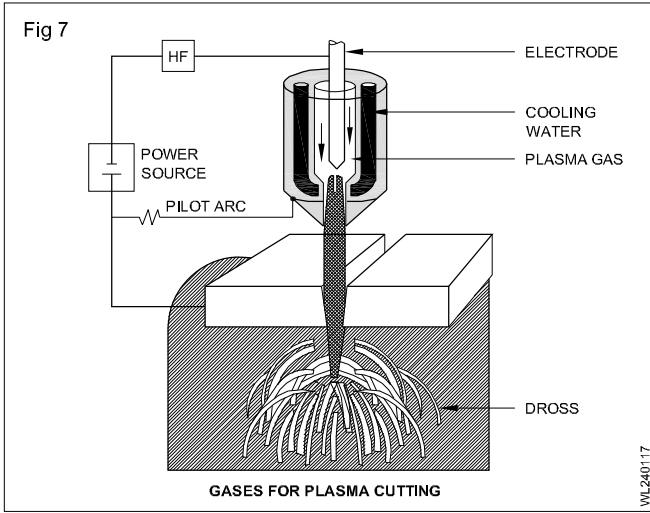
- i Torch design - constricting nozzle shape and size.
- ii Process variation - dual gas flow, water injection, air plasma.
- iii Cutting gas type and its flow rate.
- iv Distance between nozzle and job.
- v Cutting speed.
- vi Plasma cutting current.
- vii Power used during cutting.
- viii Manual/machine cutting.
- ix Material to be cut and its thickness.
- x Quality of cut required - rough or smooth.
- xi The bevel angle and round off corner etc.

Advantages of plasma cutting

- i All metals and non-metals can be cut due to the high temperature and high velocity plasma flame.
- ii Cuts are of very clear form with little or no dross.
- iii High speed piercing is achieved.
- iv Cutting of piled plates is possible, even with different materials.
- v Cutting cost is quite low as compared to other processes, especially for stainless steels.
- vi Cutting speed is high.
- vii Cutting is possible in all positions and locations (underwater also).

Gases for plasma cutting (Fig.7)

- no need to promote oxidation & no preheat
- works by melting and blowing and/or vaporisation
- "gases : air, Ar, N₂, O₂, mix of Ar + H₂, N₂ + H₂
- air plasma promotes oxidation and increased speed but special electrodes need
- shielding gas - optional
- applications : stainless steels, aluminium and thin sheet carbon steel.



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Resistance welding process & applications and limitations

Objectives: At the end of this lesson you shall be able to

- explain the principle and types of resistance welding process
- explain the main elements of a resistance welding machine
- state the applications of resistance welding in industry and its advantages.

Principle of resistance welding: Resistance welding is a welding process wherein coalescence is provided by the heat obtained from the resistance offered by the work to the flow of electric current in a circuit and the joint is effected by the application of pressure.

The fundamental principle on which all resistance welding is based is as follows.

The heat is generated due to the resistance offered by the parts to the passage of heavy electric current for a fraction of a second.

Heat produced at the junction is calculated by the formula

$$H = I^2Rt$$

where H for Heat, I stands for the amount of current in amps.

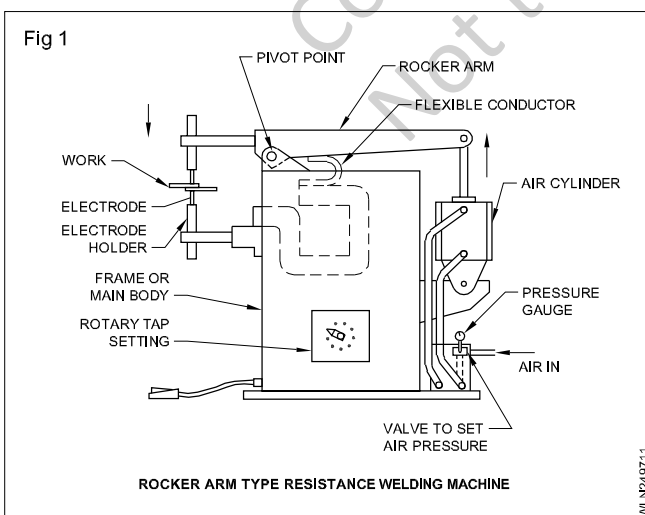
R for resistance offered in ohms

t - time taken for duration of current flow in seconds.

This heat at the junction of the two parts changes the metal to a plastic state, and when combined with the correct amount of pressure, fusion takes place.

The different types of resistance welding machines are spot welding, seam welding, projection welding, flash butt welding and upset welding machines.

A standard rocker arm type resistance welding machine is shown in Fig.1. The main parts are:



1 The frame: It is the main body of the machine which differs in size and shape for the stationary and portable types.

2 Force mechanism: The compressed air cylinder and the pivoted rocker arm gives the necessary high pressure to the lever to which the upper electrode holder is attached.

3 The electric circuit: It consists of a step down transformer which provides for the necessary current to flow at the point of weld.

4 The electrodes: The electrodes include the mechanism for making and holding contact at the weld area.

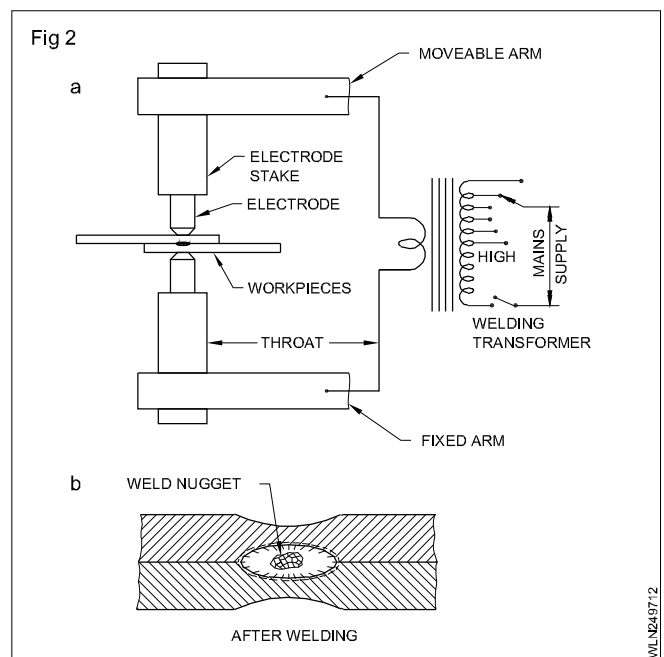
5 The timing controls: The switches which regulate the value of current, current flow time and contact period time as the timing controls.

6 Water cooling system to circulate cooling water to the electrodes.

This is the additional part consisting of a water reservoir and flow system.

Spot welding: This type of resistance welding machine is most commonly used for resistance welding. The material to be joined is placed between two electrodes as shown in Fig 2a. Pressure is applied after a quick shot of electricity is sent from one electrode through the job to the other electrode.

Spot welding is made in three steps.

