“SUITABILITY OF GTAW AND FCAW
OF
HIGH STRENGTH STEEL USED IN AIRCRAFT”

Submitted in partial fulfillment of the requirement

For the award of Degree of

MASTER OF ENGINEERING

In

(Production Engineering)

Submitted by

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CERTIFICATE

This is to certify that the Master of Engineering Major Project entitled "SUITABILITY OF GTAW AND FCAW WELDING OF HIGH STRENGTH STEEL USED IN AIRCRAFT" submitted by Mr. KRISHANA KANT SHUKLA, Department of Mechanical Engineering, Delhi College of Engineering, Delhi University, Delhi, embodies the original work carried out by him under my supervision and guidance. His work has been found excellent for the partial fulfillment of the requirement of the Degree of Master of Engineering in Production Engineering.

The project has been carried out during the session 2006-2007.

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ABSTRACT

30KHGSN2A-VD (RUSSIAN MATERIAL) is an imported alloy steel used in aerospace industry for load bearing parts (CANARD BEAM). This steel has an excellent combination of high strength, impact toughness and ductility .Welding is extensively used as a fabrication process for joining parts made from this material.

Messer's Hindustan Aeronautics Limited (Nasik Division) produces military aircrafts under licensed production from Russia. Canard beam (suspension beam) involves GTAW and FCAW by manual metal arc techniques. A number of instances are encountered where the welding defects exceed the norms specified for correction. (For critical parts, not more than 20 % of seam length can be reworked and also the defective zone cannot be reworked more than twice.) These limitations have been imposed by the original manufacturer i.e. Russia.

In the absence of sufficient data on the effects of welding (since not supplied by the manufacturer), rework is more and costly imported material part is rejected. Whenever it exceeds the norms recommended by the supplier. i.e. rework is more than two times the productivity is lost. Hence this project work is aimed at improve the quality and to provide the methodology for welding of 30KHGSN2A-VD with following guidelines:

(a) Welding of standard test specimen of 30KHGSN2A-VD with GTAW and after welding part is not post heated.

(b) Welding of standard test specimen of 30KHGSN2A-VD with GTAW and after welding part is post heated.

(c) Welding of standard test specimen of 30KHGSN2A-VD with GTAW followed by FCAW and after welding part is post heated.

(d) Comparison of results for the aforesaid.

The experimentation involved in the preparation of standard test specimens with varying treatments is explained. The specimens have been tested subsequently for mechanical and metallurgical properties.

Both destructive as well as non-destructive tests were carried out .Mechanical tests for Ultimate Tensile Strength (UTS), Bend test, were used and ND test of radiography (x-ray) was used for quality control of welded joints.

Metallographic examination was conducted for analysis of Heat Affected Zone (HAZ), Base Metal, Weld Zone and microstructure. The test specimen fabricated and tested as per the Russian standards.

CONTENT

Nomenclature

30	(30/100) % OF CARBON(C)
KH	CHROMIUM(Cr)
G	MANGANESE(Mn)
S	SILICON(Si)
N2	NICKEL (not more than 2%)(Ni)
A	Grade for high quality
VD	VACUUM DEGASSING
s	suplhur
p	phosphorus
°C	degree centigrade
μ	micron
μm	micrometer
mm	millimeter
α	alpha (ferrite iron)
δ	delta iron
γ	gamma (austenite iron)
σb	tensile strength
ΓOST (GOST)	RUSSIAN STANDARD
X	MAGNIFICATION
P	Pearlite

F	Ferrite
TM	Tempered Martensite
RA	Retained Austenite
Ms	Martensite
GTAW	Gas Tungsten Arc Welding
FCAW	Flux Cored Arc Welding

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CHAPTER 1

INTRODUCTION

1.1. About Hal

Hindustan Aeronautics Limited (HAL) came into existence on 1st October 1964. HAL, over the last six decades, has grown progressively into an integrated Aerospace Organization and has spread its wings to cover various activities in the areas of design, development, manufacture and maintenance of advanced fighters, piston and jet engine Trainers, commercial aircraft, helicopters and the associated aero-engines, aircraft systems, equipment and avionics. [1]

Sukhoi Su-30 MKI is a variant of the Sukhoi Su-30, jointly developed by Russia's Sukhoi Corporation and India's Hindustan Aeronautics Limited for the Indian force.

Figure 1.1: Sukhoi Su-30 MKI [2]

In aeronautics, canard is an airframe configuration of fixed wing Aircraft in which the tail plane is ahead of the main lifting surfaces. Canard mean any horizontal airfoil mounted in front of the main wing, whether moving or not. Canards are installed to increase lifting effectiveness and enhance maneuverability of the Aircraft; they are deflected automatically to ensure controllable flight at high angle of attack. [2]

Figure 1.2: CANARD (small wing)[2]

1.2. Welding

Welding is a fabrication process that joins materials, usually metals or thermoplastics, by causing coalescence. This is often done by melting the workpieces and adding a filler material to form a pool of molten material (the weld puddle) that cools to become a strong joint, but sometimes pressure is used in conjunction with heat, or by itself, to produce the weld. This is in contrast with soldering and brazing, which involve melting a lower-melting-point material between the work pieces to form a bond between them, without melting the work pieces.

Many different energy sources can be used for welding, including a gas flame, an electric arc, a laser, an electron beam, friction, and ultrasound. While often an industrial process, welding can be done in many different environments, including open air, underwater and in space. Regardless of location, however, welding remains dangerous, and precautions must be taken to avoid burns, electric shock, poisonous fumes, and overexposure to ultraviolet light. [3]

Figure 1.3: pipe welding [3]

Until the end of the 19th century, the only welding process was forge welding, which blacksmiths had used for centuries to join metals by heating and pounding them. Arc welding and oxyfuel welding were among the first processes to develop late in the century, and resistance welding followed soon after. Welding technology advanced quickly during the early 20th century as World War I and World War II drove the demand for reliable and inexpensive joining methods. Following the wars, several modern welding techniques were developed, including manual methods like shielded metal arc welding, now one of the most popular welding methods, as well as semi-automatic and automatic processes such as gas metal arc welding, submerged arc welding and flux-cored arc welding. Developments continued with the invention of laser beam welding and electron beam welding in the latter half of the century. Today, the science continues to advance. Robot welding is becoming more commonplace in industrial settings, and researchers continue to develop new welding methods and gain greater understanding of weld quality and properties. [3]

1.3. Welding Shop

Aircraft welding is accelerated in HAL Welding shop. There several parts fabricated and welding process is followed strictly as per Russian technology. There are TIG welding, FCAW and Spot welding is available, and heating furnace is also available for preheating and post heating the weld part. Welding of suspension beam (canard SUSPENSION BEAM-su-30) is carried out here. It involves Argon arc welding (TIG) and flux cored arc welding; all the procedure is follow up with safety rules. Quality welding is the main objective of HAL. For this crucial checkups and test performed. Welding of stainless steel and carbon steel materials is the major activity of welding shop.

1.4. Quality Control in Welding Shop

For maintaining Quality in the parts which is to be welded, the experimentation involved starts with the preparation of standard test specimens. Defects are not permitted for the weld of acceptable criteria. After each pass part is sent for quality check. To maintain the quality certain points should be followed:

1. Proper study of technology.
2. Meticulous follow up of technology
3. proper welding
4. Quality control at each stage including x-ray test.
5. Right at the first time with zero defects is less rework.

1.5. Need For The Project

30KHGSN2A-VD is an imported alloy steel used in aerospace industry for load bearing parts. CANARD is made up of 30KHGSN2A-VD and is very CRITICAL part. A number of instances are encountered where the welding defects exceed the norms specified for correction. For critical parts, not more than 20 % of seam length can be reworked and also the defective zone cannot be reworked more than twice.

In the Lack of proper methodology for welding, rework is more and costly imported material made part is rejected. Whenever it exceeds the norms recommended by the supplier. i.e. rework is more then two times the productivity is lost. Hence this project work is aimed at improve the quality and to provide the methodology for welding of 30KHGSN2A-VD.

CHAPTER 2

LITERATURE REVIEW

2.1. General

The emphasis is on the mechanical testing (tensile strength, bend test, hardness) of TIG welding and flux cored Arc welding on carbon-chromium-manganese-silicon-nickel (C-Cr-Mn -Si -Ni) high strength low alloy steel ,and seen the effects of preheating and with and without post heating on high strength steel by comparison of microstructure.

2.2. Existing Studies On High Strength Steels

A series of Cr–Ni alloys were overlaid on a low alloy surface by tungsten inert gas arc welding (TIG) technology. The microstructure of the Cr–Ni surface layers were analysed by means of optical metallography, scanning electron microscopy (SEM)and X-ray diffraction (XRD). The results indicated that when the appropriate TIG parameters were used and Cr25–Ni13 and Cr25–Ni20 alloys were used for the overlaid materials, the Cr–Ni surface layers were crack-free. The matrix of the surface layer wasaustenite (A), pro-eutectoid ferrite (PF), acicular ferrite (AF), carbide-free bainite (CFB) and lath martensite (LM), distributed onthe austenitic grain boundaries as well as inside the grains. The phase constituents of the Cr25–Ni13 surface layer were γ-Fe,Fe3c, an Fe–C compound and an Fe–C–Cr compound. The microhardness of the fusion zone was lower than that ofthe Fe3Al base metal and Cr25–Ni13 surface layer**. [4]**

The application of high-strength steels (HSS) has been growing rapidly in the aircraft industry. Because of their high-strength, thinner sheet metals can be used for body components to achieve both weight savings and increased safety. However, this will lead to greater springback deviation from design after the forming operation. Fundamental understanding and prediction of springback are required for springback compensation and tooling design. While various types of continuum mechanics based models have been proposed to simulate the mechanical behavior of advanced high-strength steels, few of them consider microstructural effects such as material heterogeneity. In this study, through sheet thickness strength variation has been observed in DP 780 andTRIP 780 steels.. This is verified through our experimental work using bend testing. The results suggest that microstructural effects should be considered to accurately simulate springback of HSS. Based on these results, implications of different microstructural designs will be discussed**. [5]**

The selection and use of any method to be used for radiography depends on a number of considerations, these in general being:

a) The size, shape, orientation and distribution of imperfection in the weld.

b) The dimensions, geometry and physical properties of the weld and material.

c) The radiographic sensitivity required by the Standard, Code or Specification.

d) Cost of radiography.

e) The location where the radiography will be carried out.

f) When Se 75 can be used to replace X-ray.

Radiography is suitable for the detection of volume-type flaws. Under assured circumstances it is also suitable for the detection of lack of fusion, cracks and crack-like planar flaws which are oriented in the direction of the radiation beam; however, however it needs to be remembered that the ability of radiography to detect such planar flaws diminishes with unfavourable orientation.

The successful use of radiography depends on the ability of the radiation source, be it x-ray or gamma, to provide sufficient radiation to penetrate the material and produce an image of acceptable contrast and definition on the processed radiographic film, using an acceptable and economic time.

This paper presents the results of various techniques used on selected samples. These samples used contained a variety of flaws. The samples were subjected to radiographic inspection using X-rays, Ir 192 and Se 75 and the use of different classes of film. [6, 16]

Spatially resolved X-ray diffraction (SRXRD) experiments have been performed during gas tungsten arc (GTA) welding of AISI 1045 C-Mn steel at input powers ranging from 1000 to 3750 W. In-situ diffraction patterns taken at discreet locations across the width of the heat-affected zone (HAZ) near the peak of the heating cycle in each weld show regions containing austenite (γ), ferrite and austenite(α-γ), and ferrite (α). Changes in input power have a demonstrated effect on the resulting sizes of these regions. The largest effect is on the α phase region, which nearly triples in width with increasing input power, while the width of the surrounding two-phase α-γ region remains relatively constant. An analysis of the diffraction patterns obtained across this range of locations allows the formation of austenite from the base-metal microstructure to be monitored. After the completion of the transformation, a splitting of the austenite peaks is observed at temperatures between approximately 860 °C and 1290 °C. This splitting in the austenite peaks results from the dissolutionof cementite laths originally present in the base-metal pearlite, which remain after the completion ofthe transformation, and represents the formation of a second more highly alloyed austenite constituent. With increasing temperatures, carbon, originally present in the cementite laths, diffuses from the second newly formed austenite constituent to the original austenite constituent. Eventually, a homogeneous austenitic microstructure is produced at temperatures of approximately 1300 °C and above, depending on the weld input power. [7]

Fusion welds, high-temperature joints were created from alloy 617 base metal The microstructures of all joint types and tensile properties of fusion welds were characterized. Sound fusion welds were created by the Gas-Tungsten Arc

Weld (GTAW) process with alloy 617 filler wire. Cross-weld tensile strengths were equal to the parent metal at temperatures of 25, 800, and 1000°C; ductilities of the joints were only slightly lower than that of the parent metal. Failure occurred in the weld fusion zone at room temperature and in the parent metal at elevated temperatures, believed to be due to tenacious Al and Ti oxide formation. Incompletely bonded butt joints showed relatively poor tensile properties. A second set of braze joints has been created with faying surfaces electroplated with pure Ni prior to brazing; characterization of these joints is in progress. Conditions resulting in good diffusion bonds characterized by grain growth across the bond line and no porosity were determined: vacuum bonding at 1150°C for 3 hours with an initial uniaxial stress of 20MPa (constant ram displacement). A 15 µm thick pure Ni interlayer was needed to achieve grain growth across the bond line. Tensile testing of fusion bonds is in progress. [8]

The most important parameter controlling the transformation plasticity effects in multiphase low alloy steels is the stability of the retained austenite (RA). In this work the thermodynamic stability of the retained austenite has been characterized by the $M_s\sigma$ temperature. A model predicting the $M_s\sigma$ temperature has been developed taking into account the major parameters affecting the stability of RA. Along with the development of this model, the $M_s\sigma$ temperature measured with the Single-Specimen Temperature-Variable Tension-Test technique (SS-TV-TT) taking into account the effect of bainite isothermal transformation (BIT) temperature and time in two low alloy steels in order to determine the effect of heat treatment on the RA stability. The results indicated that the $M_s\sigma$ temperature varies with BIT temperature and time and higher stability of the RA (lower $M_s\sigma$ temperature) was observed for the higher BIT temperature. Additionally, the chemical stabilization of the RA associated with carbon enrichment from the growing bainite is lowered at short BIT times due to carbide precipitation which is comes earlier in the Nb-containing steel. At longer BIT times the RA dispersion becomes finer and its stability rises due to size stabilization. The experimental results are in good agreement with model predictions within the range of anticipated carbon enrichment of the RA and measured austenite particle size. [9]

The aim of this work is to study the effect of the cooling rate on the microstructure and hardness of the melted material of welds in steels AISI304 and AISI316L. The increase of weld heat input, consequently the decrease in the cooling rate produces only a smooth increase of the ferrite content and a small decrease of hardness in the melted material of autogeneous TIG welds. [10]

A reliable detection of defects in welded joints is one of the most important tasks in non-destructive testing by radiography, since the human factor still has adecisive influence on the evaluation of defects on the film. An incorrect classification may disapprove a piece in good conditions or approve a piece with discontinuities exceeding the limit established by the applicable standards. The progresses in computer science and the artificial intelligence techniques have allowed the welded joint quality interpretation to be carried out by using pattern recognition tools, making the system of the weld inspection more reliable, reproducible and faster. In this work, we develop and implement algorithms based on statistical approaches for segmentation and classification of the weld defects. Because of the complex nature of the considered images and so that the extracted defect area represents the most accurately possible the real defect, and that the detected defect corresponds as well as possible to its real class, the choice of the algorithms must be very judicious. In order to achieve this, a comparative study of the various segmentation and classification methods was performed to demonstrate the advantages of the ones in comparison with the others giving to the most optimal combinations. [11]

The microstructures that develop in the high temperature heat-affected zone1 (HT-HAZ) of single pass T.I.G. welded plates of two different low carbon martensitic stainless steels have been investigated using optical microscopy and energy dispersive Xray microanalysis. Particular attention has been given to the presence of retained δ-ferrite in the HT-HAZ. The region containing δ-ferrite was found to be larger in the HAZ of the

Highest alloyed steel. Evidence of former Widmanstätten austenite structure was found in the weld metal and in the grain coarsened heat-affected zone (CG-HAZ) of the highest alloyed steel. [12]

The influence of tempering on the microstructure and mechanical properties of HSLA-100 steel (with C-0.34, Mn-0.87, Cu-1.77, Cr-0.58, Mo-0.57, Ni-3.54, and Nb-.038 pct) has been studied. The plate samples were tempered from 300 8C to 700 8C for 1 hour after austenitizing and water quenching. The transmission electron microscopy (TEM) studies of the as-quenched steel revealed a predominantly lath martensite structure along with fine precipitates of Cu and Nb(C, N). A very small amount of retained austenite could be seen in the lath boundaries in the quenched condition. Profuse precipitation of Cu could be noticed on tempering at 450 8C, which enhanced the strength of the steel significantly (yield strength (YS)—1168 MPa, and ultimate tensile strength (UTS)—1219 MPa), though at the cost of its notch toughness, which dropped to 37 and 14 J at 25 8C and 285 8C, respectively. The precipitates became considerably coarsened and elongated on tempering at 650 8C, resulting in a phenomenal rise in impact toughness (Charpy V-notch (CVN) of 196 and 149 J, respectively, at 25C and 85 C) at the expense of YS and UTS. The best combination of strength and toughness has been obtained on tempering at 600 8C for 1 hour (YS-1015 MPa and UTS-1068 MPa, with 88 J at 85C). [13]

Radiography Film processing and artificial intelligence technologies are applied to the radiographic inspection of weld joint. In this paper, the method of categorization of weld defects is introduced. The senior inspectors often use the specific knowledge acquired from their experiments for the identification weld defects in testing. In this study, two methods are used in conjunction for the categorization of weld defects. One of them is based on the data base of the defect's feature, and the other is based on the knowledge base acquired from interviews with inspectors. It is shown that the results inferred by the expert system compare very well with the inspectors' judgements, and weld defects identification ought to be inferred by using the knowledge obtained from those other than films as well as those obtained directly from a film. [14]

The authors have developed a computer-aided radiographic inspection system for X-ray testing of a weld joint using digital image processing. In this report, a technique is introduced distinguishing a specific weld defect from others in the radiographic image of a weld joint, which is one of the principal functions of this system. In identifying defects, inspectors do not always follow the same procedure but use various kinds of knowledge

obtained from elsewhere than films. Therefore it is very difficult to express the process of defect identification by a procedure-oriented programming language. In this study, experience and knowledge are extracted through interviews with inspectors at first, and then the identification method using artificial intelligence technology is proposed. Although the final goal of this work is the development of a fully automated radiographic inspection system, this paper describes the first stage in which a trial has been made to

categorize defects and classify films. [15]

The use of real-time radiography, radioscopy using X-rays to detect internal flaws in welded joints is described. Radioscopy allows the part under inspection to be moved, enlargement or reduction of the image, image-enhancement techniques and the ability to automate the inspection sequence. The fundamentals of radioscopy and the opportunities it offers in **process** control are outlined. The basic principles of the geometric configuration of X-ray source, part to be inspected and imaging system are discussed. [16]

High-strength, low-alloy (HSLA) steels have nearly the same composition as plain carbon steels. However, they are up to twice as strong and their greater load-bearing capacity allows engineering use in lighter sections. Their high strength is derived from a combination of grain refinement; precipitation strengthening due to minor additions of vanadium, niobium, or titanium; and modifications of manufacturing processes, such as controlled rolling and controlled cooling of otherwise essentially plain carbon steel. HSLA steels are less formable than lower strength steels, but dual phase steels, which evolved from HSLA steels, have ferrite-martensite microstructures and better formability than HSLA steels of similar strength. This improved formability has substantially increased the utilization potential of high-strength steels in the manufacture of complex components. This article reviews the development of HSLA and dual-phase steels and discusses the effects of variations in microstructure and chemistry on their mechanical properties. [

CHAPTER 3

THEORETICAL BACKGROUND

3.1. High Strength Steel (30KHGSN2A-VD)

The steel 30KHGSN2A-VD is widely used in the aircraft industry for the fabrication of load bearing and critical parts ,last few years .The parts for which following strength requirement are necessary, are fabricated from the steel 30KHGSN2A-VD[18]

1 (Tensile strength) σb =160-180 kg/mm^2 .Such tensile strength is obtained with the hardening in oil or isothermal hardening followed by low temperature tempering. Isothermal hardening ensures higher ductility of steel.

2. Auxillary tensile strength σb=140-160 kg/mm^2, it is used for those cases where the heat treatment to σb =160-180 kg/mm^2 is not required, for example when it is designed for stiffness.

With the considerable variation in the dimensions of parts, the range of tensile strength (20 kg/mm^2) may be widened and set it to 160-180 kg/mm^2 .

3. Shear strength for steel 30KHGSN2A-VD may be taken as 0.60-0.68 times of tensile strength.

In spite of the fact, that the steel 30KHGSN2A-VD, heat treated to high strength, has a good combination of tensile strength, impact strength and ductility. While designing the parts and specifying the technology series of specific characteristics, applicable to steel heat-treated to high strength, should be taken into the consideration. Basically is the increased sensitivity towards stress concentration at static and repeated static loads and high sensitivity towards hydrogen brittleness. [18]

The steel 30KHGSN2A-VD is subjected to Argon arc welding (manual and machine) and TIG welding. Welded parts should permit the x-ray inspection . they can be satisfactorily used for fitting works. [19]

In order to avoid the formation of welding cracks parts should be preheated up to 200-300°C and after welding the welded parts should be kept immediately into a furnace at 600-650°C, for 30 min ; then cooling in air . For hardened parts of the simple shape, the temperature may be reduced to 250 °C. The welded parts should be put in the furnace at 650 °C, such that the metal at the welding zone does not cool down quickly below 250 °C. In case when the welded seam is very long, welding should be carried out in several attempts with intermediate heating up to 650°C and cooling in air or the seams should be prevented from cooling during welding by using heating arrangements.

Table 3.1: Chemical Composition of 30khgsn2a (In %)

(30/100)	(G)	(S)	(KH)	(N2)	S	P
C	Mn	Si	Cr	Ni	Not more than	
0.27-0.34	1.00-1.30	0.90-1.20	0.90-1.20	1.40-1.80	0.03	0.03

- **VACUUM DEGASSING**

V.D. is for primarily to control hydrogen containing steels, production of clean steels. A vacuum is created through steam injectors' .pressure as low as 0.5mm of mercury is checked. [20]

The laddle sits in a vacuum tank and stirred by inert gas with provision for heating through electrodes and additions due to this low oxygen, low hydrogen are achieved.

High degree of desurphurisation level with sulphur as low as 0.005%.V.D. is now widely used for producing clean steels in the world. it is also called Vacuum

Arc Degassing or Vacuum Arc Melting. 30KHGSN2A-VD; VD stands for Vacuum Degassing. This particular Russian Grade of steel with a controlled chemistry is manufactured in India for HAL by M/S Mahindra Ugine Steel Company. (MUSCO), PUNE.

This material is not available in another standard; it is special alloy which is developed by Russian .Special steel 30KHGSN2A-VD (cheaper material) is replacing Cr-Mo (costly material) which is exclusively made for Russian aircraft.russia is a country which run special GOST, Now which comes in international standard.

3.2. Arc welding

Arc welding belongs to the liquid state category of welding processes. These involve the melting of the interface between the two workpieces to be welded. The energy supplied to produce the arc is electrical. There are many variations of the basic Arc welding process. Some of these use a consumable electrode. In others, the electrode is used to provide the energy but it is not consumed. [21]

Arc welding belongs to the liquid-state category of welding processes. These involve the melting of the interface between the two work pieces to be welded. The energy supplied to produce the arc is electrical.

There are many variations of the basic Arc welding process. Some of these use a consumable electrode. In others, the electrode is used to provide the energy but it is not consumed. This fact sheet provides information on consumable electrode processes. A separate fact sheet deals with the non-consumable electrode processes

- **Description of the Process**

This welding process uses electricity as the primary energy source, which is converted into heat through an electric arc. The electric arc needs two electrodes to be established. The welding rod or wire is one of the electrodes and the work piece acts as the second electrode. The welding rod may be consumable or non-consumable and may be coated or not coated.

The electrode and the work piece are connected to the electric supply (normally DC) one to the positive pole and the other one to the negative.

The arc produces high temperatures ranging between 5,000°C and 30,000°C depending on the equipment and the gas used. The arc is generated by electrons flowing from the negative pole to the positive. The generated heat melts the electrode and the work piece where it creates a crater filled with molten metal. The electric arc and the magnetic field that it generates helps the transfer of the electrode metal to the work piece. If the molten metal is not shielded, it is exposed to the atmosphere and will absorb oxygen and nitrogen, resulting in a porous and brittle weld. Shielding can be provided by using coated electrodes or by inert gas such as argon, helium. [22]

3.2.1. GTAW (TIG)

The TIG welding process can be applied to almost any type of welding that would normally use the oxyacetylene or oxygen fuel process and the shield arc process. This process can produce strong beads over an extremely wide range of metals. [23] The major joint designs that are used in TIG welding are the square butt joint, the single V- bevel and the double V- bevel. Selection of the proper design for a particular weldment depends upon the chemical properties that are desired in the weld, the type of metal that is used in the base metal etc. Regardless of the joint design incorporated into the weldment, if a good weld is to be made, the base metal must be thoroughly cleaned. When TIG welds must meet rigid specifications, all atmospheric contaminants such as oxygen must be removed from the back side of the weld. [24]

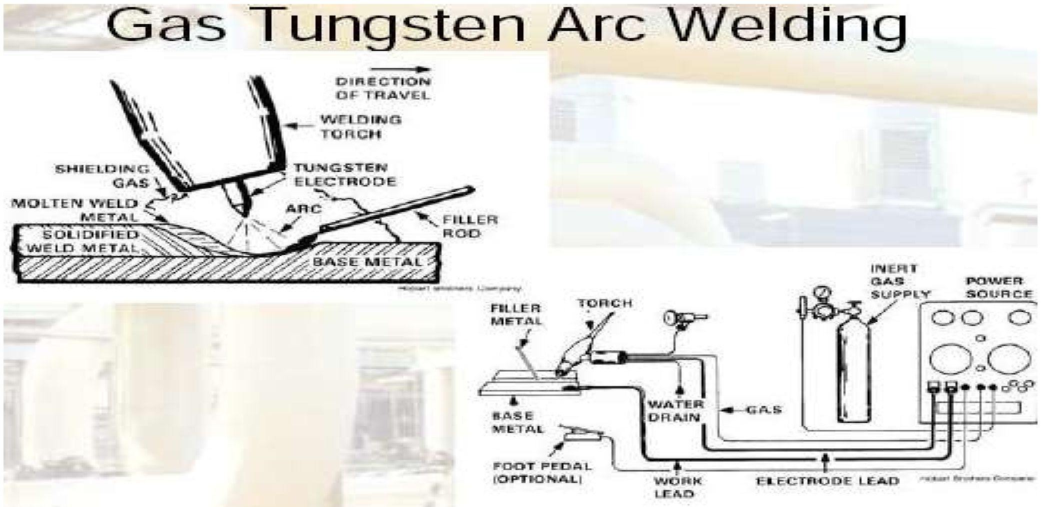


Figure 3.1: TIG welding

TIG welding process can be used for fusion welding of aluminum, magnesium, stainless steel, low alloy steels, high alloy steels, mild steel, monel, inconel, brass, bronze, tungsten, silver, molybdenum and a wide range of other metals. Also, this process can be used to weld many dissimilar metals. The aircraft industry developed the GTAW process for welding Magnesium during the late 1930s and early 1940s. During that time Helium was the primary shielding gas used along with DCEP welding current. Since hot Tungsten is sensitive for oxygen in the air, good shielding with oxygen free gases is required. When Argon became plentiful and DCEN was recognized as more suitable than DCEP, the GTAW process became more common. Tungsten, atomic symbol W, has the following properties:

- High Tensile Strength (3447 kg/m^2)
- Hardness, Rockwell C 45
- High Melting Temperature (3140 °C)
- High Boiling Temperature (5630 °C) and
- Good Electrical Conductivity.

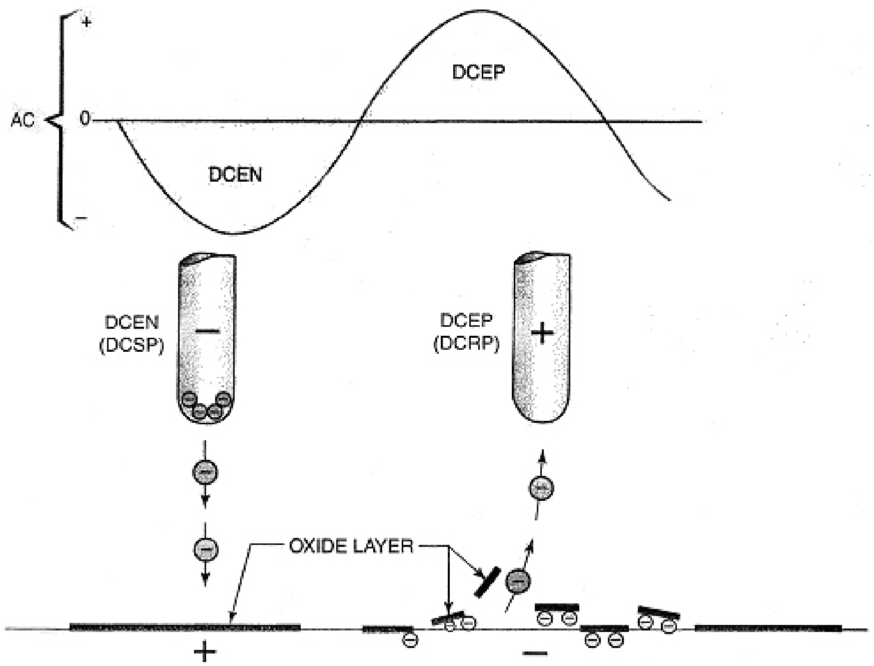


FIGURE Electrons collect under the oxide layer during the DCEP portion of the cycle and lift the oxides from the surface.

Figure 3.2: Electron collect under the oxide layer during the DCEP in GTAW. [24]

Because of the intense heat of the arc some erosion of the electrode will occur. This eroded metal is transferred across the arc slow erosion of the electrode results in limited tungsten inclusions in the weld, which are acceptable. The tungsten inclusions are hard spots that cause stress to concentrate, possibly resulting in weld failure. A few ways of limiting erosion include:

- Using as low a current as possible
- Using a water cooled torch
- Using as large a size of tungsten as possible
- Using DCEN current and
- Using an alloy tungsten electrode.

The torch end of the electrode is tightly clamped in a collet. Again, large diameter electrodes conduct more current because the resistance heating effects are reduced. In general, the current carrying capacity at DCEN is about ten times greater than that in DCEP. With AC, the tip is subjected to more heat than with DCEN. For GTAW, tungsten electrodes are classified as

- Pure Tungsten
- 1% Thoriated Tungsten
- 2% Thoriated Tungsten
- ¼ % to ½ % Zirconium Tungsten
- 1%Lanthanum Tungsten.

Thorium oxide, when added in percentages up to 0.6%, to tungsten improves its current carrying capacity. These also provide a much easier arc starting characteristics than pure or zirconiated tungsten. These work well with DCEN. They can maintain a sharpened point well.[25] They are very well pointed for making weld on steel, steel alloys(including stainless), nickel alloys and most other metals other than Al or Mg. Thoriated does not work well with AC. Thorium is a very low level radioactive oxide, ZrO_2 electrodes can be used with both AC and DC . Zirconiated tungsten are more resistant to weld pool contamination than pure tungsten. These are not radioactive. Cerium tungsten has an improved arc starting and arc stability characteristics similar to thoraited tungsten. These works with slightly higher voltage may be used for both AC and DC welding currents. The major differences among the currents are in their heat distribution and the presence of degree of arc cleaning. Fig 3.2. Shows the heat distribution for each of three types of currents. [23]

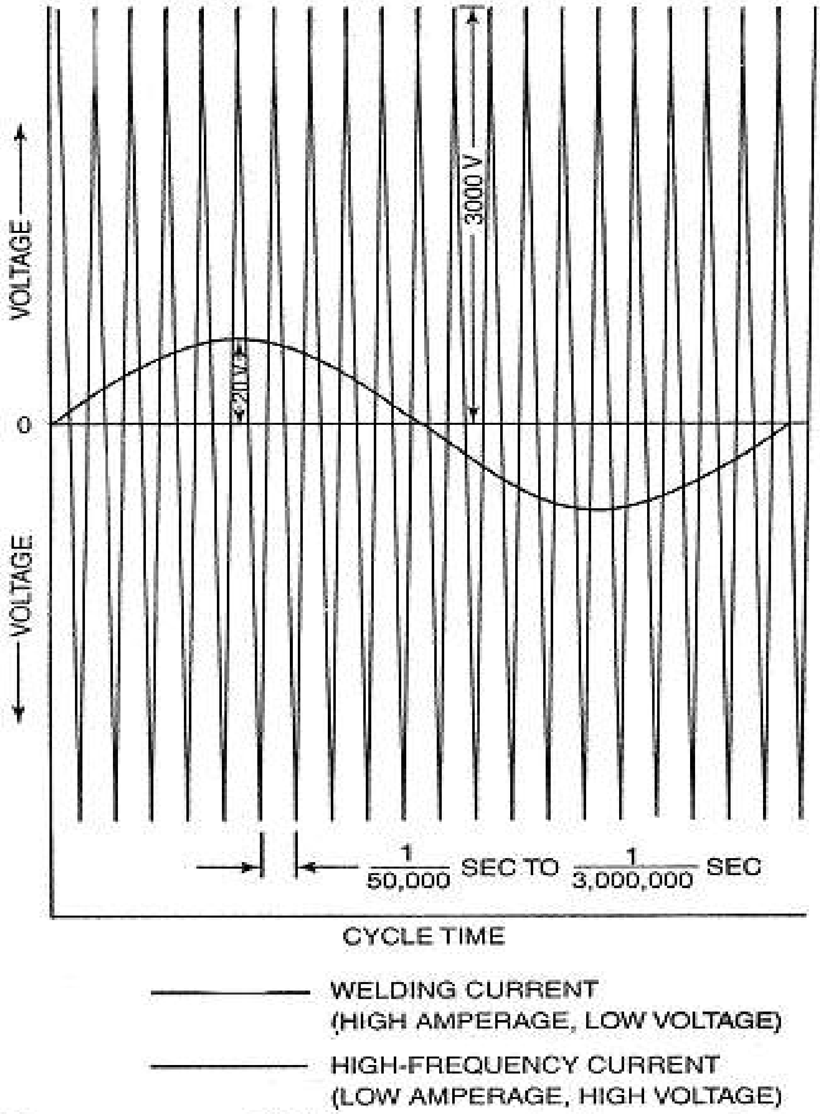


FIGURE High frequency arc starting current shown over the low frequency welding current.

Figure 3.3: Low Frequency Welding Current [24]

AC concentrates about half of its heat on the work and the other half on the tungsten. Referring to fig. 3.3, the current is at its maximum peak at points A & B. The rate gradually decreases until it stops at points C &D. The arc at these points is extinguished and as the current reversal begins, must be reestablished. This event requires the emission of electrons from the cathode to ionize the plasma. When the hot emissive electrode becomes the cathode, reestablishing the arc is easy. However it is often quite difficult to reestablish the arc when the colder and less emissive workpiece becomes the cathode. Because voltage from the power supply is designed to support a relatively low voltage arc, it may be insufficient to initiate electron flow. Thus, a voltage assist from another source is needed. A high voltage but low current spark gap oscillator commonly provides the assist at a relatively low cost. The high frequency ensures that a voltage peak will occur reasonably close to the current reversal in the welding arc, creating a low-resistance ionized path for the welding current to follow. This same device is often used to initiate direct current arcs, a particularly used technique for mechanized welding.

The high – frequency current is established by capacitor discharging across a gap set on points inside the machine. Changing the point gap setting will change the frequency of the current. The closer the points are, the higher the frequency; the wider the spacing between the points, the lower the frequency. The voltage is stepped up with a transformer from the primary voltage supplied to the machine. The available amperage to the high-frequency circuit is very low. Thus, when the circuit is complete, the voltage quickly drops to a safe level. The high frequency is induced on the primary welding current in a coil. [26]

The high frequency may be set so that it automatically cuts off after the arc is established, usually with DC. It is used as a continuous current with AC. When it is used in this manner, it is referred to as alternating current, high frequency stabilized, or ACHF.

- **Advantages of GTAW:-**

The combination of GTAW for root pass welding with either shielded metal arc (SMA) or gas metal arc (GMA) welding for fill passes is particularly advantageous for pipe. [21]The GTAW process is especially effective in producing quality root passes. Some of the major benefits of the process are as follows:

1. Produces quality welds
2. Free of spatter
3. Can be used with or without filler metal
4. Excellent control of root pass joint penetration
5. Produces inexpensive autogeneous welds
6. Uses economical power sources
7. Precise control of welding variables
8. Very good for joining thin base metals
9. Especially good for joining Al & Mg, both of which form hard refractory oxides
10. Very useful process for joining reactive metals such as Titanium
11. Filler metal additions and heat source can be controlled independently.