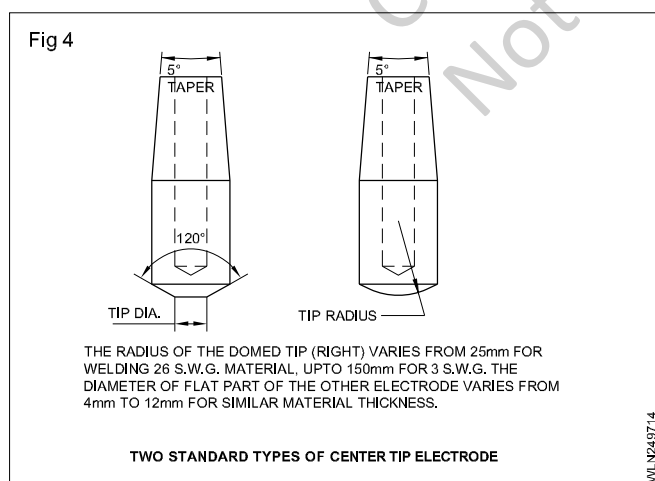
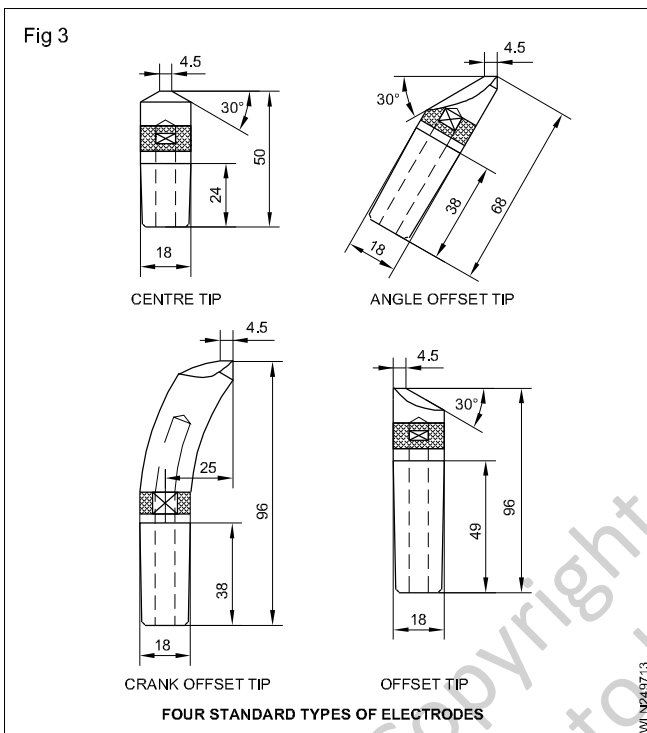


The first step is when the parts to be joined are clamped between the electrodes. In the second step, a high current is allowed to pass through the clamped members and is raised to the welding temperature. The third step sees the current being cut off and high pressure being applied to the joint and the joint completed. A nugget is formed as shown in Fig 2b.

A special copper alloy material has been developed for use as electrodes.

Cooling of the electrodes is accomplished by internally circulating water.

Electrodes are of many shapes and sizes, the most common being the centre tip and offset tip types. (Figs 3 and 4)

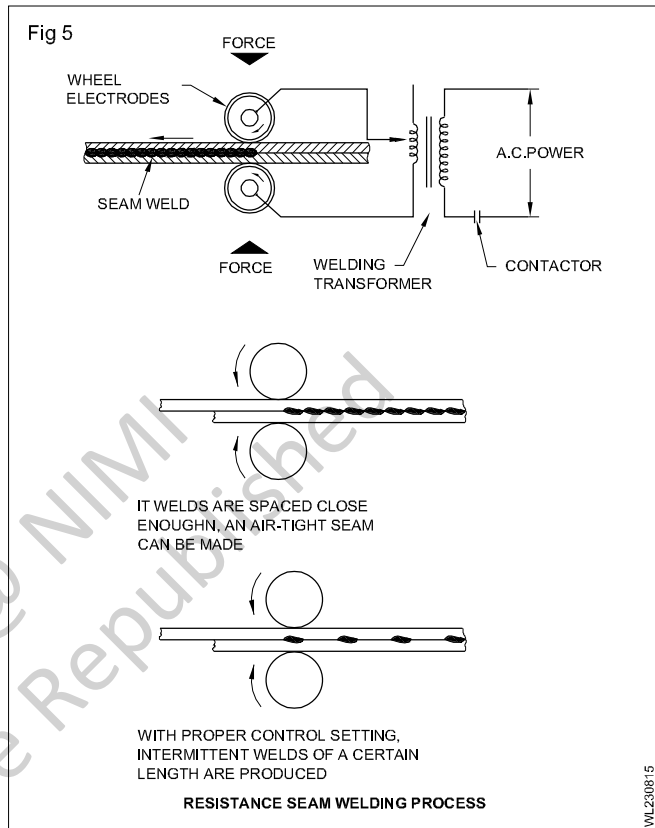


Regular spot welding leaves slight depressions on the metal. These depressions are minimized by the use of larger sized electrode tips and by inserting 1.6 mm copper sheets between the electrode and the job.

Spot welds may be made one at a time or several welds may be completed at one time.

Spot welding is utilized extensively for welding steel, and when equipped with an electronic timer, it can be used for other materials, such as aluminium, copper, stainless steel, galvanised metals etc.

Seam welding: Seam welding is like spot welding except that the spots overlap one another, making a continuous weld seam. In this process the metal pieces pass between the roller type electrodes as shown in Fig 5.



As the electrodes revolve, the current is automatically turned 'on' and 'off' at intervals corresponding to the speed at which the parts are set to move. With proper control, it is possible to obtain airtight seams suitable for containers, water heaters, fuel tanks etc.

When spots are not overlapped long enough to produce a continuous weld, the process is sometimes referred to as roller spot welding.

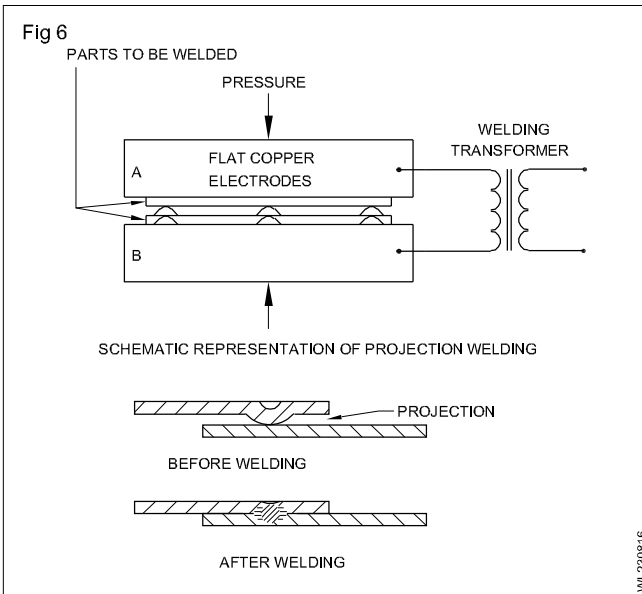
Cooling of the electrodes is accomplished either by circulating water internally or by an external spray of water over the electrode rollers.

Both lap and butt joints are welded by seam welds. In the case of butt joints, foils of filler metals are used on the joints.

Projection welding: Projection welding involves the joining of parts by a resistance welding process which closely resembles spot welding. This type of welding is widely used in attaching fasteners to structural members.

The point where welding is to be done has projections which have been formed by embossing, stamping or machining. The projections serve to concentrate the

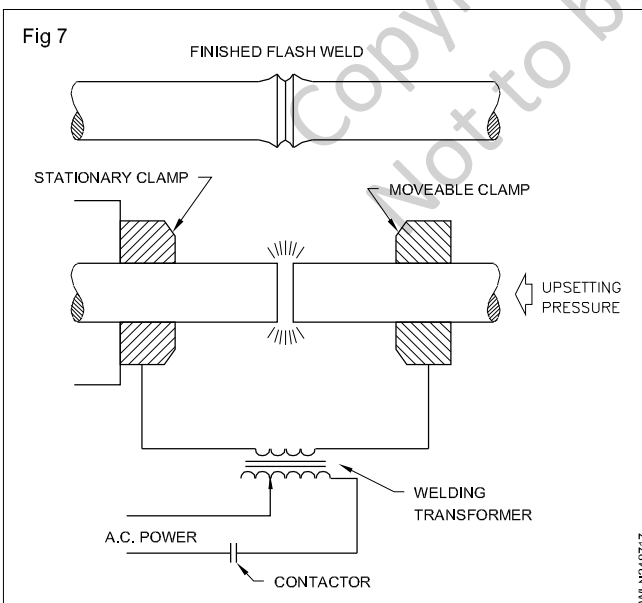
welding heat at these areas and facilitate fusion without the necessity of employing a large current. The welding process consists of placing the projections in contact with the mating part and aligning them between the electrodes (flat copper electrode) as illustrated in Fig 6.