- **Process Limitations:-**

Effective gas shielding is required with this process. The basic requirement tends to limit the process to indoor applications, although with proper shielding techniques, it can be used outdoors. Some limitations are as follows:-

1. Deposition rates are low compared to process with consumable electrodes
2. There is a need for more dexterity and co-ordination for manual welding than with other arc processes
3. Shielding the weld zone is difficult if there are drafty conditions

- **Potential Problems**

1. If the electrode is allowed to touch the weld pool or becomes overheated, pieces of Tungsten may become embedded in the weld creating problems [24]
2. The weld metal may become contaminated if the filler metal is not properly shielded by the gas stream or if the shielding gas does not properly protect the weld pool
3. There is low tolerance for contaminants on filler metal and base metals

4. Possible contamination or porosity be caused by leakages from cooler torches
5. Arc blow can be a concern.

- **Electrode Configuration, Contamination & Dust Precautions**
  1. The shape of the Tungsten electrode tip is an important variable
  2. With AC welding pure or Zirconiated Tungsten electrodes form a hemispherical balled end
  3. Thoriated, ceriated and lanthanated tungsten electrodes do not ball as readily and they are typically used with DC. For these electrodes the end is typically beveled to a conical shape, with a specific included angle.
  4. Electrode tip geometries affected the weld bead shape and size. Typically as the included angle increases, weld penetration increases and the width of the weld bead decreases.
  5. Metal contamination of the Tungsten electrode is most likely to occur when a welder accidentally dips the tungsten into the molten weld pool or touches the tungsten with the filler metal.[24]
  6. The tungsten electrode may also become oxidized by use of an improper shielding gas, insufficient gas flow, or leaking fittings, or gas nozzle.
  7. When the tungsten electrode becomes contaminated, the welding operation should be stopped and the contaminated portion cut off and the electrode properly dressed.[27]
  8. Sharpening the tungsten electrode generates metal dust, which can be a health hazard. Transparent eye shields, dust extractors and filters should be used. A vacuum or exhaust system should be used.[21]

3.2.1.1.Shielding Gases

The Shielding gases used for the GTAW process are:

- Argon
- Helium
- Hydrogen
- Nitrogen
- Mixture of two or more of these gases

The purpose of the shielding gas is to protect:

1. The molten weld pool and tungsten electrode from the harmful effects of air
2. The shielding gas also affects the amount of heat produced by the arc and resulting weld bead appearance

Argon and helium are noble inert gases. Ar and He may be found in mixtures but never as compounds. [24]

- **Argon**

1. It is a by-product in air separation plants
2. It is distributed in cylinders as gas or in bulk as liquid forms
3. It is denser than air and effectively shields weld in deep grooves in the flat position
4. Because of higher density in overhead position higher flow rate are necessary
5. It is relatively easy to ionize, suitable for AC applications and easier starts
6. Permit fairly long arcs at lower voltages and is to changes in arc length

- **Helium**

1. It is a by-product of the natural gas industry
2. It offers the advantages of deeper penetration
3. GTAW with He is especially by effective for welding aged aluminum alloys prone to overaging
4. It also is very effective at high welding speeds, as for tube mills
5. But it is less forgiving for manual welding
6. With He penetration and bead profile are sensitive to the arc length
7. He has been mixed with Ar to gain combined benefits of cathode cleaning and deeper penetration
8. It is difficult to ionize, flow rate must be more, AC arcs are very unstable

- **Hydrogen**

1. Not used as primary shielding gas

2. can be added with Argon when deep penetration and high welding speeds are needed
3. Improves welds surface cleanliness and bead profile on some grades of SS that are very sensitive to oxygen
4. Causes porosity in aluminum welds
5. Can cause porosity in carbon steels

Argon-Helium Mixtures Are Used Also Because: [23]

Argon provides greater coverage of the weld pool at low flow rates. Combination of Ar and He are widely used for automatic welding and are available in various percentages in cylinders

- Argon-Hydrogen mixtures frequently are used to weld stainless steel, Inconel and Monel alloys and in applications where porosity is problem
- The purpose of Ar-H_2 mixtures is to increase the welding speed and help control weld bead profile
- Ar- H_2 mixtures are not suitable for plain carbon or low alloy steel applications
- SS can be welded with mixtures containing upto 15% H_2
- The most common Ar- H_2 mixture are 95%Ar-5% H_2 or 85% Ar-15%H_2

Cylinder Gas Contamination: [21]

To prevent contamination of inert gas cylinders with other gases the user is requested to have a certain residual pressure in the cylinder at all times usually a residual pressure of 25 psi (1.754×10^{-2} kg/mm^2) is sufficient.

- Hoses and connections must be thoroughly checked against bakage. Every care must be taken to ensure that the pure gas from the cylinder is coverage to the weld pool
- The system must be completely leak proof
- If commercial grade Ar or He is used for welding, the residual gases in the cylinders contaminate the weld pool

3.2.1.2.Gas Flow: [27]

The minimum flow of gas required for maintaining adequate and effective coverage of the welding area is influenced by the following variables:

- Shielding gas
- Distance of gas-nozzle orifice from the work surface
- Design of the weld joint
- Size of gas nozzle
- Shape of gas nozzle
- Size of weld pool
- Amount of welding current
- Presence of drafts or wandering air current
- Inclination of the torch
- Arc length
- Welding speed
- Position of work piece
- Metal or alloy being welded

3.2.1.3.Filler Metals Prefer: [25]

- The selection of proper metal is based primarily on the composition of the base metal being welded
- Closer control of composition purity and quality is exercised for filler metals than for base metals
- Choice of a filler metal depends on the proposed application. Other consideration in the choice of a filler metal include
- Tensile properties and notch toughness
- Electrical and thermal conductivity
- Corrosion resistance
- Weld appearance
- Deoxidizers may be added to improve weld soundness

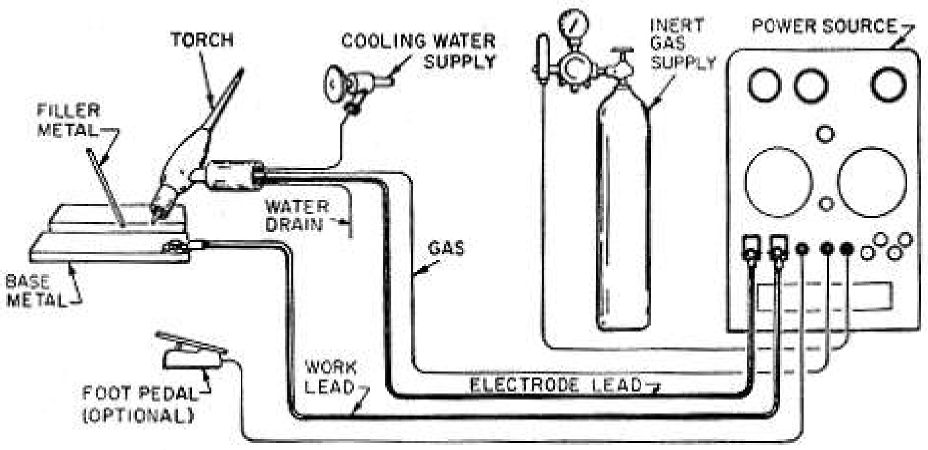


Figure 3.4: welding set up in GTAW [24]

3.2.1.4.Variations of the Process

There are a number of variations of the GTAW process. The most popular of these are:

- Pulsed GTAW
- Manual Programmed GTAW
- Hot Wire GTAW
- Gas Tungsten Arc Brazing
- Gas Tungsten Arc Cutting
- Gas Tungsten Arc Spot welding

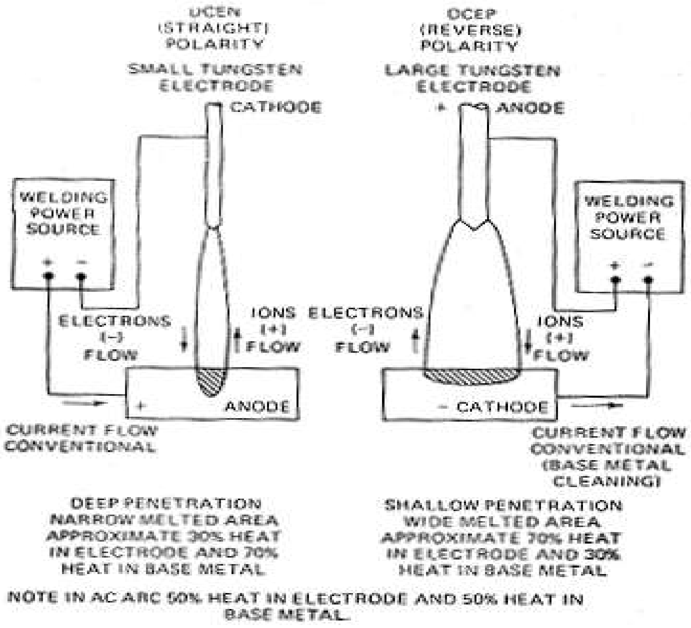


Figure 3.5: mode in AC arc welding. [24]

The most popular variation of this process is known as Pulsed GTAW. This model of welding is primarily a way to control heat input. It offers a number of advantages over conventional or steady current welding as follows: [24]

- Control puddle-size and fluidity (especially out of position)
- Increased penetration
- Oscillation travel and dwell control.
- Travel speed control
- Better consistent quality

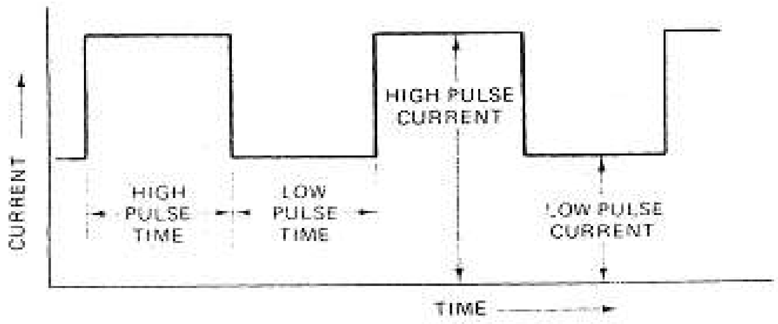


FIGURE *Pulsed current time and current relationship.*

Figure 3.6: Pulsed Current Time And Current Relationship. [24]

In conventional GTAW the amount of welding current at the arc or heat input are essentially the same. The pulsed current mode provides a system in which welding current continually changes between two levels.

During the periods of high pulsed current heating and fusion takes place and during the low-pulse current periods, cooling and solidification takes place.

There are four factors that must be considered and controlled in order to successfully weld with the pulsed current mode. These are:

- High-pulse Current or Pulse Current – The welding current during the high-pulse time period.
- Low-pulse Current or Background Current – The current during the low-pulse time period.
- High-pulse time – The time period or duration of high pulse current.
- Low-pulse time – The time period or duration of low pulse current.

3.2.2. Flux-cored arc welding (FCAW)

Flux-cored arc welding is a semi-automatic or automatic arc welding process. FCAW requires a continuously-fed consumable tubular electrode containing a flux and a constant voltage or, less commonly, a constant electric current welding power supply. An externally supplied shielding gas is sometimes used, but often the flux itself is relied upon to generate the necessary protection from the atmosphere. The process is widely used in construction because of its high welding speed and portability. [28]

FCAW was first developed in the early 1950's as an alternative to shielded metal arc welding (SMAW). The advantage of FCAW vs. SMAW is that the use of stick electrodes (like those used in SMAW) was unnecessary. This helped FCAW to overcome many of the restrictions associated with SMAW

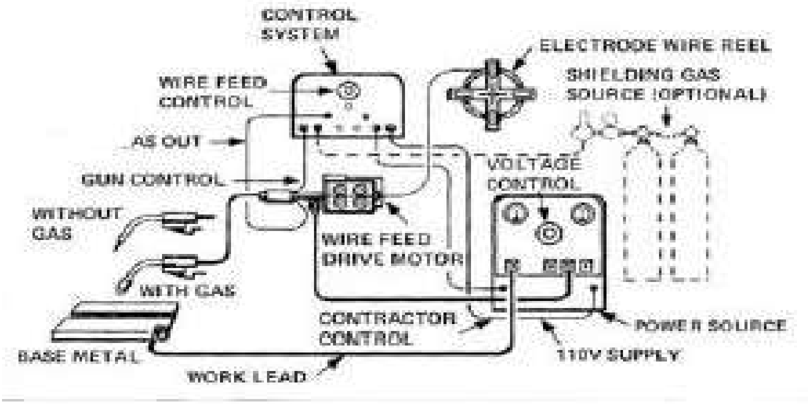


Figure 3.7: FCAW Setup [24]

- **Two Types of FCAW**

The first type of FCAW is the type that requires no shielding gas. This is made possible by the flux core in the tubular consumable electrode. However, this core contains more than just flux; it also contains various ingredients that when exposed to the high temperatures of welding generate a shielding gas for protecting the arc. This type of FCAW is preferable because it is portable and has excellent penetration into the base metal. Also, the conditions of air flow do not need to be considered. [21]

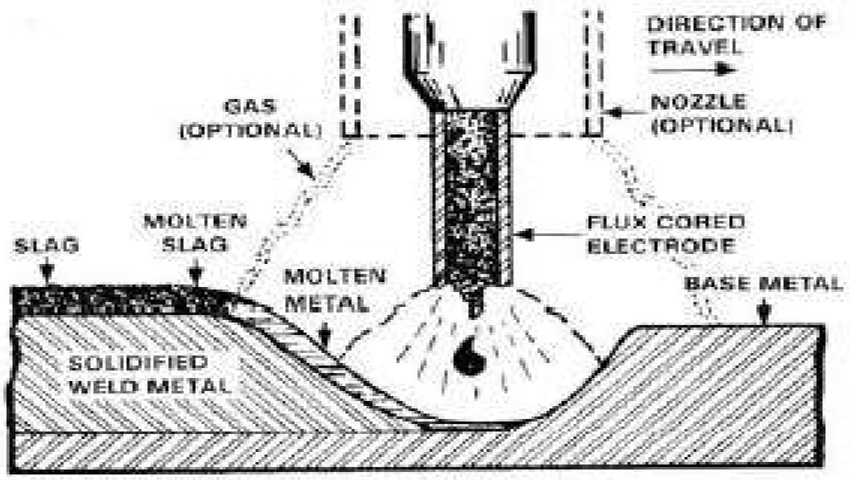


Figure 3.8: FCAW welding [21]

The second type of FCAW actually uses a shielding gas that must be supplied by an external supply. This type of FCAW was developed primarily for welding steels. In fact, since it uses both a flux cored electrode and an external shielding gas, one might say that it is a combination of gas metal (GMAW) and flux-cored arc welding (FCAW). This particular style of FCAW is preferable for welding thicker and out-of-position metals. The slag created by the flux is also easier to remove. However, it cannot be used in a windy environment as the loss of the shielding gas from air flow will produce visible porosity (small craters) on the surface of the weld. [21]

➢ FCAW key process variables

- Wire feed speed (and current)
- Arc voltage
- Electrode extension
- Travel speed

- Electrode angles

- Electrode wire type

- Shielding gas composition (if required) Note: FCAW wires that don't require a shielding gas commonly emit fumes that are **extremely** toxic; these require adequate ventilation or the use of a sealed mask that will provide the welder with fresh air.

➢ FCAW advantages and applications

- FCAW may be an "all-position" process with the right filler metals (the consumable electrode)

- No shielding gas needed making it suitable for outdoor welding and/or windy conditions

- A high-deposition rate process (speed at which the filler metal is applied)

- Some "high-speed" (e.g., automotive applications)

- Less precleaning of metal required

- Metallurgical benefits from the flux such as the weld metal being protected initially from external factors until the flux is chipped away

- Low operator skill is required

Used on the following alloys:

- Mild and low alloy steels

- Stainless steels

- Some high nickel alloys

- Some wearfacing/surfacing alloys

- **FCAW disadvantages**

Of course, all of the usual issues that occur in welding can occur in FCAW such as incomplete fusion between base metals, slag inclusion (non-metallic inclusions), and cracks in the welds, etc . . . But there are a few concerns that come up with FCAW that are worth taking special note of: Melted Contact Tip – happens when the electrode actually contacts the base metal, thereby fusing the two

- Irregular wire feed – typically a mechanical problem

- Porosity – the gases (specifically those from the flux-core) don't escape the welded area before the metal hardens, leaving holes in the welded metal

- More costly filler material/wire as compared to GMAW

- Less suitable for applications that require painting, such as automotive body work

- **Basic Electrodes (Russian standard)[29]**

BASIC ELECTRODES

УОНИ-13/45 (UONI-13/45)

ГОСТ 342A, ISO E434B20,
DIN E4340B10, EN E35AB22H10

Basic electrodes are employed for welding structures of mild and low carbon steels where welds of higher ductility and impact properties are required. Welding in all positions except vertical-down can be used. Suitable for welding at DC(+) current.

Type of electrode - basic.
Deposition rate factor - 9,5 g/A·h.
Efficiency of deposition (for dia 3,0 mm) - 1,3 kg/h.
Consumption of electrodes per kg deposited metal - 1,6 kg.

Typical all weld metal chemical analysis, %

C 0,09   Mn 0,57
Si 0,23   S 0,025
P 0,027

Typical all weld metal mechanical properties

Tensile strength, MPa 460
Yield strength, MPa 350
Elongation, % 26
Impact values (U-notch specimen), Joule/sm^2 200

Special properties

Welds has good cracking resistance and low hydrogen contents. UONI-13/45 sometimes is used for making root pass in welding of higher tensile strength steels to prevent cracking in root bead.

Technological features of welding process

Keeps arc short, clean and dry edges of base metal before welding. Dry electrodes before welding at 250-300°C for one hour.

Dia, mm	Length, mm	Current range, A
2,0	300	40-80
2,5	350	50-100
3,0	350	60-130
4,0	450	110-180
5,0	450	130-220

Approvals

GOST R, UkrSEPRO, Russian River Register, GOSATOMNADZOR

УОНИ-13/55К (UONI-13/55К)

ГОСТ 346A, ISO E433B20H,
DIN E4330B10H,
EN E38AB22H10

Electrodes are employed for welding of hard structures of carbon and low alloyed steels where difficult stress conditions cannot be avoided. Electrodes are suitable for welding of different machine's structures where high resistance to shock variable loads at low temperatures are required. Electrodes are easy to handle in all positions except vertical-downward. Welding at DC(+) current is used.

Type of electrode - basic.
Deposition rate factor - 9,5 g/A·h.
Efficiency of deposition (for dia 4,0 mm) - 1,3 kg/h.
Consumption of electrodes per kg deposited metal - 1,6 kg.

Typical all weld metal chemical analysis. %

C 0,06   Mn 0,58
Si 0,24   S 0,016
P 0,024

Typical all weld metal mechanical properties

Tensile strength, MPa 490
Yield strength, MPa 400
Elongation, % 28
Impact values (U-notch 230

Special properties

Weld metal has excellent resistance to hot and cold cracking and low hydrogen contents.

Technological features of welding process

Keep welding arc short as possible, clean and dry edges of base metal before welding. Dry electrodes before use at 250-300°C for one hour.

Dia, mm	Length, mm	Current range, A
3,0	350	60-130
4,0	450	100-180
5,0	450	140-220

Approvals

GOST R, Russian Maritime Register of Shipping

УОНИ-13/55 (UONI-13/55)

ГОСТ 350A, AWS E7015,
ISO E514B20, DIN E5140B10,
EN E380B22H10

UONI-13/55 is insensitive to the composition of the base material within rather wide limits. The electrode can be used for welding of carbon and low alloyed steels with tensile strength up to 490 MPa where difficult stress conditions cannot be avoided and weld metal has ductility and impact values. Welding in all positions except vertical-down at DC(+) current can be used.

Type of electrode - basic.
Deposition rate factor - 9,5 g/A·h.
Efficiency of deposition (for dia 4,0 mm) - 1,4 kg/h.
Consumption of electrodes per kg deposited metal - 1,7 kg.

Typical all weld metal chemical analysis. %

C 0,09   Mn 0,83
Si 0,42   S 0,022
P 0,024

Typical all weld metal mechanical properties

Tensile strength, MPa 540
Yield strength, MPa 410
Elongation, % 29
Impact values (U-notch specimen), Joule/sm^2 260

Special properties

Excellently smooth and slag-free welds. Crack resistant deposits of high toughness. Low hydrogen contents in the deposit.

Technological features of welding process

Welding with short as possible arc on cleaned adges of base metal is used. Dry the electrodes before welding at 250-300°C for one hour.