Either single or a multitude of projections can be welded simultaneously.

Not all metals can be projection-welded. Brass and copper do not lend themselves to this method because the projections usually collapse under pressure. Galvanised iron and tin plates, as well as most other thin gauge steels, can be successfully projection-welded.

Flash butt welding: In the flash butt welding process the two pieces of metals to be joined are firmly held in clamps which conduct current to the work. (Fig 7)



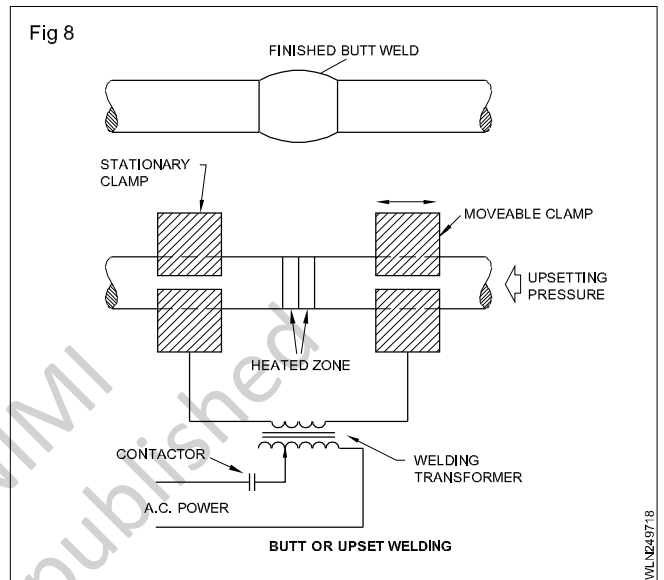
The ends of two metal pieces are moved towards and away from each other until an arc is established. The flashing action across the gap melts the metal, and as the two molten ends are forced together, fusion takes place. The current is cut off just before the heavy pressure is applied through the movable clamp.

Flash butt welding is used to butt-weld plates, bars, rods, tubing and extruded sections. It is not generally recommended for welding cast iron, lead and zinc alloys.

The only problem encountered in flash butt welding is the resultant bulge at the point of the weld. It should be removed by grinding or machining if the part needs finishing.

Butt or upset welding (Slow butt weld)

In butt welding the metals to be welded are in contact under pressure. An electric current is passed through them, and the edges are softened and fused together as illustrated in Fig 8.



This process differs from flash butt welding in that constant pressure is applied during the heat process which eliminates flashing. The heat generated at the point of contact results from resistance. The operation and control of the butt welding process is almost identical to that of flash butt welding.

Butt or upset welding is limited to parts with a cross-section area of not more than 200-250 mm². Bars with cross-sectional area of 250mm² and above are joined by flash butt welding.

Application: Spot, seam and projection welding is widely used in the production of cars, tractors, farm machines, rail coaches etc. where thin sheets are to be joined.

Large sections like square, rectangular, cylindrical rods with regular and irregular end faces are welded without any edge preparations by flash butt or butt welding processes.

Advantages of resistance welding

- Widely used for joining sheet metals.
- Speedy process.
- No distortion.
- Less skilled operators can do the job.
- No problem of edge preparation.

Metallizing, types, principles equipments, their advantages and its application

Objective: At the end of this lesson you shall be able to
• **explain the purpose of metallizing in various process.**

Definition

Metallizing is a very common coating process which is used to improve the resistance of material against corrosion, wear and fatigue.

Metallizing is the general name for the technique of coating metal on the surface of objects. Metallic coating may be decorative, protective or functional.

Types

Metallizing can be done by following

- 1 By electric arc spray process
- 2 By spray process
- 3 By thermal spray coating

Application

- 1 Arc metalizing of products that will not corrective or rust proof
- 2 A steel structure protected by metalizing.
- 3 To improve the resistance of the material against the corrosion.

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Principles of operations and applications

Objective: At the end of this lesson you shall be able to
 • describe the manual powder coating process.

Principles of powder coating

The powder coating process is very similar to a painting process except that the paint is a dry powder rather than a liquid.

The powder sticks to the parts due to electrostatic charging of the powder and grounding of the parts.

Any substance can be used that can tolerate of the heat of curing the powder and that can be electrically grounded to enhance charged particle attachment. The powder flows and cures during the application of heat.

Advantages of powder coating

- 1 Powder recovery for reuse
- 2 Expenditure will be less
- 3 Can be more durable than paints
- 4 Easily can do a work

Disadvantages of powder coating over paints are

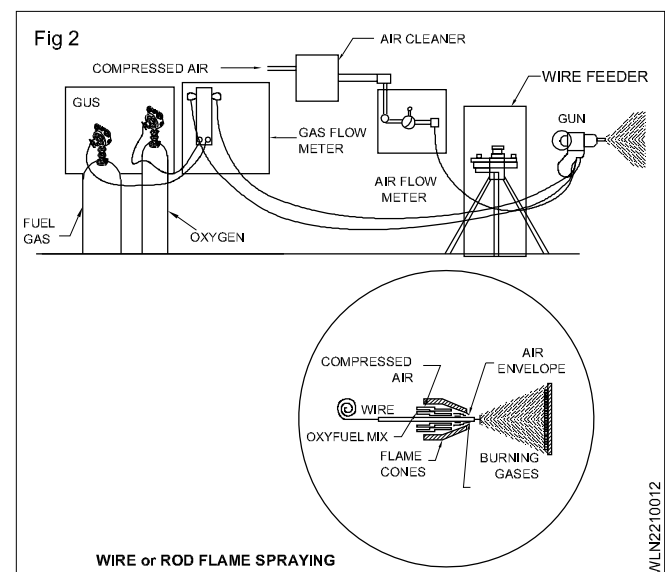
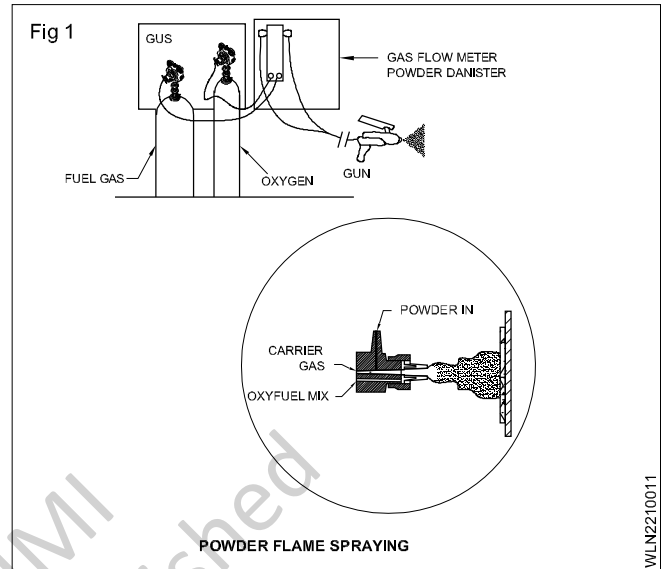
- 1 Can have less leveling than paint
- 2 Curing is similar, typically more energy intensive than point drying due to higher temperature requirements.
- 3 Difficult to set a certain plants.

Operations

- 1 Cleaning
- 2 Rinsing
- 3 Phosphating
- 4 Drying
- 5 Powder coating
- 6 Curing

Uses of powder coating operating wings

- 1 Railway factory
- 2 BEML factory
- 3 Dozer can be painted
- 4 Complicated parts are to be painted
- 5 Used in large scale industries
- 6 Maintenance of fabricated parts.



Welding codes and standards - WPS & PQR

Objectives: At the end of this lesson you shall be able to

- describe the welding codes and standards
- explain about WPS & PQR

Welding procedure, Performance, Qualification and codes

Introduction

'Code' is any set of standards set forth and enforced by a local government for the protection of public safety, health etc.. as in the structural safety of building, (building code) health requirements for plumbing, ventilation etc.... (Sanitary or health code) and the specifications for fire escapes or exits (Fire code)

'Standard' is defined as 'something considered by an authority or by general consent as a basis of comparison, an approved model'.

As a practical matter, codes tell the user what to do and when and under what circumstances to do it. Codes often legal requirements that are adopted by local jurisdictions that then enforce their provisions.

Standards tell the user how to do it and are usually regarded only as recommendations that do not have the force of law.

The uses of welding in Engineering Industries are Boilers, Heat Exchangers, Pressure Vessels, Bridges, Ships, Pipelines, Reactors, Storage tanks, Construction Structures and Equipment etc. When a design engineers designs a welding structure, the function of production & Quality control personnel is to translate that design in to a real component.

From a design point of view properties of the weld joint are designed as

- 1 Physical soundness (free from discontinuities)
- 2 Related Theory for Exercise 2.6.06 Metallurgical compatibility (Chemistry of weldment, base metal, gas etc.)
- 3 Mechanical Properties

The welding Procedure Specification (WPS) is written exactly to translate these property requirements on to relevant welding variables.

The procedure has to be testified on a test piece for its intended performance by a qualified welder. To draw a correct weld procedure, performance methods and qualification criteria, there are popular codes and standards are available.

All the codes specifies the rules for the preparation of welding procedures specification and the qualification of welding procedures, welders and welding operators. This code specifies the rules for all manual and machine welding processes.

Reading of Welding Procedure specifications (WPS) & Reading of Procedure Qualification Record (PQR)

Government as well as private organizations develop and issue standards that apply to a particular area of interest. Many standards with regard to the welding industry are prepared by the American Welding Society (AWS). Many countries have their own national standards on the subject of welding.

The following are examples of the various standards, and the bodies responsible for them.

Standard codes	Country	Responsible bodies
IS	India	Bureau of Indian Standards (BIS)
BS	U.K	British Standard issued by British Standard Association
ANSI	U.S.A	The American National Standards Institute (ANSI)
AWS	U.S.A	American Welding Society
ASME	U.S.A	American Society of Mechanical Engineers
API	U.S.A	American Petroleum Institute
DIN	Germany	German standard issued by the Deutsches Institute fuer Normung
JIS	Japan	Japanese industrial standard issued by the Japanese standards Association

There is also the International Organization for Standardisation (ISO). The main goal of ISO is to establish uniform standards for use in international trade.

The American Welding Society publishes numerous documents on welding and some of them are listed below:

Welding procedure qualification

A welding procedure qualification is the test to prove that the properties of a weld to withstand the service conditions as designed for particular/specific purpose.

Welder performance qualification

A welder's performance qualification is the test to certify a welder's or a welding operator's ability to deliver consistently quality welds. This performance qualification is always done in accordance with a qualified weld procedure specification.

Weld procedure specification

A WPS is deemed to have been qualified if through tests that are conducted on the weld test coupon meeting the requirements or the acceptance criteria. Acceptance criteria and the specification format may vary depending on the code of design and manufacture. The tests that are carried out on the weld test coupon are destructive tests, and they help to evaluate the mechanical properties of the weldment carried out in accordance with WPS.

The results of this qualification are generally recorded in a format and these are generally recorded in a particular format and this is usually referred to as an Procedure Qualification Record (PQR). Thus for every WPS there has to be at least ONE PQR and vice versa.

A performance qualification is generally done to evaluate the performance of a welder on a welding operator. It is done to evaluate the ability of a welder or operator to perform consistently and deliver sound and good quality welds. As this is done to a WPS which has already been qualified most codes of practice generally permit the evaluation to be done by the use of non destructive tests viz, radiography. Welders and operators who fulfill the requirements are deemed to be certified for welding to the specific WPS/WPSs.

ASME sections IX, AWS B2.1, API 1104 are some of the popular American codes specifying welding procedures and welder performance qualification.

BS 2633, BS 4870/4871, BS 4872, DIN 8560, AD Merkblatt HP 2 and HP 3, eN 288-2 and EN 287-1 are some of the European standards for welding procedures and performance qualification.

IBR chapter 13, IS 2825, IS 7307, IS 7310, IS 7318 are the major Indian codes on welding qualifications.

Weld procedure specifications, variables and logic for requalification

A WPS (Weld Procedure Specification) is a document which lists out all the essential characteristics for performing a weld. For purposes of qualifying for the WPS, a test coupon is welded adhering to all parameters as stated/

listed in the WPS. A WPS is valid only when supported by a relevant PQR.

The characteristics listed in the WPS, those in this chapter, are otherwise known as variable. As the term signifies, these characteristics may be changed or varied. When these "variables" are changed we have a new WPS. Whenever a change in a particular "variable" is bound to influence the mechanical properties of the weld, then that "variable" is termed as an ESSENTIAL variable. The variable which do not have any impact on the mechanical properties of the weld are generally termed as NON-ESSENTIAL variables. However, under certain conditions, some of the variables could influence the mechanical properties of the weld. Such variables are termed as supplementary essential variables. A more detailed treatment of these is made in the code of manufacture and the same could be referred to.

Similarly those variable that have an influence on the welder's ability to produce sound welds are referred to as essential variables for purposes of Welder Performance Qualification. An example that comes to one's mind right way would be the position in which a weld is made.

Introduction to ASME Sec.IX

Welding procedure and performance qualification

Section IX of the ASME code specifies the rules for the preparation of welding procedure specification and the qualification of welding procedures, welders and welding operators.

This code specifies the rules for all manual and machine welding processes.

Materials

All the materials that can be used for pressure vessel manufacture have been grouped (Table 1) under different 'P' numbers. The object of grouping the base materials is to reduce the number of qualifications required. The 'P' numbers grouping of materials is based essentially on comparable metal characteristics such as composition, weldability and mechanical properties.

Table 1

'P' Number grouping

P1 to P11	Steel and steel alloy
P21 to P30	Aluminium and aluminium based alloys
P31 to P35	Copper and copper based alloys
P43 to P47	Nickel and nickel based alloys
P51 to P52	Titanium and titanium based alloys.

Filler metals

The filler metals are grouped as both "F" numbers and "A" numbers.

"F" numbers

All the electrodes and filler metals are grouped under different "F" numbers. The object of the "F" number grouping (Table 2) is to reduce the number of welding procedures and performance qualifications.

Table 2
"F" Number grouping

F1 to F6	Steel and steel alloys
F21 to F24	Aluminium and aluminium based alloys
F31 to F 37	Copper and copper based alloys
F41 to F45	Nickel and nickel based alloys
F51	Titanium and titanium alloys
F61	Zirconium and zirconium alloys
F71 to F72	Hard facing weld metal overlay.

The "F" number grouping is based essentially on their usability characteristics, with respect to coating. This fundamentally determines the ability of the welder to make a satisfactory weld with a given filler metal. For example, the low hydrogen electrodes have been grouped under "F" Number 4 and rutile steel electrode4s under "F" Number 2.

Obviously, a welder who is able to produce a sound weld with a E6013 (rutile) electrode may not be able to produce a sound weld with a low hydrogen lime powder coated electrode.

The skill required to use these electrodes is definitely not the same. "F" Number 1 is thus the easiest (iron powder) electrode used only in downhand fillet/butt and horizontal fillet positions.

'A' Numbers

A part from classifying the filler metals under "F" numbers, they are again classified under 'A' number as shown in Table 3. 'A' number classification of the filler metals is based on the weld metal chemical analysis whereas the 'F' number classification is based on the usability, or rather operation characteristics. With these definitions of 'P' numbers and 'A' numbers, we shall now see what the code says regarding welding procedures and welders qualification.