Dia, mm	Length, mm	Current range, A
2,0	300	40-90
2,5	350	50-100
3,0	350	60-130
4,0	450	100-180
5,0	450	140-210

Approvals

GOST R, UkrSEPRO, Russian Maritime Register of Shipping, Lloyd's Register of Shipping, "Moscow Quality", Russian River Register, GOSATOMNADZOR

- **Flux [29]**

ГОСТ 946, AWS E6012,
ISO E433AR24, DIN E4330AR7,
EN E38AR12

Rutile-ilmenite electrodes are employed of welding of carbon steels with carbon contents ≤0,25%. Welding in all positions except vertical-down can be used. Suitable for welding at DC(±) or AC current. The open circuit is not less 65 V.

Type of electrode - rutile-ilmenite.
Deposition rate factor - 8,5 g/A·h.
Efficiency of deposition (for dia 4,0 mm) - 1,7 kg/h.
Consumption of electrodes per kg deposited metal - 1,7 kg.

Typical all weld metal chemical analysis, %

C	0,11	Mn	0,35
Si	0,17	S	≤0,040
P	≤0,040		

Typical all weld metal mechanical properties

Tensile strength, MPa	471
Yield strength, MPa	373
Elongation, %	20
Impact values (U-notch specimen), Joule/sm^2	150

Special properties

Electrodes are used for welding of wet, rust and bad cleaned metal, have high efficiency of welding.

Technological features of welding process

Welding of middle or big cross sections of weldments can be used at higher welding currents with bend forward electrode in the direction of welding. Welding must be done at medium length of arc. Dry electrodes before welding at 140-180°C for half an hour.

Dia, mm	Length, mm	Current range, A
3,0	350	80-140
4,0	450	120-170
5,0	450	130-240

Approvals

GOST R, UkrSEPRO

ГОСТ 946, AWS E6013,
ISO E432R12, DIN E4330R3,
EN E38AR12

General purpose electrode for welding of complicated structures of mild and carbon steel with tensile strength up to 450 MPa. Welding in all positions at DC (±) or AC current is used.

Type of electrode - rutile.
Deposition rate factor - 8,5 g/A·h.
Efficiency of deposition (for dia 4,0 mm) - 1,2 kg/h.
Consumption of electrodes per kg deposited metal - 1,7 kg.

Typical all weld metal chemical analysis, %

C	0,09	Mn	0,60
Si	0,15	S	0,017
P	0,026		

Typical all weld metal mechanical properties

Tensile strength, MPa	510
Yield strength, MPa	420
Elongation, %	25
Impact values (U-notch specimen), Joule/sm^2	137

Special properties

Easy to handle electrode in all positions of tack welding and joint welding for all branches of sheet metal fabrication and pipe line construction. Very suitable for welding with low amperage from small (home) transformers. Extraordinarily good efficiency in welding of concave fillets and rust edged metal.

Technological features of welding process

Electrodes are suitable for welding in wide range of arc length and easy to strike and restrike, slag is easy to remove. Dry electrodes before welding at 150-180°C; 0,5 hour.

Dia, mm	Length, mm	Current range, A
2,0	300	30-90
2,5	350	50-110
3,0	350	70-130
4,0	450	110-180
5,0	450	130-220

Approvals

GOST R, UkrSEPRO, Lloyd's Register of Shipping, Russian Maritime Register of Shipping, "Moscow Quality", Russian River Register

ГОСТ 946, AWS E6012,
ISO E433AR24, DIN E4330AR7

Electrodes for welding of structures of mild stees with tensile strength up to 410 MPa in all positions at AC and DC(-).

Type of electrode - ilmenite.
Deposition rate factor - 8,5 g/A·h.
Efficiency of deposition (for dia 4,0 mm) - 1,7 kg/h.
Consumption of electrodes per kg deposited metal - 1,7 kg.

Typical all weld metal chemical analysis, %

C	0,10	Mn	0,55
Si	0,09	S	0,024
P	0,034		

Typical all weld metal mechanical properties

Tensile strength, MPa	500
Yield strength, MPa	420
Elongation, %	27
Impact values (U-notch specimen), Joule/sm^2	100

Special properties

Electrodes can be used for welding of rustand bad cleaned metal.

Thechnological features of welding process

Welding must be done at medium length of arc. Dry electrodes before use at 140-180°C for 0,5 hour.

Dia, mm	Length, mm	Current range, A
3,0	350	80-150
4,0	450	110-230
5,0	450	130-280

Approvals

GOST R

- **Types of electrode[29]**

ГОСТ 346, AWS E7024,
ISO E432RR16046,
DIN E4320RR11160,
EN E38ARR74

A very fast high efficiency rytile iron powder electrode giving a metal recovery of approx. 180%. Particularly suitable for fillet welds on mild steel with tensile strength up to 450 MPa. Can be used for welding only in flat position on AC or DC(+) current.

Type of electrode - rutile.
Deposition rate factor - 15,0 g/A·h.
Efficiency of deposition (for dia 4,0 mm) - 3,3 kg/h.
Consumption of electrodes per kg deposited metal - 1,3 kg.

Typical all weld metal chemical analysis, %

C .... 0,10 Mn 0,60
Si .... 0,20 S 0,030
P 0,030

Typical all weld metal mechanical properties

Tensile strength, MPa 490
Yield strength, MPa 390
Elongation, % 27
Impact values (U-notch specimen), Joule/sm^2 140

Special properties

The electrode is very easy to strike and is ideal for short welds. OZS-3 gives smooth weld beads, and slag is easy to remove.

Technological features of welding process

Keep arc short as possible with touching tip of the electrode to the molten pool. Dry electrodes at 150-170°C for one hour.

Dia, mm	Length, mm	Current range, A
3,0	350	150-210
4,0	450	180-240
5,0	450	240-320

Approvals

GOST R

ГОСТ 346, AWS E6020,
ISO E430RR12023,
DIN E4300RR11120,
EN E38ARR32

Electrode with metal powder in coating for welding of mild steel of tensile strength up to 450 MPa. Suitable for welding in all positions except vertical-downward. Welding at AC or DC(+) current.

Type of electrode - rutile.
Deposition rate factor - 10,0 g/A·h.
Efficiency of deposition (for dia 4,0 mm) - 1,8 kg/h.
Consumption of electrodes per kg deposited metal - 1,5 kg.

Typical all weld metal chemical analysis, %

C .... 0,10 Mn .... 0,55 Si 0,16
S .... 0,020 P 0,030

Typical all weld metal mechanical properties

Tensile strength, MPa 480
Yield strength, MPa 390
Elongation, % 26
Impact values (U-notch specimen), Joule/sm^2 120

Special properties

Excellently smooth and slag-free welds. Easy to weld base metal with rusted edges. OZS-6 is easy to strike and restrike and is therefore an ideal electrode for tacking.

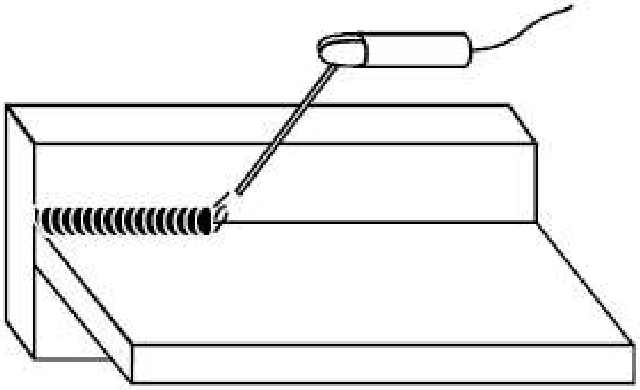
Technological features of welding process

Easy handling in all positions. Welding can be used in wide range of arc length. Slag is easy to remove. Dry electrodes before welding at 150-180°C for 0,5 hour.

Dia, mm	Length, mm	Current range, A
3,0	350	60-130
4,0	450	100-210
5,0	450	150-280

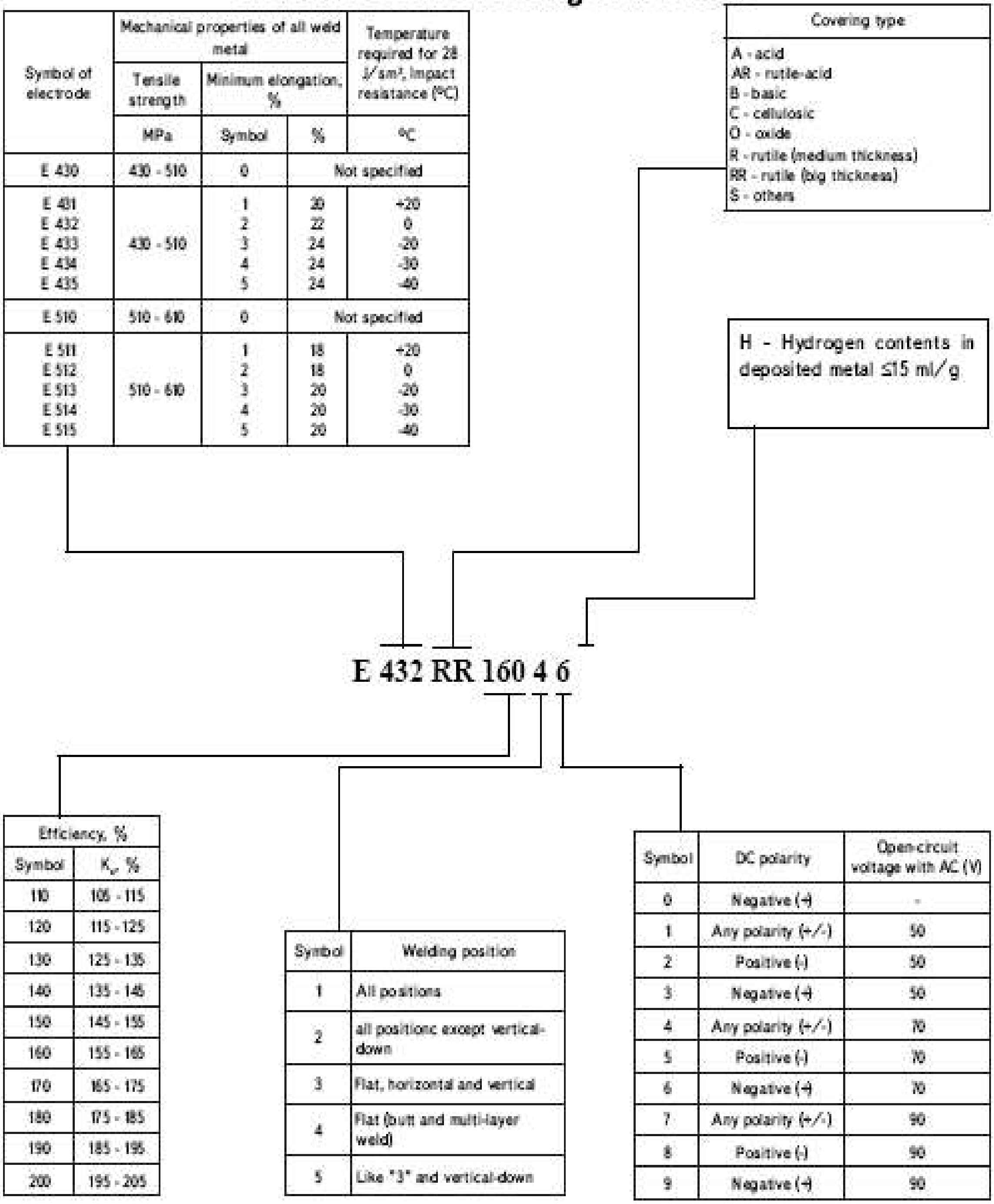
Approvals

GOST R, UkrSEPRO, GOSATOMNADZOR



- **Classification of electrode[29]**

Classification of Electrodes for Welding of Carbon and low Alloyed Structure Steels According to ISO 2560



Symbol of electrode	Mechanical properties of all weld metal			Temperature required for 28 J/sm², Impact resistance (ºC)
	Tensile strength	Minimum elongation, %		
	MPa	Symbol	%	ºC
E 430	430 - 510	0	Not specified	
E 431 E 432 E 433 E 434 E 435	430 - 510	1 2 3 4 5	20 22 24 24 24	+20 0 -20 -30 -40
E 510	510 - 610	0	Not specified	
E 511 E 512 E 513 E 514 E 515	510 - 610	1 2 3 4 5	18 18 20 20 20	+20 0 -20 -30 -40

Covering type

A - acid
AR - rutile-acid
B - basic
C - cellulosic
O - oxide
R - rutile (medium thickness)
RR - rutile (big thickness)
S - others

H - Hydrogen contents in deposited metal ≤15 ml/g

E 432 RR 160 4 6

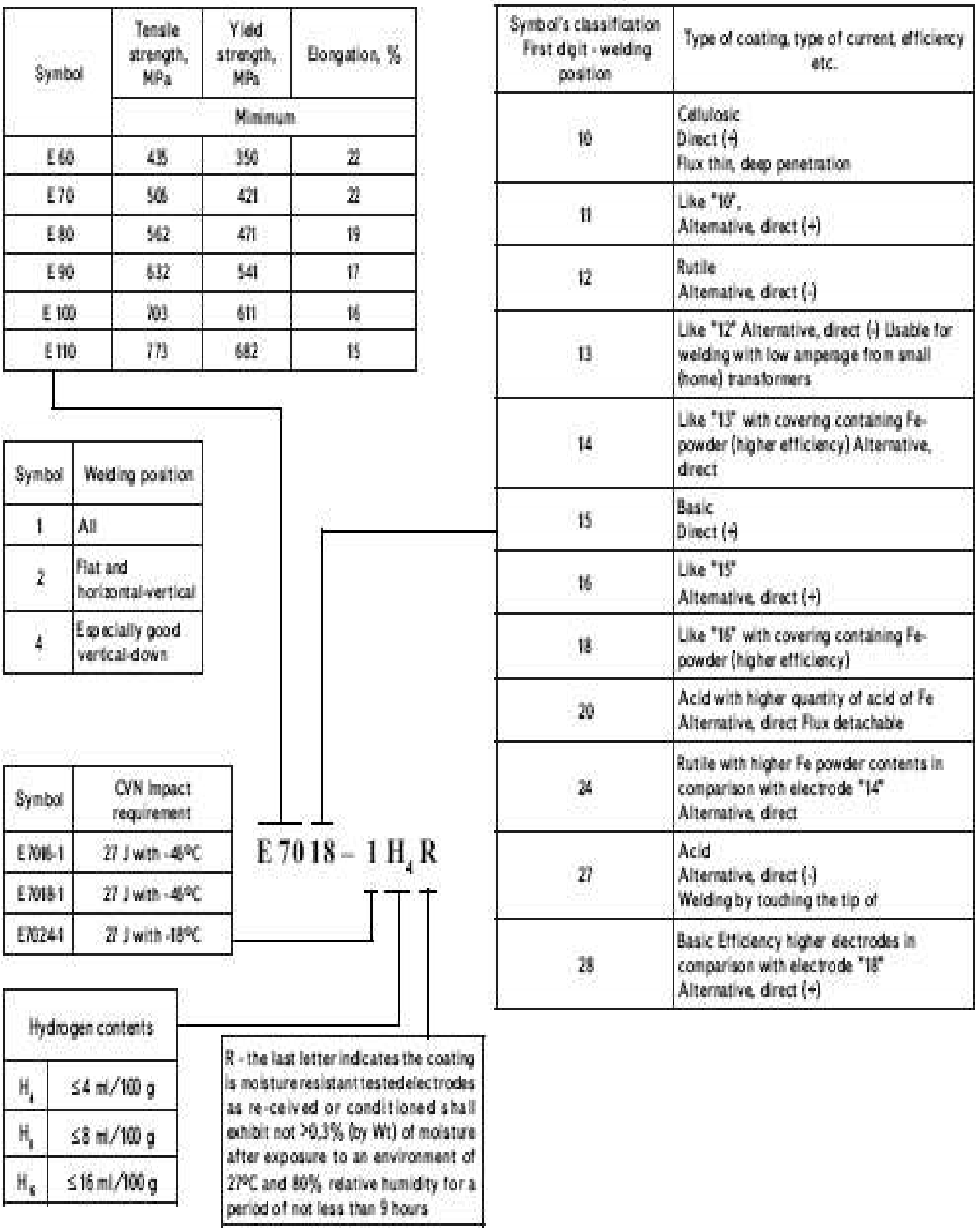
Efficiency, %	
Symbol	K_v, %
110	105 - 115
120	115 - 125
130	125 - 135
140	135 - 145
150	145 - 155
160	155 - 165
170	165 - 175
180	175 - 185
190	185 - 195
200	195 - 205

Symbol	Welding position
1	All positions
2	all positionc except vertical-down
3	Flat, horizontal and vertical
4	Flat (butt and multi-layer weld)
5	Like "3" and vertical-down

Symbol	DC polarity	Open-circuit voltage with AC (V)
0	Negative (+)	-
1	Any polarity (+/-)	50
2	Positive (-)	50
3	Negative (+)	50
4	Any polarity (+/-)	70
5	Positive (-)	70
6	Negative (+)	70
7	Any polarity (+/-)	90
8	Positive (-)	90
9	Negative (+)	90

- **AWS classification of electrode[29]**

Classification of Covered Electrodes for Welding of Carbon and Low Alloyed Structure Steels According to AWS A5.1



Symbol	Tensile strength, MPa	Yield strength, MPa	Elongation, %
	Minimum		
E 60	435	350	22
E 70	506	421	22
E 80	562	471	19
E 90	632	541	17
E 100	703	611	16
E 110	773	682	15

Symbol	Welding position
1	All
2	Flat and horizontal-vertical
4	Especially good vertical-down

Symbol	CVN impact requirement
E7016-1	27 J with -46°C
E7018-1	27 J with -46°C
E7024-1	27 J with -18°C

Hydrogen contents	
H_4	≤4 ml/100 g
H_8	≤8 ml/100 g
H_{16}	≤16 ml/100 g

R - the last letter indicates the coating is moisture resistant tested electrodes as re-ceived or conditioned shall exhibit not >0,3% (by Wt) of moisture after exposure to an environment of 27°C and 80% relative humidity for a period of not less than 9 hours

Symbol's classification First digit - welding position	Type of coating, type of current, efficiency etc.
10	Cellulosic Direct (+) Flux thin, deep penetration
11	Like "10", Alternative, direct (+)
12	Rutile Alternative, direct (-)
13	Like "12" Alternative, direct (-) Usable for welding with low amperage from small (home) transformers
14	Like "13" with covering containing Fe-powder (higher efficiency) Alternative, direct
15	Basic Direct (+)
16	Like "15" Alternative, direct (+)
18	Like "16" with covering containing Fe-powder (higher efficiency)
20	Acid with higher quantity of acid of Fe Alternative, direct Flux detachable
24	Rutile with higher Fe powder contents in comparison with electrode "14" Alternative, direct
27	Acid Alternative, direct (-) Welding by touching the tip of
28	Basic Efficiency higher electrodes in comparison with electrode "18" Alternative, direct (+)

3.2.3. Limitations for Welding

Electric welding shops and sections should have heating arrangement for providing temperature not lower than +12°C (for structural and hardened steel not lower than +15°C).

In premises where welding is carried out, performance of work connected with formation of dust, smoke and soot (gas cutting, cleaning with emery wheels etc.) is not permitted. Prevent occurrence of drafts. Speed of movement of air in the zone of welding should not exceed 0.5 m/s. "If necessary make partitions, cabins.

During assembly displacement of edges is allowed depending upon category of connections. While preparing welding connections of I category, on individual portions, displacement of edges not more than 15 % from thickness of welded metal, but not more than 1.5 mm, in total extent up to 20 % from length of seam. For connections of the second category-displacement of edges not more than

20 % from thickness of welded metal, but not more than 2.0 mm, in the total extent up to 20 % from length of seam but not more than 2.0mm, total length up to 20% of length of seam. For connections of the third category-displacement of edges not more than 30 % from thickness of welded metal, but not more than 2.0 mm, the total extent up to 20 % from length of seam.

Irrespective of category along the whole length of seam displacement of edges not more than 10 % from thickness of welded part is allowed. During assembly of parts with thickness of 0.5…0.8 mm, at which the welded joint has directional curvature, local displacement of edges up to 0.3-S on portions in the total extent not more than 20 % from length of seam is allowed.[19]

3.2.4. Control And Rectification Of Defects Of Welded Joints

Defects of welded joints, ways of their detection, the reasons for their formation. While analyzing defects of welded joints: Pay special attentions to lack of fusion not emerging on the surface .They are detected by ultrasonic and fractional radiographic defectoscopes. Separate pores, accumulation of pores and inclusions - with the help of radiographic inspection; [18]

Blowholes and air holes are detected depending on place of their location visually or with the help of radiographic or magnaflux inspection, ultrasonic or capillary defectoscopes.

Inclusions (particles of tungsten, slag) are detected by radiographic inspection, oxide films – by metallographic inspection;Cracks can be located in seam and zone of in the direction along and across the seam. They are detected by radiographic inspection and ultrasonic defectoscopes, and in some cases – by metallographic inspection. The cracks emerging to the surface, are detected except for the listed kinds, by defectoscopes, and in certain cases - visually; [18]

Crater - a depression in metal of seam, connected with shrinkage of metal when arc is broken without special measures taken on gradual decrease of current. It is detected by methods of radiographic inspection.

Displacement of welded edges in butt joints - rise or lowering surfaces of one of edges with respect to another in infringement of instructions of the drawing- is detected visually;

Excessive fusion - results in exit of molten metal from opposite side by penetration of fused welded elements it is detected visually;

Undercuts are found out visually and by means of radiographic inspection, metallographic inspection;

Fusion can settle down from the facing and reverse side of seam – it is found out visually.

3.3. NONDESTRUCTIVE TESTING

For detecting defects or flaws in welds we do non destructive testing of weldments.

Non-destructive testing is the branch of engineering concerned with all methods of detecting and evaluating flaws in materials. Flaws can affect the serviceability of the material or structure, so NDT is important in guaranteeing safe operation as well as in quality control and assessing plant life. The flaws may be cracks or inclusions in welds and castings, or variations in structural properties which can lead to loss of strength or failure in service.

Some of these NDT methods include the following:

1. Liquid penetration testing,
2. Magnetic particle testing,
3. Eddy current testing,
4. Radiographic testing,
5. Ultrasonic testing.

3.3.1. Radiography Testing - (RT)

I have opted **Radiography Testing (x-ray)** for the detection of weld defects in weldments.

X-RAY TEST this is a radiographic test method used to reveal the presence and nature of internal defects in a weld, such as cracks, slag, blowholes, and zones where proper fusion is lacking. In practice, an X-ray tube is placed on one side of the welded plate and an X-ray film, with a special sensitive emulsion, on the other side. When developed, the defects in the metal show up as dark spots and bands, which can be interpreted by an operator experienced in this inspection method. Porosity and defective root penetration as disclosed by X-ray inspection are shown in figure 3.9. [6]

This technique involves the use of penetrating gamma or X-radiation to examine parts and products for imperfections. An X-ray machine or radioactive isotope is used as a source of radiation. Radiation is directed through a part and onto film or other media. The resulting shadowgraph shows the internal soundness of the part. Possible imperfections are indicated as density changes in the film in the same manner as an X-ray shows broken bone. [7,49]

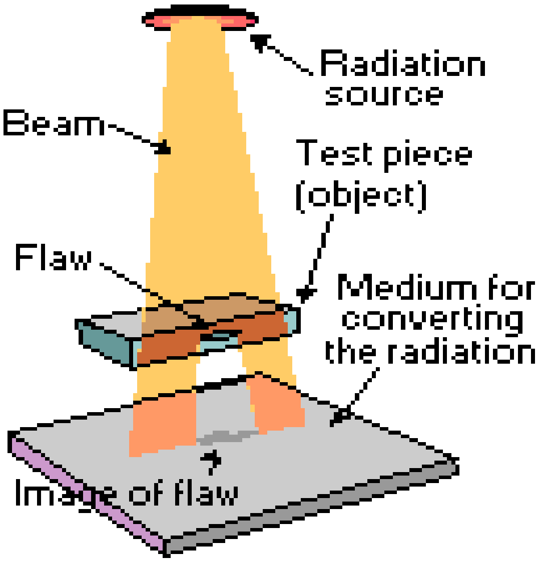


Figure 3.9: working of x-ray. [49]

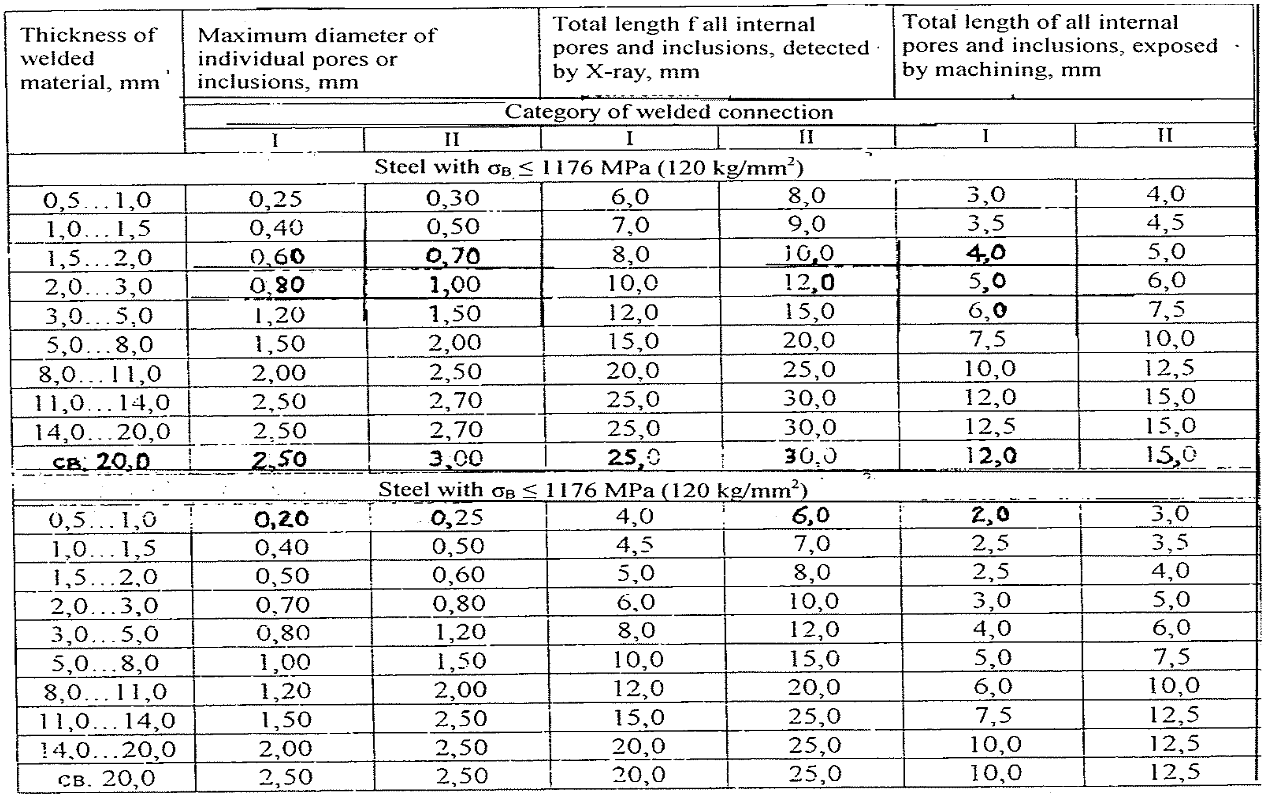
Radiographic applications fall into two distinct categories evaluation of material properties and evaluation of manufacturing and assembly properties. Material property evaluation includes the determination of composition, density, uniformity, and cell or particle size. Manufacturing and assembly property evaluation is normally concerned with dimensions, flaws (voids, inclusions, and cracks), bond integrity (welds, brazes, etc.), and verification of proper assembly of component pieces. [7]

X-rays or gamma rays, which are both used in radiography, are placed closed to the specimen, and are captured on a medium such as film. The film is then processed, and the image appears as a series of gray shades between black and white. The choice of radiation type (x-ray or gamma ray) depends on material thickness. Radiography equipment caters to a vast spectrum of industries, including automotive manufacture, pipe inspection, ship building, and **aerospace** defense and ammunitions, among other areas. [14]

Radiography equipment, which can be featured in the form of portable units, cabinets, permanently-installed equipment, or tire inspection systems, includes the following techniques:

- Real-time radiography: Technique that ensures immediate viewing of test results.
- Computed radiography (CR): Utilizes a photostimulable phosphor imaging plate instead of film.
- Computed tomography (CT): Provides a near three-dimensional view of the test object, thus offering a realistic image of possible flaws.

Table 3.2: Allowable without correction, internal pores and inclusions which have been detected by x-ray [17]



Thickness of welded material, mm	Maximum diameter of individual pores or inclusions, mm		Total length f all internal pores and inclusions, detected by X-ray, mm		Total length of all internal pores and inclusions, exposed by machining, mm	
	Category of welded connection					
	I	II	I	II	I	II
Steel with $\sigma_B \leq 1176$ MPa (120 kg/mm^2)						
0,5…1,0	0,25	0,30	6,0	8,0	3,0	4,0
1,0…1,5	0,40	0,50	7,0	9,0	3,5	4,5
1,5…2,0	0,60	0,70	8,0	10,0	4,0	5,0
2,0…3,0	0,80	1,00	10,0	12,0	5,0	6,0
3,0…5,0	1,20	1,50	12,0	15,0	6,0	7,5
5,0…8,0	1,50	2,00	15,0	20,0	7,5	10,0
8,0…11,0	2,00	2,50	20,0	25,0	10,0	12,5
11,0…14,0	2,50	2,70	25,0	30,0	12,0	15,0
14,0…20,0	2,50	2,70	25,0	30,0	12,5	15,0
св. 20,0	2,50	3,00	25,0	30,0	12,0	15,0
Steel with $\sigma_B \leq 1176$ MPa (120 kg/mm^2)						
0,5…1,0	0,20	0,25	4,0	6,0	2,0	3,0
1,0…1,5	0,40	0,50	4,5	7,0	2,5	3,5
1,5…2,0	0,50	0,60	5,0	8,0	2,5	4,0
2,0…3,0	0,70	0,80	6,0	10,0	3,0	5,0
3,0…5,0	0,80	1,20	8,0	12,0	4,0	6,0
5,0…8,0	1,00	1,50	10,0	15,0	5,0	7,5
8,0…11,0	1,20	2,00	12,0	20,0	6,0	10,0
11,0…14,0	1,50	2,50	15,0	25,0	7,5	12,5
14,0…20,0	2,00	2,50	20,0	25,0	10,0	12,5
св. 20,0	2,50	2,50	20,0	25,0	10,0	12,5

Table 2. Allowable without correction, internal pores and inclusions which have been detected by x-ray

3.4.DESTRUCTIVE TESTING

Destructive Examination renders the weld or material unfit for further service

In destructive testing, sample portions of the welded structures are required. These samples are subjected to loads until they actually fail. The failed pieces are then studied and compared to known standards to determine the quality of the weld. The most common types of destructive testing are known as free bend, guided bend, nick-break, and impact; fillet welded joint, etching, and tensile testing. The primary disadvantage of destructive testing is that an actual section of a weldment must be destroyed to evaluate the weld. This type of testing is usually used in the certification process of the welder. [28]

Some of the testing requires elaborate equipment that is not available for use in the field. Three tests that may be performed in the field without elaborate equip-ment are the free-bend test, the guided-bend test, and the nick-break test.

3.4.1. Common methods used in Destructive Examination

- Bend testing
- Tensile testing
- Impact testing
- Hardness testing
- Chemical analysis
- Hydrostatic testing to destruction
- Peel testing
- Spark testing

3.4.2. Bend Test

Bend test be carried out on a tensile testing machine with the help of certain attachments as described later in this section. A bend test is an easy and inexpensive test to apply. The method is fast and shows most weld faults quite accurately. [30]

Bend tests may be used to find a number of weld properties such as

(i) Ductility of the welded zone
(ii) Weld penetration

(iii) Fusion

(iv)Crystalline structure (of the fractured surface)

(v) Strength.

To conclude, the bend test is an easy and useful method of comparing one welded joint with another of the same type and of revealing abnormalities and defects at or near the surface in tension.

3.4.2.1. Types of Bend Tests

Bend tests may be categorized as

(a) Free Bend Test

(b) Guided Bend Test

Bend tests may be further classified as

(i)Transverse bend test

(ii)Root bend test

(iii)Face bend test

(iv)Longitudinal bend test

(v)Side bend test.

3.4.2.1.1. Guided-Bend Test

We use the GUIDED-BEND TEST to determine the quality of weld metal at the face and root of a welded joint. This test is made in a specially designed jig. An example of one type of jig is shown in figure.

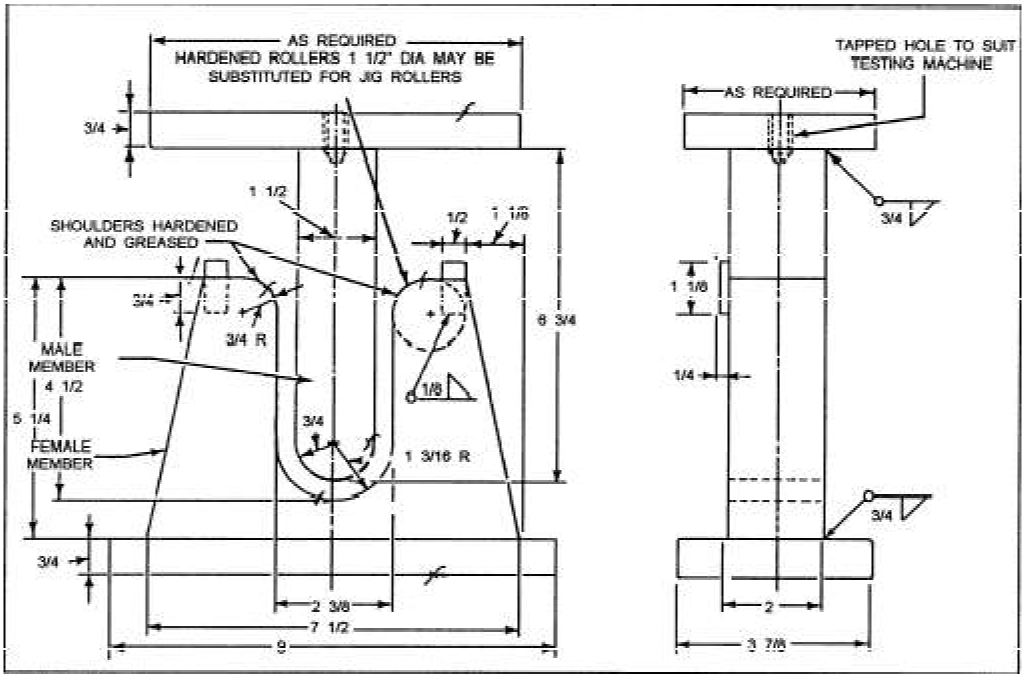


Figure 3.10: guided bend test fixture and plunger [25]

The test specimen is placed across the supports of the die. A plunger, operated from above by hydraulic pressure, forces the specimen into the die. To fulfill the requirements of this test, you must bend the specimen 180 degrees—the capacity of the jig. No cracks should appear on the surface greater than 1/8 inch. The face-bend tests are made in this jig with the face of the weld in tension (outside), as shown in above figure. The root-bend tests are made with the root of the weld in tension (outside), as shown in figure below

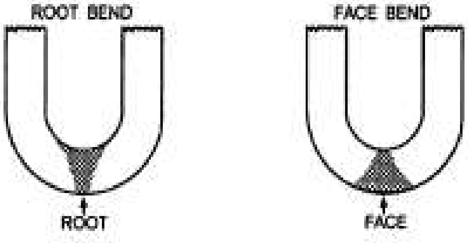


Figure 3.11: Guided bend test specimen [21]

Figure 3.12 shows a machine used for making the guided-bend test. It is used in many welding schools and testing laboratories for the daily testing of specimens. Simple in construction and easy to use, it works by hydraulic pressure and can apply a direct load up to 40,000 pounds, and even more on small specimens. When you make the test, positions the specimens in the machine as previously indicated and start pumping the actuator. Keep your eye on the large gauge and watch the load increase. You will know the actual load under which the test piece bends by the position of an auxiliary hand that is carried along by the gauge pointer. The hand remains at the point of maximum load after the pointer returns to zero. [31]

Figure 3.12: Testing machine for bend test [36]

3.5.TENSILE TESTING

a)This test is used to measure the strength of a welded joint. A portion of a to locate the welded plate is locate the weld midway between the jaws of the testing machine (fig.3.13). The width thickness of the test specimen are measured before testing, and the area in square inches is calculated by multiplying these before testing , and the area in square inches is calculated by multiplying these two figures (see formula, fig.3.13). The tensile test specimen is then mounted in a machine that will exert enough pull on the piece to break the specimen. The testing machining may be either a stationary or a portable type. A machine of the portable type, operating on the hydraulic principle and capable of pulling as well as bending test specimens, is shown in figure. As the specimen is being tested in this machine, the load in pounds is registered on the gauge. In the stationary types, the load applied may be registered on a balancing beam. In either case, the load at the point of breaking is recorded. Test specimens broken by the tensile strength test are shown in figure.3.13 [32]

b) The tensile strength, which is defined as stress in pounds per square inch, is calculated by dividing the breaking load of the test piece by the original cross section area of the specimen. The usual requirement for the tensile strength of welds is that the specimen shall pull not less than 90 percent of the base metal tensile strength.

c) The shearing strength of transverse and longitudinal fillet welds is determined by tensile stress on the test specimens. The width of the specimen is measured in inches. The specimen is ruptured under tensile load, and the maximum load in pounds is determined. The shearing strength of the weld in pounds per linear inch is determined by dividing the maximum load by the length of fillet weld that ruptured. The shearing strength in pounds per square inch is obtained by dividing the shearing strength in pounds per linear inch by the average throat dimension of the weld in inches. The test specimens are made wider than required and machined down to size. [34]

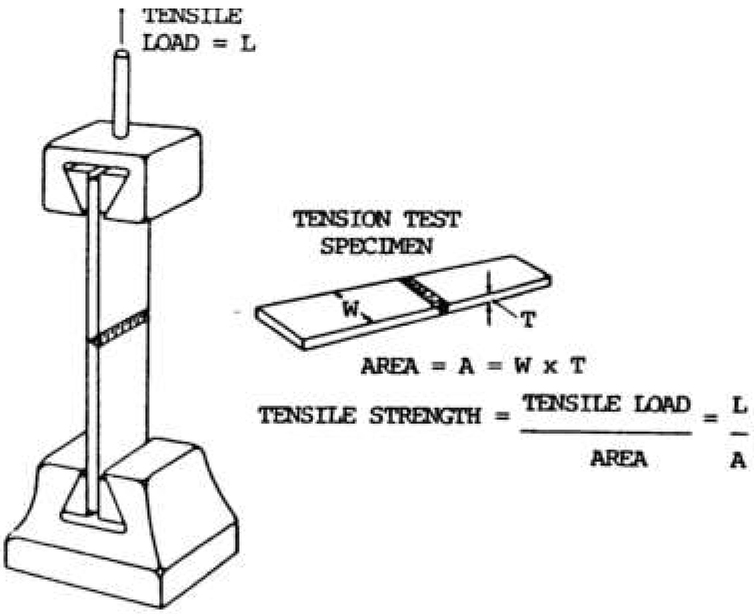


Figure 3.13: Tensile test specimen and test method [34]

As mentioned earlier the tensile test is used to provide information that will be used in design calculations or to demonstrate that a material complies with the requirements of the appropriate specification - it may therefore be either a quantitative OR a qualitative test.