Table 3
'A' number grouping

A 1	Mild steel
A 2	Carbon - Molybdenum
A 3 to A 5	Chrome - Molybdenum
A 6	Chrome - Martensitic
A 7	Chrome - Ferritic
A 8 to A 9	Chrome - Nickel
A 10	Nickel - 4%
A 11	Manganese-Molybdenum
A12	Nickelchrome-Molybdenum

Welding procedures qualification

The codes stipulate that all the details of the welding procedure should be listed in the 'Welding procedure specification' (WPS).

Each of these welding procedure specifications shall be qualified by the welding of test coupons, and the mechanical testing of the specimens cut from these coupons are required by this code. The welding date for these coupons and the results of these tests shall be recorded in a document known as 'procedure qualification record (PQR)'.

A WPS may require the support of more than one PQR, while alternatively, one PQR may support a number of WPSs. A WPS will be applicable equally for a plate, pipe and tube joints. The WPS should contain the following nine points in detail.

1 Joints: details

The groove design, the type of backing used etc. are to be specified in this. If a change in the type of edge preparation (Single Vee, Single 'U' or double Vee etc.) is made or if the joint backing is removed, a new WPS has to be written but need not be qualified by a test.

2 Base metals

The base metal (P) number and the thickness ranges for which the procedure is applicable etc. have to be mentioned here. If the range of thickness has to be increased or a change of base metal from one 'P' number to another 'P' number is required, a new WPS should be prepared and supported by a PQR after due tests.

3 Filler metals

The details of the electrodes, and filler wires such as the 'F' number, 'A' number and the type of the filler metals have to be specified here. The electrodes, flux compositions, (basic, rutile, etc.) are also to be mentioned. A change in 'F' number or 'A' number shall require a new WPS and PQR. A change in the diameter of the electrode also requires a new WPS but need not be qualified by a test. The addition or deletion of filler metals requires a new WPS and PQR after re-tests.

4 Position

The positions in which the welding should be done shall be mentioned here. The qualification test can be done in any position but still the same procedure is applicable to all positions.

5 Preheating

The preheating temperature, interpass temperature etc. shall be clearly specified. If the preheat is to be decreased by more than 550C, then a new WPS has to be prepared and qualified by a test.

6 Post - weld heat treatment

The temperature and soaking time of the post-weld heat treatment shall be shown here. Any change in this shall require a new procedure qualification.

7 Electrical characteristics

The type of current, (AC or DC) polarity, amps and voltage etc. have to indicated here.

8 Gas

The shielding gases flow rate, details of gas purging etc. will be shown here. Change in gas composition will call for re-qualification.

9 Technique

The details of the welding techniques string or weave bead, method of initial and interpass cleaning, back gouging, single or multiple passes, root grinding etc., shall be written here. The test welding can be done either in a plate or pipe material and in any position. The maximum thickness for which the procedure is applicable is generally twice the thickness of the test plate or pipe. The welder who welds the test joint is also qualified for that procedure but only in that position in which he welds whereas the procedure is applicable to all positions. The results of the tests shall be recorded in the PQR including welding, NDT and mechanical test results.

Welder's qualification

The purpose of the welder's qualification is to determine the ability of the welder to make sound welds.

The welder may be qualified, based on the results of the mechanical test (two face bends and two root bend tests or four side bend tests) or by radiographic examination of a minimum length of 150 mm for a plate or the entire weld for a pipe. The position of the weld joint has been classified as 1G, 2G, 3G, 4G, 5G and 6G. Table 4 shows the positions qualifying for other positions.

Table 4

Range of positions qualified

Test position	Also qualifies
1G	1G
2G	1G
3G	1G
4G	1G & 3G
5G	1G & 3G
2G & 5G	All positions
6G	All positions

For positions 1G and 2G (flat and horizontal) qualification on a plate shall also qualify the welder in pipes. For all other positions, qualification on a pipe shall qualify for plate but not vice versa.

A qualification in a plate or pipe butt joint shall also qualify the welder for fillet welding in all plate thickness and pipe diameters.

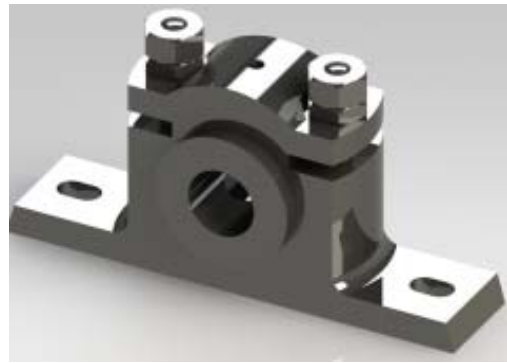
Reading of assembly drawing

Objectives: At the end of this lesson you shall be able to

- identified the assembled jobs.



a bracket bearing



b bracket bearing



Bush



Bush



Slotting



Cam shaft



Internal bush bearing



Various types of bushes



Ball bearing

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Hard facing

Objectives: At the end of this lesson you shall be able to

- explain the necessity of hard facing
- describe the method of preparation for hard facing
- describe the various hard facing alloys
- explain the advantages of hard facing.

Necessity of hard facing: This operation consists of depositing a layer of harder metal on a softer base metal in order to provide a surface having special properties such as toughness, hardness and resistance to abrasion, heat and corrosion.

This is also done to build up worn out areas of a hardened component due to long and continuous use and make them as good as new with low cost and quickly.

Preparation: Clean the surface of the part to be hard faced, by grinding, machining, filing, chipping or sand blasting until it is free from dirt, scale etc.

Remove sharp corners which melt easily or get oxidized.

Hard facing alloys

Different groups of materials used for hard facing are:

- Ferrous alloy group
- Non-ferrous alloy group
- Diamond substitute group

Ferrous alloy group: This group comprises welding electrodes having an iron base alloyed with chromium, manganese, molybdenum, nickel, zirconium, boron and silicon.

Non-ferrous alloy group: This group consists of welding electrodes which are alloys of chromium, tungsten, cobalt and molybdenum and some times small quantities of iron.

Diamond substitute group: This group composed of carbides of tungsten, tantalum, titanium and boron and the borides of chromium is so called because its hard facing materials approach the hardness of a diamond.

Hard facing electrodes are designed on the basis of hardness of their weld deposits as follows. (table)

Typical deposit composition for high temperature service
Deposit composition %

Type	C	Mn	Si	Cr	Ti	Mo	W	Co	V	Ni
A	6.0	2.7	1.0	13.0	5.2	-	-	-	-	-
B	4.6	1.0	1.1	27.0	-	3.5	-	-	-	-
C	3.0	1.3	0.81	8.3	1.5	-	-	-	-	-
D	2.0	-	-	29.0	-	-	12.0	51	-	-
E	1.6	1.8	0.9	5.8	4.2	0.5	-	-	0.4	-
F	0.7	-	-	27.0	-	-	4.5	62	-	-
G	1.75	1.0	1.5	30.0	-	1.5	-	-	-	3
H	0.8	0.5	0.65	4.0	-	8.0	1.2	-	1.0	-
I	1.9	1.5	0.60	7.4	4.6	1.4	-	-	-	-
J	4.5	0.75	0.80	28.0	-	-	-	-	-	-
K	4.2	1.7	0.10	5.0	6.8	-	-	-	-	-
L	3.1	3.1	1.7	15.0	-	-	-	-	-	-

NOTE: A to H are manual electrodes; I to L are flux-cored wires.

Type	Hardness BHN
A	250-280
B	350-380
C	280-320
D	600-625

Indian Oxygen: Stellite Grade 1, Stellite Grade 6, Stellite Grade 12, Duriod 1, 2, 3.

Larsen and Toubro Ltd
Eutectrode - 2 (AC-DC)

Advani Orlikon - Citorail I to IV Citomangan, Supersist etc.