The test is made by gripping the ends of a suitably prepared standardized test piece in a tensile test machine and then applying a continually increasing uni-axial load until such time as failure occurs. Test pieces are standardized in order that results are reproducible and comparable as shown in Fig 3.14 and Fig.3.15

Figure 3.14: Typical tensile testing machines [36]

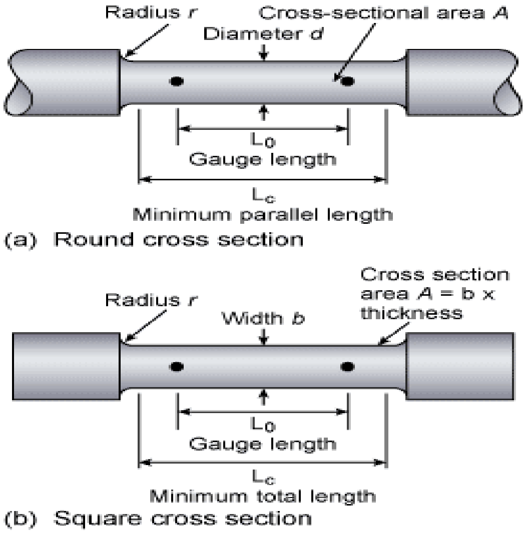


Figure 3.15: Standard shape tensile specimens [37]

Specimens are said to be *proportional* when the *gauge length*, L_0, is related to the original cross sectional area, A_0, expressed as $L_0 = k\sqrt{A_0}$. The constant k is 5.65 in EN specifications and 5 in the ASME codes. These give gauge lengths of approximately 5x specimen diameter and 4 x specimen diameters respectively - whilst this difference may not be technically significant it is important when claiming compliance with specifications. Curve [37]

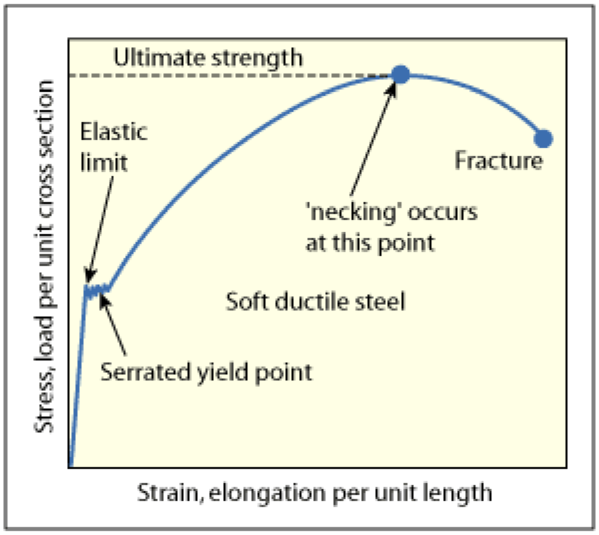


Figure 3.16: Stress/strain[37]

Both the load (stress) and the test piece extension (strain) are measured and from this data an engineering stress/strain curve is constructed, Fig.3.16 From this curve we can determine:

a) the tensile strength, also known as the ultimate tensile strength, the load at failure divided by the original cross sectional area where the ultimate tensile strength (U.T.S.), $\sigma_{max} = P_{max}/A_0$, where P_{max} = maximum load, A_0 = original cross sectional area. In EN specifications this parameter is also identified as 'R_m'; [37]

b) the yield point (YP), the stress at which deformation changes from elastic to plastic behaviour ie below the yield point unloading the specimen means that it returns to its original length, above the yield point permanent plastic deformation has occurred, YP or $\sigma y = P_{yp} / A_0$ where P_{yp} = load at the yield point. In EN specifications this parameter is also identified as 'R_e

c) By reassembling the broken specimen we can also measure the percentage elongation, El% how much the test piece had stretched at failure where El% = $(L_f - L_0 / L_o)$ x100 where Lf = gauge length at fracture and L0 = original gauge length. In EN specifications this parameter is also identified as 'A' (Fig.3.15 a & b.). [23]

d) the percentage reduction of area, how much the specimen has necked or reduced in diameter at the point of failure where R of A% $=(A_0 - A_f / A_0)$ x 100 where A_f = cross sectional area at site of the fracture. In EN specifications this parameter is also identified as 'Z', (Fig.3.17).

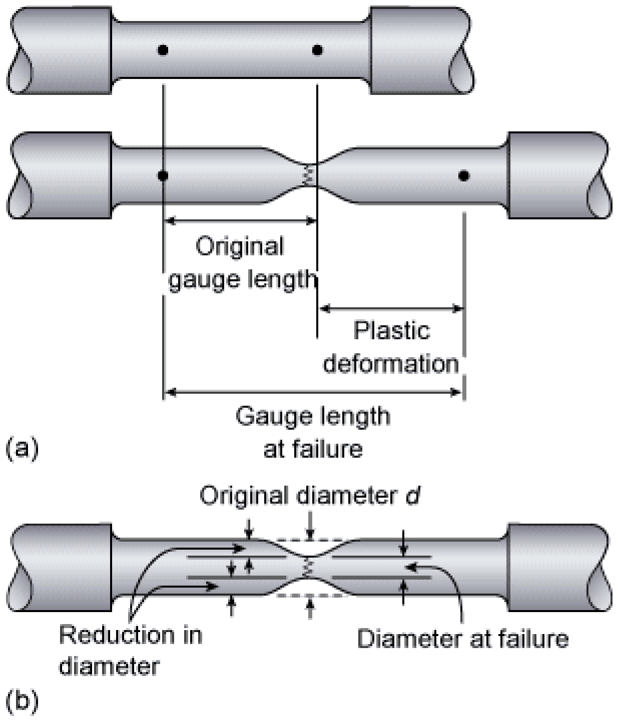


Figure 3.17: [37]

a) Calculation of percentage elongation

b) Calculation of percentage reduction of area

(a) And (b) are measures of the strength of the material, (c) and (d) indicate the ductility or ability of the material to deform without fracture.

The slope of the elastic portion of the curve, essentially a straight line, will give Young's Modulus of Elasticity, a measure of how much a structure will elastically deform when loaded.

A low modulus means that a structure will be flexible, a high modulus a structure that will be stiff and inflexible. [38]

To produce the most accurate stress/strain curve an extensometer should be attached to the specimen to measure the elongation of the gauge length. A less accurate method is to measure the movement of the cross-head of the tensile machine. [3]

The stress strain curve in Fig.3.16. Shows a material that has a well pronounced yield point but only annealed carbon steel exhibits this sort of behaviour. Metals that are strengthened by alloying, by heat treatment or by cold working do not have a pronounced yield and some other method must be found to determine the 'yield point'.[34]

This is done by measuring the proof stress (offset yield strength in American terminology), the stress required to produce a small specified amount of plastic deformation in the test piece.

The proof stress is measured by drawing a line parallel to the elastic portion of the stress/strain curve at a specified strain, this strain being a percentage of the original gauge length, hence 0.2% proof, 1% proof (see Fig 3.18.).

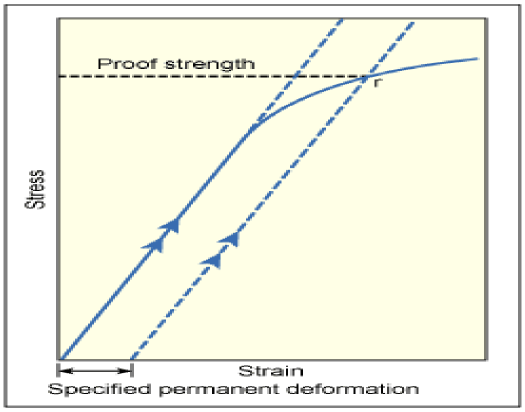


Fig. 3.18: Determination of proof (offset yield) strength [37]

3.5.1.Welding procedure approval for tensile testing.

To approve a butt welding procedure most specifications such as BS EN 288 Parts 3 and 4 and ASME IX require tensile tests to be carried out.

These are generally cross joint (CJ) tensile tests of square or rectangular cross section that, as the name suggests, are oriented across the weld so that both parent metals, both heat affected zones (HAZs) and the weld metal itself are tested (Fig.3.19). The excess weld metal in the cap of the weld may be left in-situ or machined off. [39]

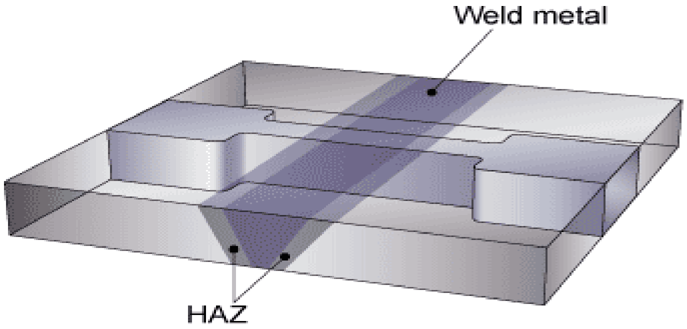


Fig3.19: Square or rectangular cross joint tensile test piece [34]

While it is possible to measure the yield strength, the elongation and the reduction of area of CJ specimens the fact that there are at least three different areas with dissimilar mechanical properties makes such measurements inaccurate and unreliable, although this is sometimes carried out purely for information purposes.[17]

The specifications mentioned above require the UTS and the position of the fracture only to be recorded. The cross joint strength is usually required to exceed the minimum specified UTS of the parent metal. In most situations the weld metal is stronger than the parent metal - it is overmatched - so that failure occurs in the parent metal or the HAZ at a stress above the specified minimum. [39]

In cases where the weld and/or the HAZs are weaker than the parent metal - welded age-hardened or cold worked aluminum alloys are good examples.

The designer must also take this into account in design calculations and provide some method of compensating for this loss of strength.

The size of a product can also influence the properties as, during heat treatment, the section thickness will affect the cooling rate with slower cooling rates, and hence softer structures, at the centre of thicker sections. This is dealt with in material standards by specifying what is known as the 'limiting ruling section', the maximum diameter of bar at which the required mechanical properties can be achieved at the centre.

In addition to variations of the properties due to the shape of the specimens and the testing temperature, the rate of loading will also affect the results.

Figure 3.20 shows how the tensile strength increases but ductility decreases as the testing speed is increased. The speed of the cross head of the tensile machine therefore needs to be controlled and BS EN 10002 specifies a stress rate range of 6MPa per second to 60MPa per second. The ASTM specifications have similar but not identical requirements. [29]

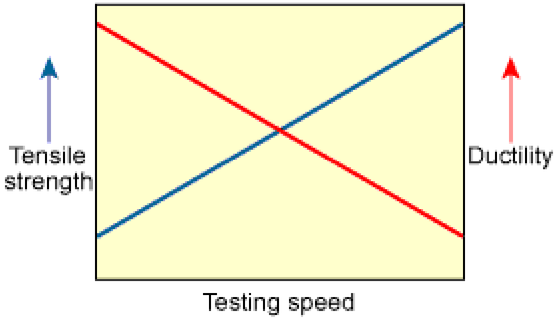


Fig.3.20: Effect of speed of testing on strength and ductility [37]

3.6. OPTICAL SPECTRA ANALYSER

Spark emission spectrometry (spark source optical emission spectrometry) is the method of choice for analyzing the chemical composition of metals and alloys.

Figure 3.21: Advance optical spectra analyzer; Germany [36]

- Rapid chemical analysis of metallic material. There is software along with the machine, put sample on lower electrode and put the clamp over the sample, then sparking will start and we can get the 25 composition at a time.

- By sparking get the radiation then radiation fall on grating equipment and spread on different wavelength.

Figure 3.22: collecting process

3.7.MICROSTRUCTURE

Alloy Steels are materials of special compositions, developed to permit the deployment of elevated mechanical properties that make them the most suitable selection for important applications like bridges, high rise towers and lifting equipment. By utilizing the most out of improved strength, hardness, ductility and impact resistance through innovative design, it is possible to build lighter structures with considerable economical gains. [38]

Welding-alloy-steel, Heat Treatable, Quenched and Tempered Alloy Steels is a challenging proposition that needs understanding and preparation. These steels have 0.25 to 0.5%C, that is medium carbon content, and typically up to 5% total alloy content.

3.7.1.What are the dangers?

The strength, hardness and ductility that can be developed are provided by hardening and tempering these steels to obtain the sought for martensitic structure. However whenever martensite deriving from Welding-alloy-steel heat cycles is still untempered, it is hard and brittle and prone to cold cracking under the effect of internal stresses. [40]

Therefore the same favorable qualities that make these materials useful for demanding applications render them more susceptible to cold cracking during Welding-alloy-steel.

The most important parameters, heat input and cooling rate, affecting Welding-alloy-steel should be addressed whenever the carbon present and the "alloy content" (meaning by that the sum of the percentages of all alloying elements) have a major influence upon the behavior of the material under the thermal cycles associated with welding. [41]

Annealed or over tempered conditions are preferred for easier Welding-alloy-steel while full deployment of properties is obtained by performing heat treatment once all welding operations have been completed.

3.7.2. Designations and basic metallurgy.

Some of these steels are known by the accepted AISI-SAE designation, as 13XX, 40XX, 41XX, 43XX, 46XX, 51XX, 61XX, 86XX, where the last two digits XX indicate the carbon content, expressed in hundredths of one percent, can be anything between 18 and 50. [22]

Some basic steel metallurgy facts should be remembered when Welding-alloy-steel. The Carbon level establishes the hardness and brittleness that will be shown by the martensitic structure. This is produced by fast cooling after austenitizing (that is after heating the steel above the transformation temperature where ferrite is changed to austenite).

The problem is further aggravated by the higher hardenability due to high alloy content of the steels, meaning their tendency to harden, by forming martensite, even at larger sizes and slower cooling rates that would not influence other less alloyed carbon steels. [44]

Higher hardenability is what differentiates alloy steels from carbon steels of the same carbon content and represents also the most important Welding-alloy-steel problem. This means, as seen above, that hard martensitic structures are reached even with slow cooling from welding temperatures.

Weldability, understood as the ease of welding without cracking, decreases in steels as the hardenability increases. This means that the higher the carbon and the alloy content, the higher the risks of cracking, if suitable precautions are not implemented. [42]

3.7.3. A useful tool.

The concept of Carbon Equivalent was developed in an effort to reduce to a single number the influence of the contribution of the various alloying elements on the difficulties encountered in Welding-alloy-steel, therefore making the problem more tractable.

One of the accepted empiric formulas equates the carbon equivalent to the sum of the percentage of each element divided by a certain factor as follows: Carbon Equivalent

$$\mathbf{CE = \%C + \%Mn/6 + \%Ni/15 + \%Cr/5 + \%Mo/4 + \%V/5.}$$

The usage of this formula is intended to provide a rule of thumb for deciding if and what special provisions should be implemented for Welding-alloy-steel: for CE equal to or less than 0.40, no provisions are required. For CE more than 0.40 but less than 0.60 some preheating should be provided before welding. For CE more than 0.60 both preheating and post-heating should be applied. [22]

It is evident that this approach to weldability evaluation oversimplifies the issue and overlooks other factors, like additional elements not accounted for, thickness, restraint of the joint, nature of the filler material, thermal gradients developed, all of which contribute to and may even decide the outcome of a Welding-alloy-steel procedure.

For any real application the complex of all the conditions involved should be evaluated. It is equally important to clean thoroughly all materials involved, base metal, consumables, fixtures and accessories, from grease, paint, moisture, rust, dirt and any other contaminant.

3.7.4. The risks of hydrogen.

For Welding-alloy-steel, hydrogen is the most dangerous of the gases because it can induce underbead cracks. It can usually be introduced by moist electrode covers or other conditions associated with poor weld preparation and poor housekeeping.

It can be absorbed in the melt in atomic form at elevated temperature, and then be rejected when the solubility drops at lower temperature, with substantial pressure increase in the passage to molecular form.

Although appealing for its simplicity, this theory has been recently questioned and displaced by another model involving the hypothesis of the presence of preexisting defect sites in the material.

There, under stress, hydrogen preferably diffuses, reducing the local cohesive strength. Failure would occur when this strength falls below the intensified stress level. Hydrogen evolves in the newly formed cavity and the process is repeated.

Because of the tendency of cold cracking, exhibited by alloy steels, it is of utmost importance to minimize the possibility of hydrogen embrittlement, by using only low hydrogen consumables.

Low hydrogen electrode covers for limiting hydrogen pick-up are formulated for Welding-alloy-steel and highly constrained joints; they need to be stored and kept dry to minimize moisture absorbance. [43]

3.7.5. Applicable processes.

All the common arc processes are applicable in Welding-alloy-steel, the selection being determined mostly by economic and practical considerations. However certain precautions must always be considered: low hydrogen consumables, preheat and post-heat to drive hydrogen away and to avoid cold cracking, besides controlling the microstructures formed.

For these reasons, Shielded Metal Arc Welding is performed with low hydrogen electrodes. The purpose of the selection of filler metal is to match in the weld metal not so much chemistry and composition, but rather the mechanical properties obtainable after proper heat treatment. Some electrodes not covered by accepted Standards are offered for special purposes by manufacturers. [21]

Gas Tungsten Arc Welding is considered best capable of controlling hydrogen content to the minimum and is therefore the process of choice for critical Welding-alloy-steel applications.

Both gas shielded manual processes (GTAW and GMAW) provide good control of chemistry and cleanliness. When higher productivity is required then mechanized processes as above or FCAW and SAW can be implemented, usually with more consistent quality. Some experts however question the capability of manufacturers to control the moisture content in the flux, and therefore advise against FCAW in critical applications. [25]

3.7.6. Filler metals.

Filler metals should be purchased from reputable manufacturers who are familiar with welding requirements and take care not only of the composition but also of surface finish and cleanliness of their materials.

Flux cored wires can be supplied with compositions adjusted to give in the weld properties similar to those of base material, after hardening and tempering. Manufacturers should be questioned to satisfy special requirements.

When the behavior is more important then the chemistry of the base metal, it is customary to select lower carbon but higher alloy filler metal to provide the required properties while easing the cracking problem. Some of these electrodes provide as welded hardness close to that of fully treated base metal even with lower carbon content.

When, in particular cases, the deployment of full quenched and tempered properties in the weld metal is not a necessity, the assembly can be put in service after stress relieve only.[19]

If appropriate, a non hardenable electrode may be selected, like an austenitic stainless or a nickel alloy: the lower strength and higher ductility contributes to obtain crack free welds.

From this exposition it results that the selection of the proper filler metal electrode is governed by the design strength level of the welded joint. This requirement should be taken care of, while the other need to minimize cracking should suggest the selection of the consumable providing maximum ductility.

3.7.7. Chemistry of the weld.

In general one should be aware of the fact that the deposited weld material in Welding-alloy-steel may differ from the composition of filler metal, because of dilution with base metal and because of arc transfer efficiency, which depends on how well the elements are transferred across the arc [44].

Therefore not all the elements in consumable electrodes are present in the weld bead in their original percentage, while filler wires used with non-consumable electrodes and fed directly to the weld puddle, are more likely to pass unaltered in the weld.

Considerable latitude of selection is often given to the welding specialist, who can choose the filler to provide for those characteristics that will give the best overall performance, even with a composition differing from that of the base metal. In particular better weldability is sometimes achieved by employing a filler composition which decreases the hardenability of the weld. [45]

3.7.8. Coefficient of Thermal Expansion.

Another factor to be taken into account is the coefficient of thermal expansion, especially for dissimilar joints, where a suitable filler metal should be selected to accommodate for different thermal behavior, and to absorb without cracking the internal stresses likely to develop in the joint because of this difference.

The joint could be weakened by carbon depletion in the base metal caused by certain filler metals. Filler having fewer tendencies to deplete carbon should be considered if the joint mechanical properties, to be verified by tensile and bend tests across the weld, are important for the application. [46]

3.7.9. Other harmful elements.

Elevated contents of sulfur or phosphorus, which are not included in the formula for Carbon Equivalent, may contribute to the appearance of hot tears in the weld. By hot tears one means cracks, caused by internal stresses, appearing at or near the end of the solidification process, while the material is still hot and weak. [47]

Sometimes the adverse effect of sulfur can be counteracted by providing a filler material with increased Manganese content, which contributes to produce harmless manganese sulfide inclusions, thus resolving the problem of sulfur generated hot shortness.

Gases trapped in the weld are revealed by the presence of porosity which is enhanced when the solubility at cooler temperature is lower than that in the liquid metal or at elevated temperature. [41]

3.7.10. Controlling microstructure.

Welding-alloy-steel provides intense local heat which affects the structures present near the joint and induces those structural changes that have to be anticipated by knowing the chemistry of the base metal, the shape and dimensions of the structural elements and the cooling rate. [6]

As already pointed out, hardness and brittleness go together. Therefore if the conditions (carbon and alloy content) are such that hard and brittle martensitic microstructures are to be expected upon cooling from Welding-alloy-steel temperatures, with the concurrent risk of development of cracks, then modification of the cooling rate is to be implemented, mostly by preheating, to prevent the hardest structures from forming, or to temper them to lower and harmless hardness levels with increased ductility.

Heat input is a major factor involved in the success of Welding-alloy-steel. While the exact knowledge of net heat input applied may not be available because of heat losses that are difficult to account for, a general appreciation of its effects may help in evaluating the possible outcomes of procedure changes. [38]

3.7.11. Preheat.

In any given situation of joints presenting certain thicknesses and configurations, heat cycles affecting martensite formation of base metal near the weld are influenced both by preheat temperature and by heat input. As a precaution all hardenable steels should be preheated to decrease the cooling rate after welding. [29]

In general the higher the preheat temperature and the lower the heat input, the conditions are more favorable for limiting martensite formation and its hardness, hopefully contributing to higher quality welds.

A similar result can be achieved sometimes simply by multiple pass Welding-alloy-steel, where successive beads temper and retard cooling of previous ones, with the benefits indicated above. If however the heat input provided by Welding-alloy-steel is not sufficient for keeping the structure as hot as needed, then external heating means must be implemented to assure the interpass temperature required. Adequate preheating must be provided in any case for the first, the root pass of Welding-alloy-steel, which is also the most crucial. [40]

The importance of preheating increases with the thickness of the base metal because of the rapid self quench capability, and with the rigidity of the welded structure because of the derived constraints.

For Welding-alloy-steel designated as structural steels and high strength plates where specifications prescribe minimum yield strength in as rolled or in normalized condition, preheating is almost always required, together with filler material of the low hydrogen type which must be kept dry or baked before use. [10]

Preheat and interpass temperatures for Welding-alloy-steel, based on chemistry of base metal and thickness of the structure elements. The temperatures covered by the above range from a minimum of 40 0C (100 0F) for low carbon (0.2%C) and thin sections (less than 13 mm = 1/2") to a maximum of 370 0C (700 0F) for medium carbon (0.5%C) and thick sections (over 50 mm = 2"). [11]

3.7.12. Postheat.

Also known as Post Weld Heat Treatment (PWHT), this procedure is used to influence the structure and the properties obtained in the weld and in the heat affected zone (HAZ). By implementing proper provisions after welding one can retard the cooling rate after Welding-alloy-steel. The purpose is to prevent the martensite transformation by keeping the temperature high until other less hard structures are formed, or to temper the martensite already formed if it could not be avoided. [43]

Putting immediately the welded structure in a furnace, or covering the weld with some insulating material, or applying a flame from a burner are some of the usual procedures.

3.7.13. Welding Steel Alloys

Steel Alloys can be divided into five groups:

- Carbon Steels
- High Strength Low Alloy Steels
- Quenched and Tempered Steels

- Heat Treatable Low Alloy Steels
- Chromium-Molybdenum Steels

Steels are readily available in various product forms. To establish a proper welding procedure it is necessary to know the material properties of the steel being welded. The American Iron and Steel Institute defines carbon steel as follows:

Steel is considered to be carbon steel when no minimum content is specified or required for chromium, cobalt, columbium [niobium], molybdenum, nickel, titanium, tungsten, vanadium or zirconium, or any other element to be added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40 per cent; or when the maximum content specified for any of the following elements does not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.60. Carbon steels are normally classified as shown below. [22]

Low-carbon steels contain up to 0.30 weight percent C. The largest category of this class of steel is flat-rolled products (sheet or strip) usually in the cold-rolled and annealed condition. The carbon content for these high-formability steels is very low, less than 0.10 weight percent C, with up to 0.4 weight percent Mn. For rolled steel structural plates and sections, the carbon content may be increased to approximately 0.30 weight percent, with higher manganese up to 1.5 weight percent.

Medium-carbon steels are similar to low-carbon steels except that the carbon ranges from 0.30 to 0.60 weight percent and the manganese from 0.60 to 1.65 weight percent. Increasing the carbon content to approximately 0.5 weight percent with an accompanying increase in manganese allows medium-carbon steels to be used in the quenched and tempered condition.

High-carbon steels contain from 0.60 to 1.00 weight percent C with manganese contents ranging from 0.30 to 0.90 weight percent.

High-strength low-alloy (HSLA) steels, or microalloyed steels, are designed to provide better mechanical properties than conventional carbon steels. They are designed to meet specific mechanical properties rather than a chemical composition. The chemical composition of specific HSLA steel may vary for different product thickness to meet mechanical property requirements. The HSLA steels have low carbon contents (0.50 to ~0.25 weight percent C) in order to produce adequate formability and weldability, and they have manganese contents up to 2.0 weight percent. Small quantities of chromium, nickel, molybdenum, copper, nitrogen, vanadium, niobium, titanium, and zirconium are used in various combinations.

Below are some typical welding considerations when welding carbon and low alloy steels:

- Carbon Equivalent of the Steel
- Weld Cooling Rates
- Solidification Cracking
- Reheat Cracking
- Lamellar Tearing
- Hydrogen Cracking

3.8. Metallurgical concepts

Microstructure refers of the microscopic description of the individual constituents of a material. The length scale is 100-1 micrometer, well above the atomic levels. That said, work has long been underway on nano-level microstructural control (although this really should be renamed nanostructure). The microstructure of a material (of which we can broadly classify into "metallic", "polymeric", "ceramic" and "composite") really is a study of the crystal structure of a material, their size, composition, orientation, formation, interaction and, ultimately, their effect on the macroscopic behaviour in terms of physical properties such as strength, toughness, ductility, hardness, corrosion resistance, high / low temperature behaviour, wearability, and so on, which in turn govern the application of these materials in industry and manufacture.[22]

The importance of studying microstructural changes in the weld metal, per se has been emphasized repeatedly because of the different primary structures that serves as a straight point. Furthermore, even though the weld metal and the base metal in a weldment may be subjected to the same post weld thermal cycling, these two components of a weld commonly display differences in microstructure that persist because of their dissimilar origins and compositions. [37]

3.8.1. Solidification of weld metal

Fusion welding could be linked to making a casting. When a casting solidifies in a metal mold, the first crystals of the casting that form at its outer surface (i.e. against the mold wall) nucleate heterogeneously. Grains then grow inward on these randomly oriented nuclei in a direction perpendicular to the mold wall. Unlike solidification in a casting, If the unique feature in the solidification of a fusion weld, epitaxial growth, were ignored, however, molten weld metal need not undergo initial nucleation during solidification , because the wetted face of the base metal provides the crystal lattice on which atoms of the cooling weld metal can site themselves and form grains. The degree of coherency between the grains sited in the base metal and those in the weld metal depends on similarities in their chemical composition, as well as their crystallographic structure. Allotropic transformation will occur with most of the carbon and low-alloy steel compositions. Welding travel speed is one of the factors that affect the manner in which epitaxial growth proceeds at the interface. [23]

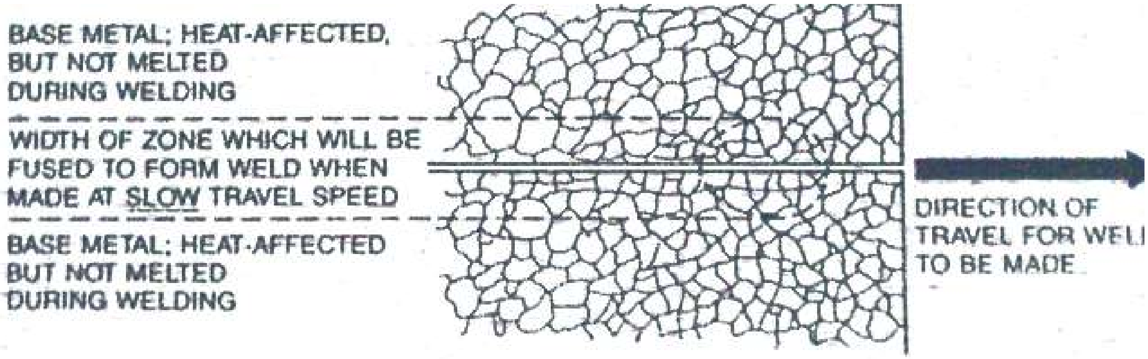


Figure 3.23: Solidification of weld metal [22]

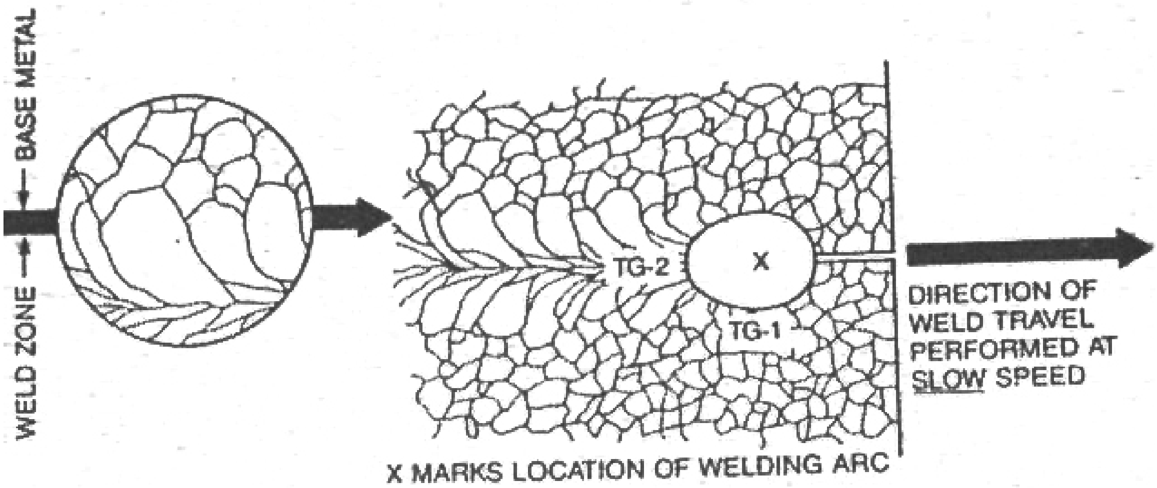


Figure 3.24: Welding at slow welding travel speed [22]

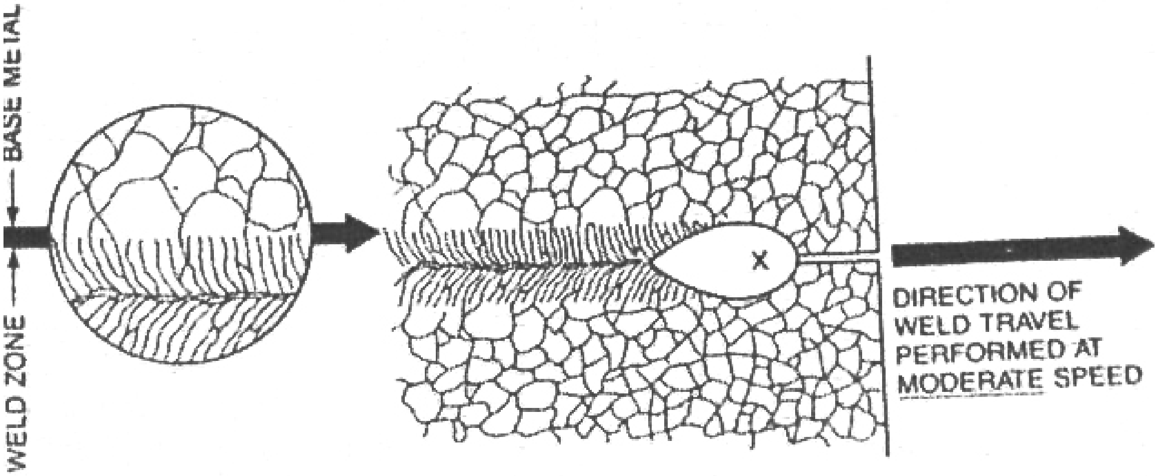


Figure3.25: welding at moderate welding travel speed [22]

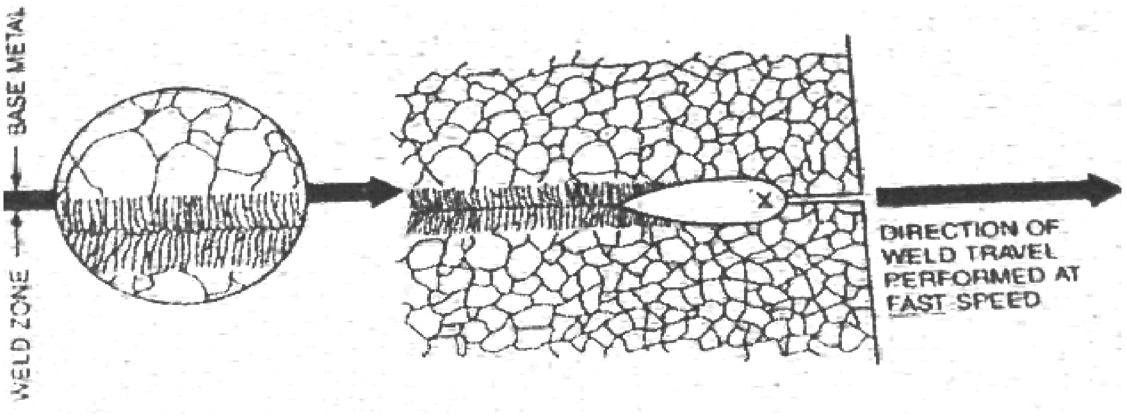


Figure 3.26: Welding at fast travel speed [22]

3.8.2. The weld zone

The weld zone, identified as zone 1, the mixes zone, in Fig.3.27 already has received much attention, and has been described with regard to sources of the metal, homogeneity, solidification mechanism and primary microstructure.

Mixed zone is important for the microstructure. After initial solidification of weld zone, the rate of cooling of the primary microstructure is important because of allotropic transformation that is likely to occur, and the influence of cooling rate on the nature of the microstructure that results from a transformation.

After initial solidification of primary microstructure, the weld zone may be reheated to some temperature level as a result of multipass welding or by application of a post weld heat treatment.

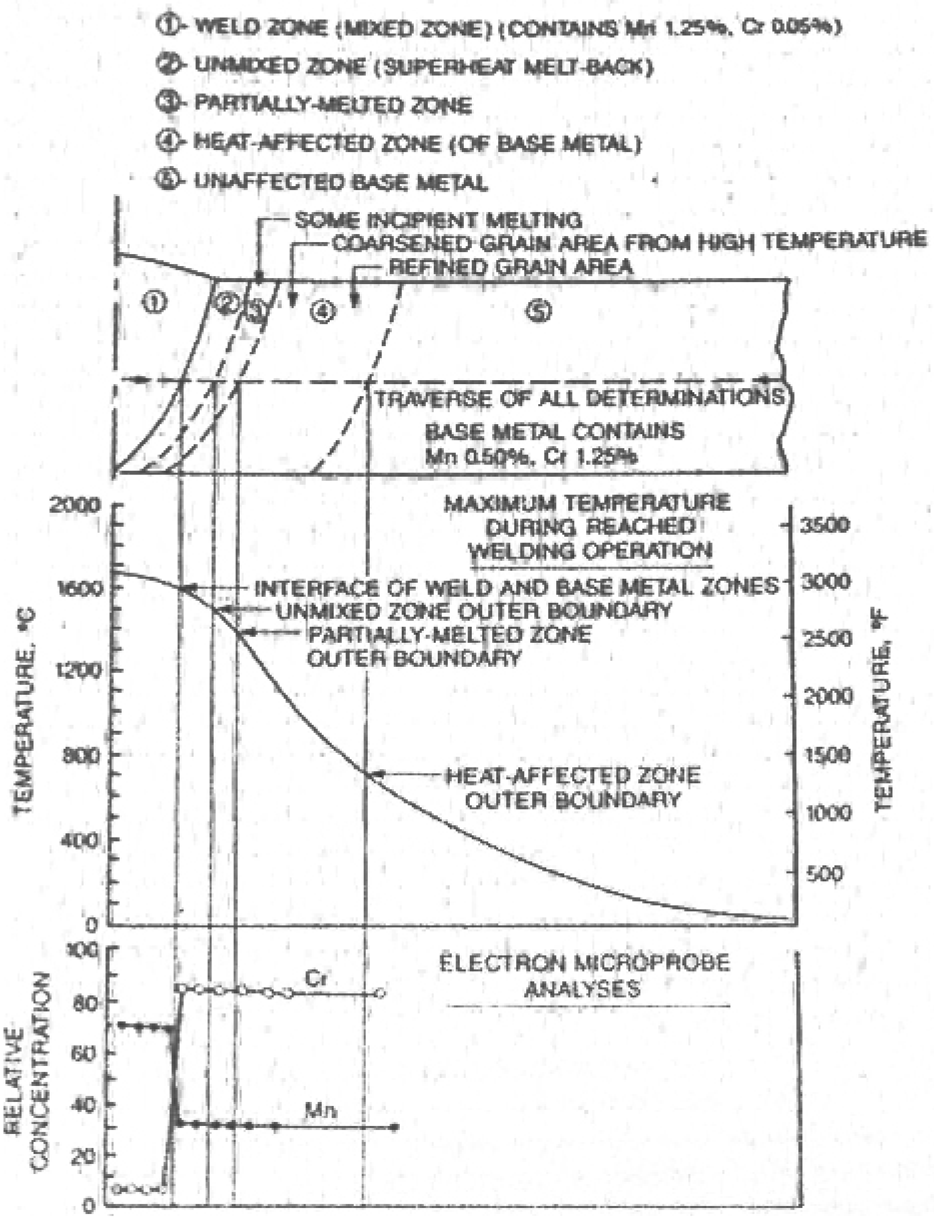


Figure 3.27: Distinct zones found in fusion welds [22]

3.8.3. The unmixed zone

The very narrow zone immediately adjacent to the weld zone, identified as a zone 2 in figure 3.27 consists of a boundary layer of melted base metal that was not mixed with the weld zone. This boundary layer is treated as a distinct zone even though it could be appropriately considered as part of the "weld zone" because of being melted, and initiating growth of grains which grow into the weld zone as solidification took place.