Electrodes commercially available:

Application: Chromium and tungsten carbide electrodes are used for severe abrasion - resistance.

High carbon type electrodes are used for moderate abrasion and impact resistance.

Stainless steel electrodes are used for severe impact and moderately severe abrasion resistance.

Hard facing with MMAW process: Clean the surface thoroughly and arrange the work in a flat position.

Preheat to about 95°-150°C.

Use only enough amperage to provide sufficient heat to maintain the arc. Avoid high current and short arc length.

This is very important to prevent dilution of the deposit with the base metal.

Use the stringer or slight weaving technique holding a medium arc.

Deposit 25 to 50 mm long beads not wider than twice the diameter of the electrode.

Allow the work to cool between each deposit of beads.

Stagger the deposits to prevent building up of high heat at only one spot.

Chip the slag between passes.

Slow cooling by covering the job with sand or ashes or slaked lime is to be done.

The number of layers will vary from job to job. But it should be noted that the first layer deposited on mild steel is diluted by the 'pick-up' from the plate. (i.e. the soft mild steel from base metal will mix with the hard deposited metal and therefore the I layer will have less hardness.

It is never advisable to make more than three layers because such a mass of metal may crack in service or during deposition.

Advantages of hard facing

Longer life of wearing parts (2 to 20 times, depending on the type of service).

Increased mechanical operating efficiency.

Reduced idle time of plant.

Use of reconditioned worn out parts instead of costly new replacement parts.

Reduced labour costs because of fewer replacements.

Greater independence during periods of replacement of parts when there is a shortage.

Applications

Different hard-faced products are illustrated in Figs 1 to 9.

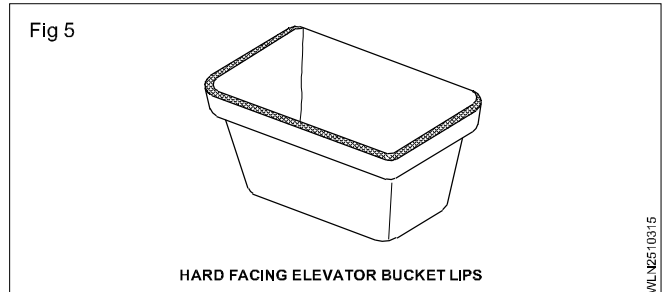
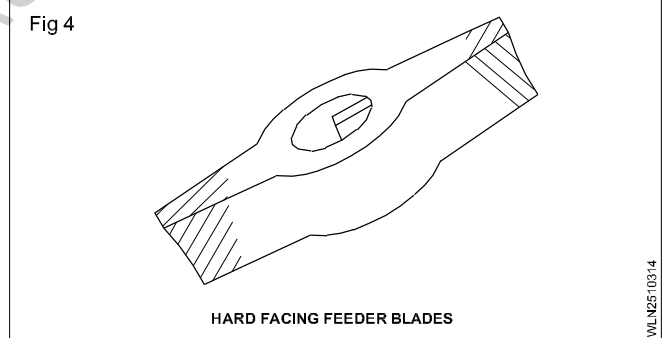
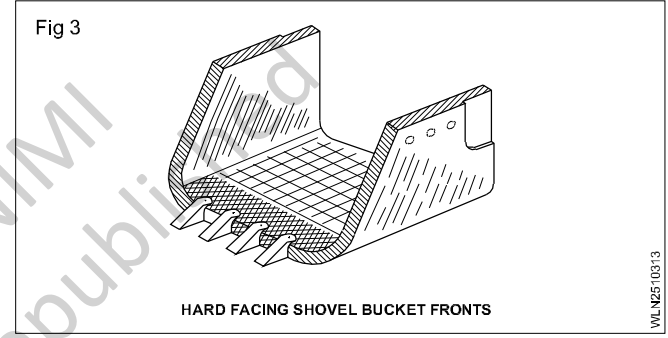
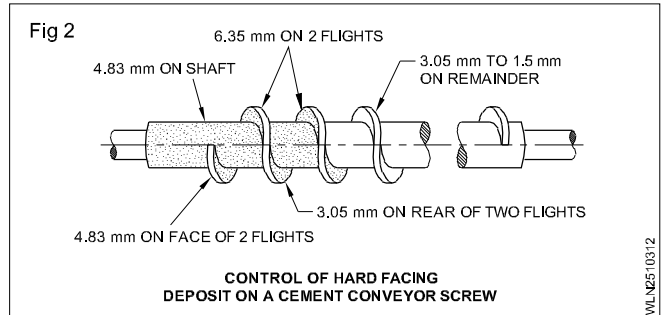
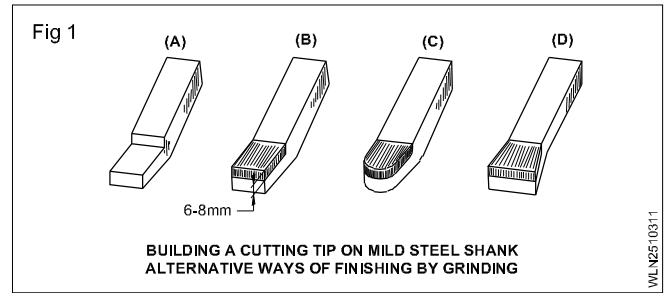
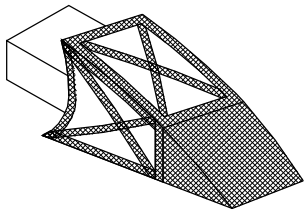


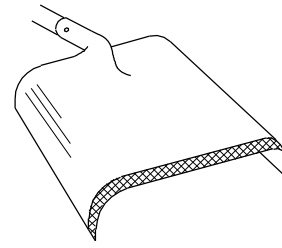
Fig 6



HARD FACING SHOVEL BUCKET TEETH

WLN2510316

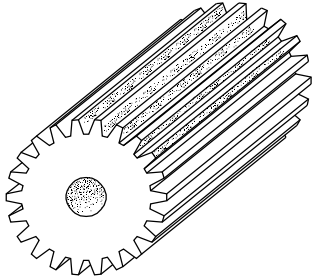
Fig 8



HARD FACING KILN SCOOP SHOVELS

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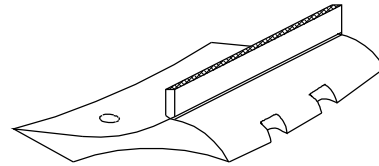
Fig 7



HARD FACING GEAR TEETH (PINION GEARS)

WLN2510317

Fig 9



HARD FACING TRACTOR GROUSERS

WLN2510319

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Surfacing/Metal build up

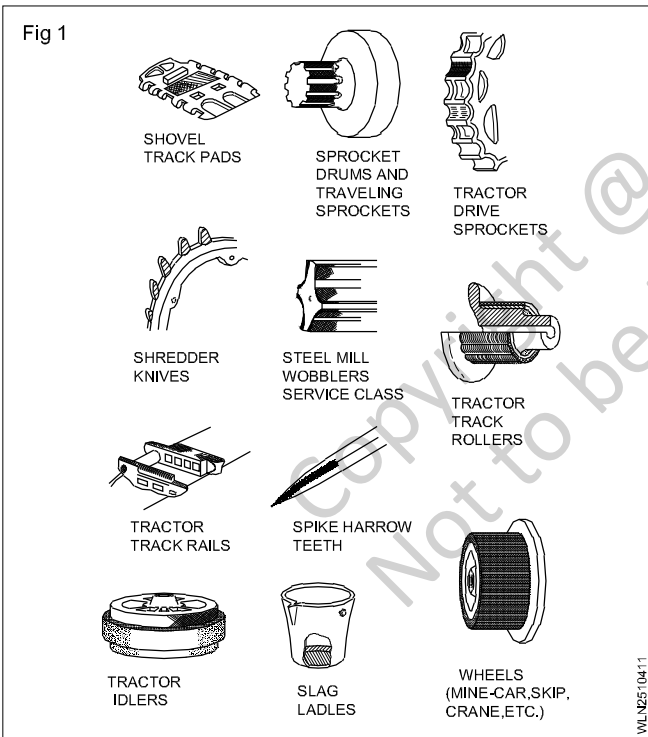
Objectives: At the end of this lesson you shall be able to

- explain the purpose of surfacing/metal build up
- describe the different applications of surfacing
- describe the factors that cause wear
- describe the method of surfacing by the M.M.A.W. process
- state the different surfacing methods.

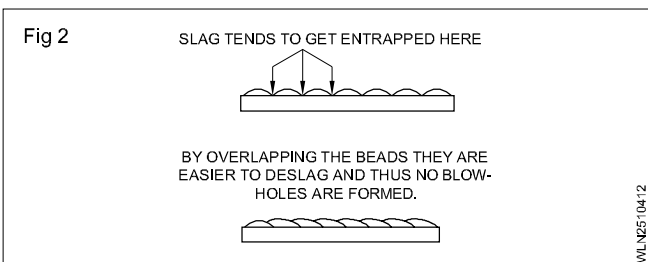
Purpose of surfacing/metal build up: Surfacing/metal build up is done to build up worn out parts whose dimensions have been reduced and make them as good as new and obtain the required properties.

Application

To repair worn out shafts, gears and other parts, (Fig 1) surfacing might be the only way to solve the problem since new parts may not be available any longer. Surfacing is done to modify a part's surface so as to improve its performance.



Weld beads running across the surface of a roller can improve its gripping or driving action. (Fig 2)



Causes of wear

There are six different factors that cause wear or affect the parts.

Abrasion is the grinding or scratching action of hard particles that cause wear.

Erosion is the wear caused by liquids or gases striking metal parts at high speed.

Impact is a blow or series of blows that can cause the metal to deform, fracture or peel off in pieces.

Corrosion is a chemical or electrochemical attack on a surface.

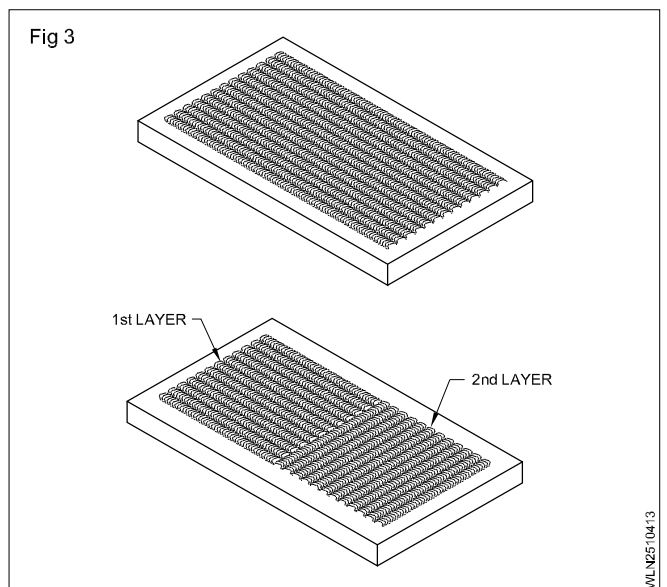
Rust is caused by oxidation.

Heat softens the metal which reduces the metal's resistance to abrasion and corrosion.

Friction on the surface of the metal results from the metals rubbing together under pressure with little or no lubrication.

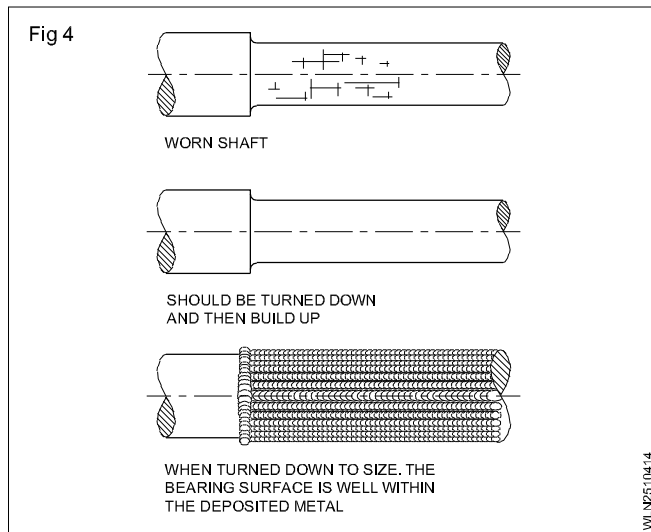
Method of surfacing / Metal build up

Padding: A plate of 10 mm mild steel about 150 mm square is used for padding. A series of parallel beads are laid side by side across the surface of the plate so as to slightly overlap one another. If the beads are laid side by side with no overlap, the slag becomes entrapped in the line where the beads meet, making it difficult to be removed and causing blow holes. (Fig 3)



Each bead is de-slugged before the next is laid.

After thoroughly cleaning and brushing all the slag and impurities from the layer, another layer is deposited on the top of this with the beads at right angles to those of the first layer. (Fig 4)

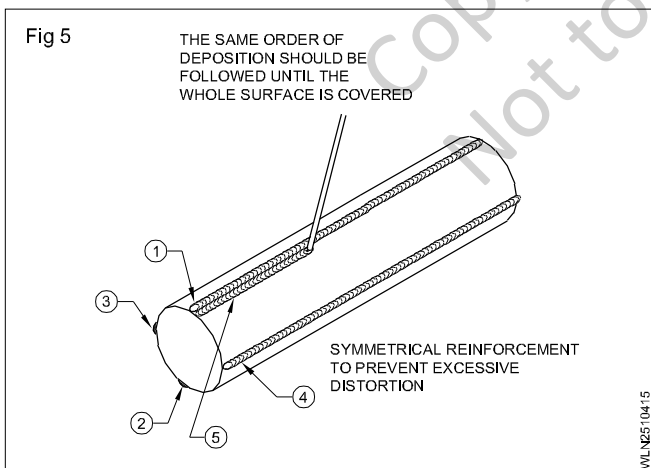


This can be continued for several layers and the pad finished.

Building up shafts: In the case of shafts worn out with small wear, such as 1 mm, it is evident that if the shafts are built up and then turned down again, the thickness of the deposited metal remaining is very small, and the bearing surface will be practically on the line of fusion.

It is advisable to turn the shaft further by 1 mm.

Bring the bearing surface well into the deposited metal. This will give much better service. (Fig 5)

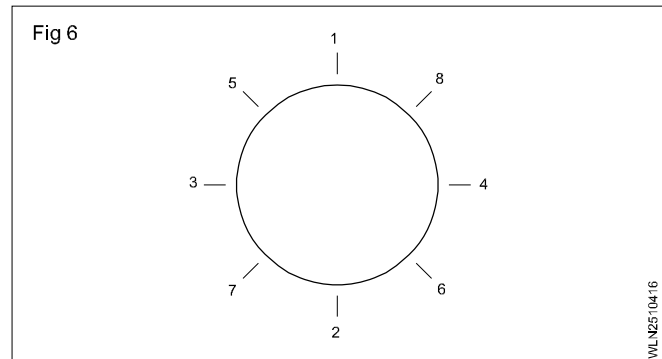


Welding deposition

Deposit beads along the side parallel to the axis.

Use a medium arc with stringer beads.

Deposit the run as shown in Fig 6 on the opposite sides, 1, 2, 3 and 4 to equalise the stresses. Complete the job depositing symmetrically.



Surfacing methods

- Oxy-acetylene method
- Shielded metal arc method
- Submerged arc method
- MIG welding method
- TIG welding method
- Plasma arc welding method

Oxy-acetylene welding method

Oxy-acetylene method has great usefulness for smooth, precise and extremely high quality surfacing deposits.

Advantages

Very thin layers of weld metal can be applied. Can be easily made to flow to the corners and edges of the job. This method is smooth, precise and is of extremely high quality.

Grooves can be filled. But this is very slow process.

Shielded metal arc welding

The equipment required for this method is the same as used for manual metal arc welding.

In plant training/project work

Objective: At the end of this lesson you shall be able to
• **prepare utility jobs as per drawings given.**

Project work for students

- 1 Fabrication for metal rack (as per drawing)
- 2 Fabrication of cylinder trolley (as per drawing)
- 3 Fabrication of welding fixture (as per drawing)

Students are expected to write following details in brief and fabricate all above jobs.

- a Project name
- b Material specification and thickness
- c Name of the part (s)
- d Job sequence
- e Skill sequence

f Time availed for completion

g Inspection

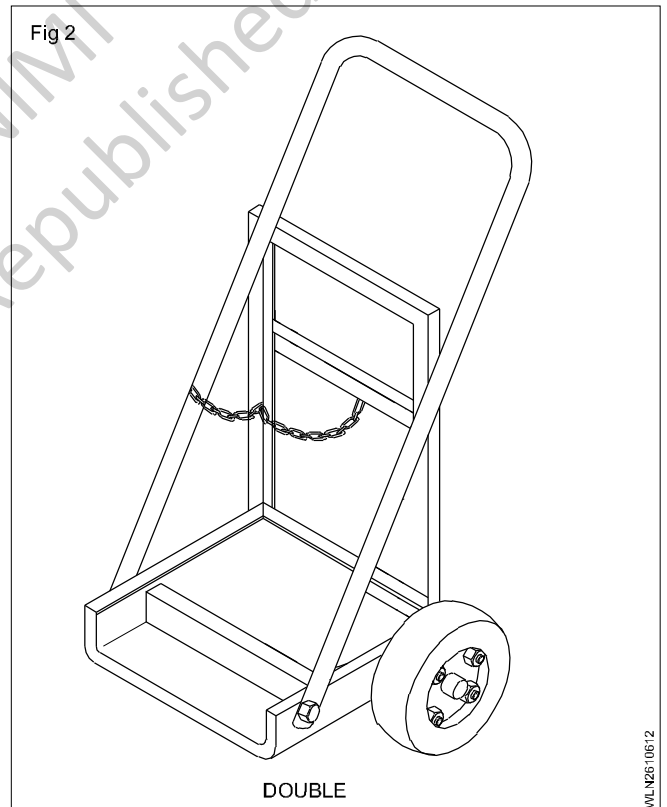
- Visual
- Dimentions
- Fillet sizes etc.

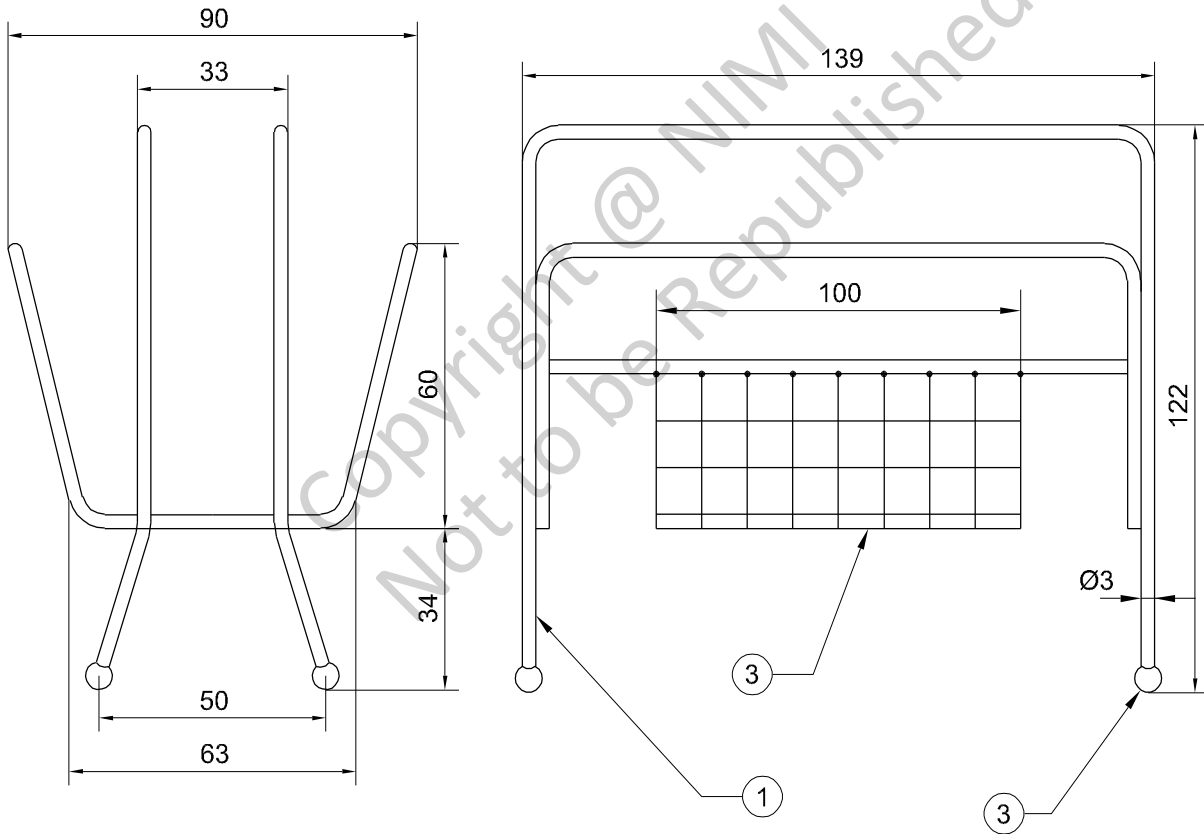
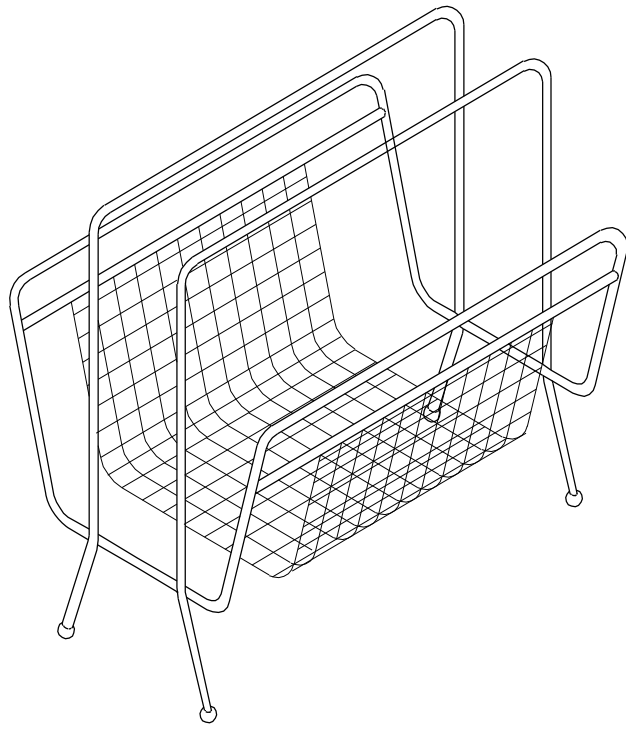
h Method of controlling distortion

k Remarks/assessment

The instructor to guide the further project work for training purpose

Cylinder trolley with chain provision for locking





4	Ø8 BALL		Fe310		3	
1	WELD MESH 100 x 180		Fe310		2	
1	Ø3 - 1800		Fe310 - W		1	G - 65
NO.OFF	STOCK SIZE	SEMI-PRODUCT	MATERIAL	PROJECT NO.	PART NO.	EX. NO.
SCALE		METAL RACK			TOLERANCE	TIME 10 Hrs
					WLN2510418	