This zone also has been called the “superheat melt back zone” since it is produced by thermal energy contained in the weld zone in excess of that required to form an adequate molten weld.

The unmixed zones in most steel weldments seldom cause problems, and they ordinarily can be overlooked or ignored. Yet, there are circumstances with steel weldments where this zone can detract from performance. The abrupt decrease in manganese level and increase in chromium level clearly locates the mixed-unmixed boundary. [48]

3.8.4. The partially melted zone

The partially melted zone, identified as zone 3in figure 3.27.and does not always develop in every fusion weld made in steel. Its occurrence depends on a base metal chemical composition and microstructure in which small areas are melted by exposure to a temperature that approaches the usual liquids of approximately 1525°C.carbon steels ordinarily show little or no evidence of a partially melted zone in fusion welds.

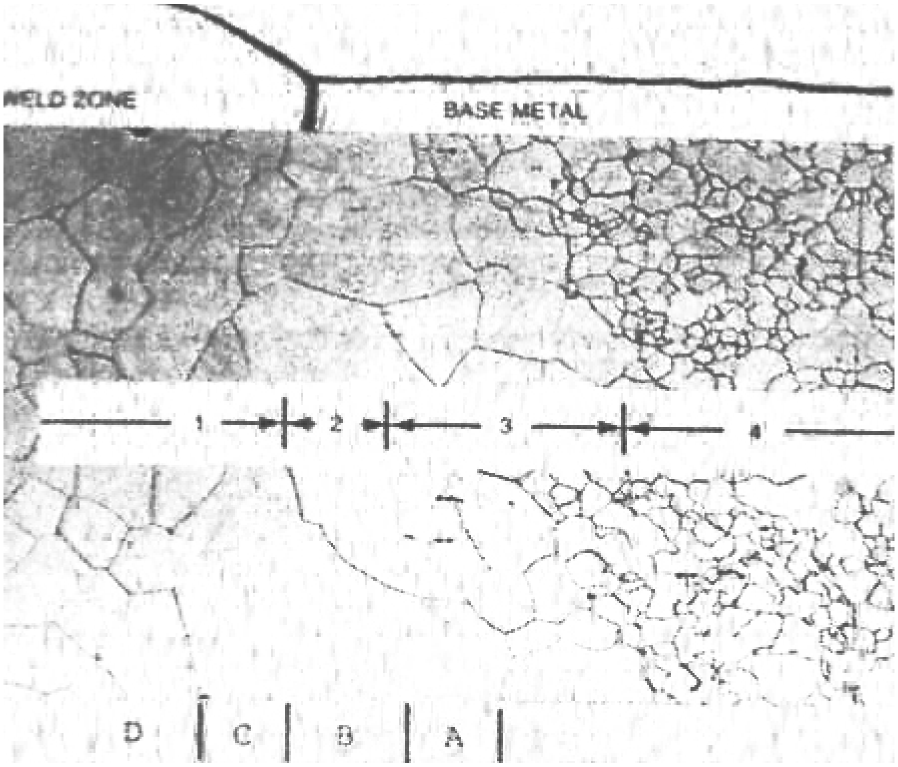


Figure3.28: Metallographic specimen prepared through weld made by GTAW

- **The heat affected zone [22]**

Beyond the zones in the base metal that involves melting is a much broader area called the heat-affected zone (HAZ). The HAZ is identified as zone 4 in figure 29 AWS defines the "heat affected zone" as the "portion of base metal whose mechanical properties or microstructure have been altered by the heat of welding. To avoid any confusion, the HAZ is in the present text will be entire zone in which properties and microstructure are altered by the heat of welding, as defined by AWS.

Most of the carbon and low alloy steels undergo the reversible allotropic transformations that are innate to their iron base, and this behaviour controls the majority of microstructural alterations from the heat affect of welding. [43]

3.8.5. Unaffected base metal

Although not changed in microstructure or properties, the base material is significant to the HAZ because its microstructure can influence its transformation during the heating portion of the thermal cycle .important are its grain size . banding of any kind ,center segregation ,and kind and number of nonmetallic inclusions . For example, if the base metal carbides have agglomerated as large, spheroidized particles, the start of austenite transformation and their dissolution will be delayed until a temperature somewhat higher than 727°C .[12]

3.9. Phase changes in steel

In steels, iron exists in two crystallographic forms:

(1) The bcc structure which when exisisting at a temperature of 912°C and bellow is called "ferrite" but specifically is alpha ferrite (a Fe), but when existing at a high temperature just below the solidus is designated delta ferrite (δFe).[5]

(2) The fcc structure which is called austenite (γFe) instead of gamma phase when carbon is present. Cementite is the name given to the hard iron carbide compound (Fe_3C) that forms in steels because of the chemical affinity that iron holds for carbon.

Initial presentation of microstructure appearance will be based on steel that has been slowly cooled from the molten state to room temperature.

3.9.1. Ferrite

Ferrite, the bcc phase, has been shown in figure 3.29 to explain such phenomena as recrystallisation, grain size, and epitaxial grain formation figure is presented here to show the general character of a completely ferritic microstructure in a commercial low carbon steel that contains so little carbon that no cementite or carbide particles have formed as a secondary phase.

Figure 3.29: Microstructure of ferrite found in slowly cooled steel [22]

3.9.2. Austenite

Austenite, the FCC phase, appears in low carbon and low alloy steel only of the particular steel composition; then it exists up to either the austenite to delta phase transformation range, or to the melting range in steels containing more than about 0.60 percent carbon. [33]

Departure from slow cooling of the austenite to other cycles will still cause the austenite to transform to ferrite, but other mechanism can be involved and markedly different forms of carbide dispersal will be produced . Accelerated cooling is the most common circumstance that causes the austenite to transform under non equilibrium conditions and rapid cooling is certainly the usual case in fusion welding. Other microstructures that can evolve from austenite are called bainite, martensite, and acicular ferrite.etc.these must be recognized when they appear in two or more of these phases. For this reason austenite is looked upon as the mother of microstructures. [31]

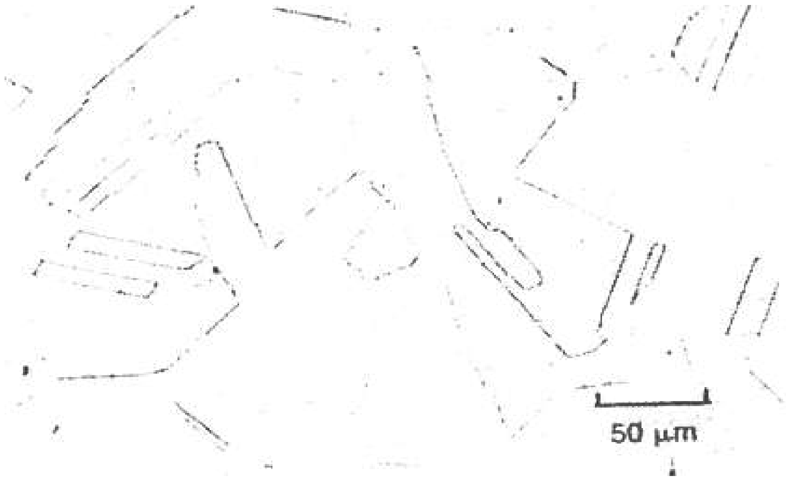


Figure 3.30: Microstructure of austenite in carbon and low alloy steel [22]

3.9.3. Cementite

Cementite or iron carbide appears in many configurations depending upon the initial distribution of carbon in the austenite, the cooling rate of austenite during transformation to a body centered type crystalline structure and the temperature level at which cooling is stopped .The configuration of cementite can range from a dispersion of sub-microscopic size particles to large globules and several unusual configurations in between .the globular or spheriodal carbides are not as large as the grains of ferrite that make up the matrix of the microstructure.[22]

3.9.4. Pearlite

Pearlite is the microstructural configuration in which cementite is most often found in steels. This is a two phase eutectoid structure which consists of alternating platelets of lamellae of cementite and ferrite as shown in figure . pearlite forms when austenite is cooled through some transformation range at a rate that is not too fast to allow the nucleation and growth process by which pearlite is formed. [42]

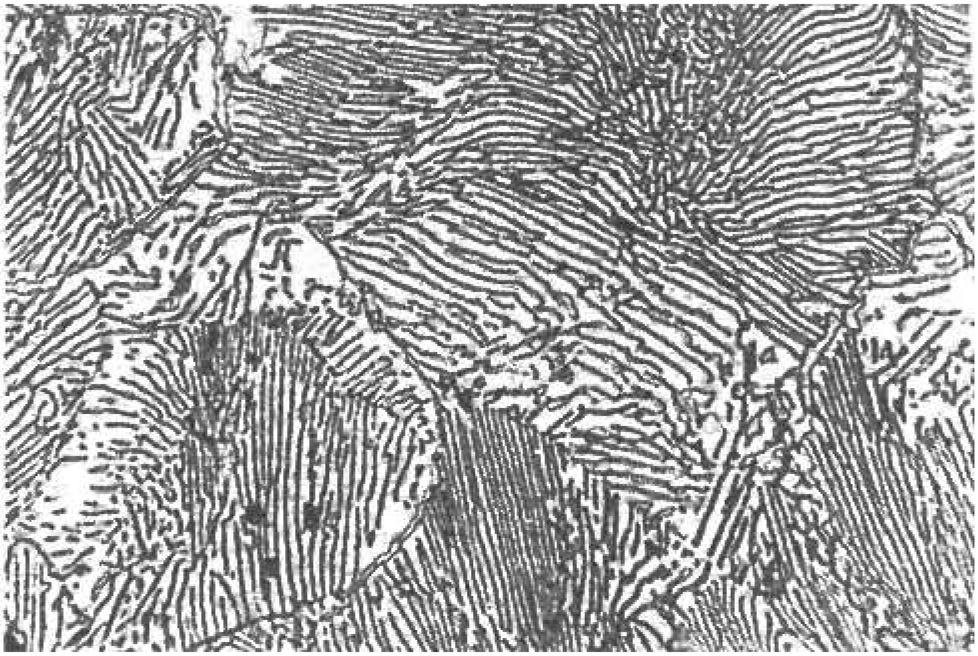


Figure 3.31: Microstructure of pearlite formed in steel containing 0.31% carbon [22]

3.9.5. Martensite

Martensite is the hardened microstructure that forms in an austenized steel when cooled at a rate too fast to permit the nucleation and growth mechanism by which pearlite is formed . instead , transformation of austenite to martensite takes place by a very rapid diffusion less mechanism after under cooling to a markedly lower temperature. As the austenite transforms to martensite , carbon is trapped as solute atoms in an interstitial solid solution. the mechanics of austenite to martensite transformation is unique and is a very important behavioural aspect of steel.[39]

I.Qualitative effects of alloying elements on Martensite formation (Ms) Temperature.

Table 3.3: effects of alloying elements on Martensite formation (Ms) [22]

Alloying element	**Qualitative Effect**
carbon	Lowers Ms markedly
Manganese	Lowers Ms
silicon	Virtually no effect
chromium	Lowers Ms
nickel	Lowers Ms
molybdenum	Lowers Ms
copper	Lowers Ms
vanadium	Lowers Ms
Tungsten	Lowers Ms
cobalt	Raises Ms
Aluminium	Raises Ms

II.-Calculation of martensite formation (Ms) Temperature from chemical Composition.

$$Ms\ (\text{Deg. F}) = 1000-650\ (\%C)-70\ (\%\ Mn)-35\ (\%Ni)-70\ (\%Cr)-50\ (\%Mo)$$

This equation is applicable to steels falling within the following Composition limits:

Table 3.4: steels falling within the Composition limits

carbon	0.1-0.55
Manganese	0.2-1.75
silicon	0.1-0.35
chromium	3.5 max
nickel	5.0 max
molybdenum	1.0 max

3.10. Microstructural changes in steel during heating

Microstructural changes during heating are important because conditions created in various areas or zones at the end point of heating often set the stage for the nature of transformation events that follows during cooling. While heat treating operation applied to steel are carried out at control temperature to secure particular microstructure and properties, welding introduce the broadest possible range of temperatures, a gradient of end points of heating from which cooling starts. Certain end points temperatures that lies somewhere between

1. The high peek that produce the liquation found in a partially melted zone

2. Much lower temperature further away from the weld that produces no

Perceptible change in microstructure,

Will be found to have significant affect on the microstructure finally produce at given points in the HAZ of the base metal.

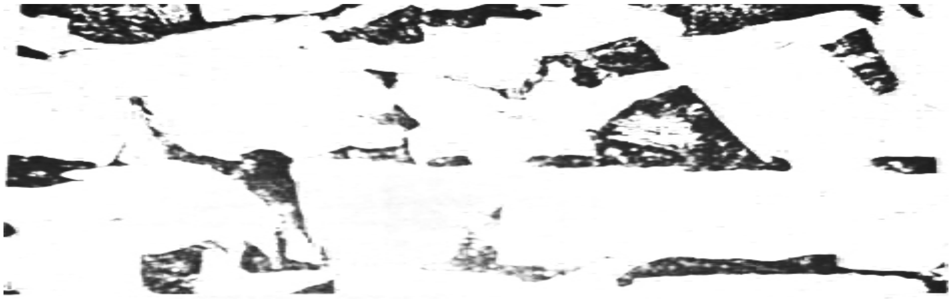
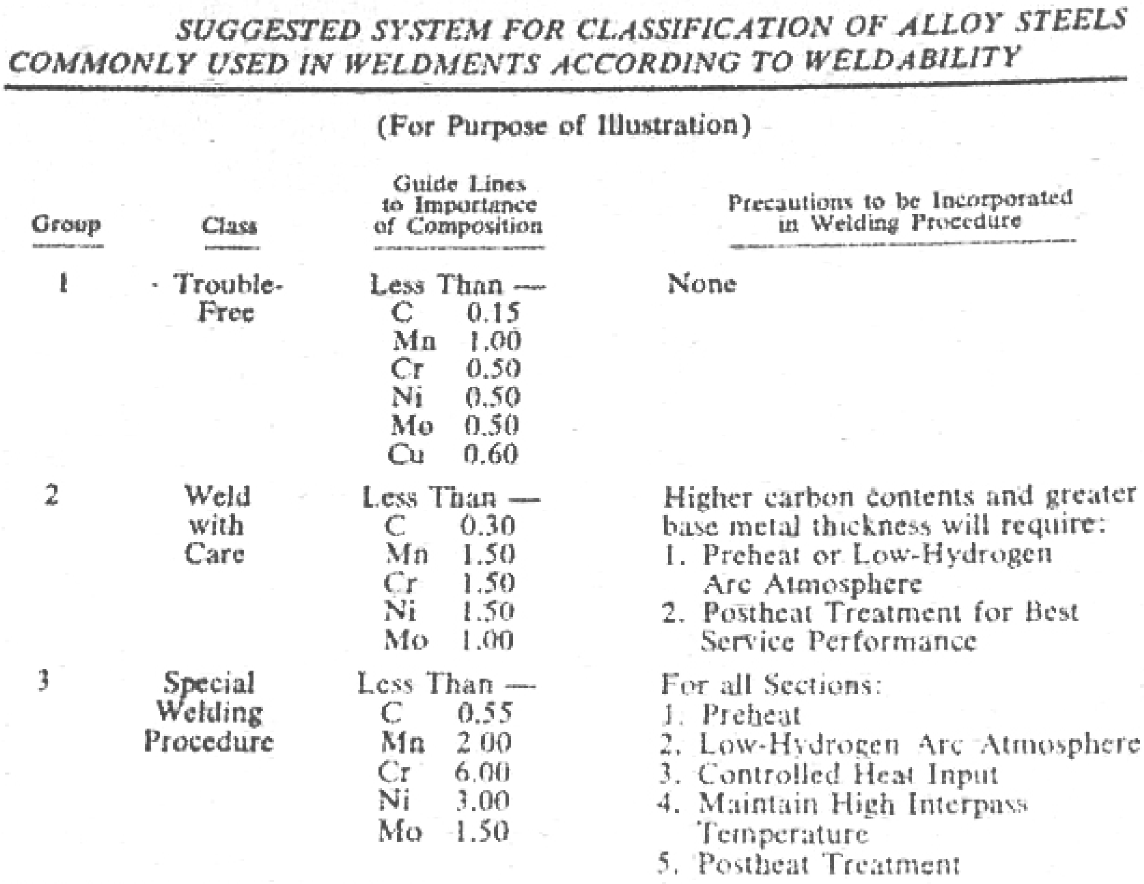


Figure 3.32: Microstructure of pearlite and ferrite of a steel containing 0.31 % carbon [22]

Table 3.5: classification of alloy steels commonly used in weldments according

To weld ability [22]



SUGGESTED SYSTEM FOR CLASSIFICATION OF ALLOY STEELS COMMONLY USED IN WELDMENTS ACCORDING TO WELDABILITY

(For Purpose of Illustration)

Group	Class	Guide Lines to Importance of Composition	Precautions to be Incorporated in Welding Procedure
1	Trouble-Free	Less Than — C 0.15 Mn 1.00 Cr 0.50 Ni 0.50 Mo 0.50 Cu 0.60	None
2	Weld with Care	Less Than — C 0.30 Mn 1.50 Cr 1.50 Ni 1.50 Mo 1.00	Higher carbon contents and greater base metal thickness will require: 1. Preheat or Low-Hydrogen Arc Atmosphere 2. Postheat Treatment for Best Service Performance
3	Special Welding Procedure	Less Than — C 0.55 Mn 2.00 Cr 6.00 Ni 3.00 Mo 1.50	For all Sections: 1. Preheat 2. Low-Hydrogen Arc Atmosphere 3. Controlled Heat Input 4. Maintain High Interpass Temperature 5. Postheat Treatment

Table 3.6: Qualitative effect of elements over indicated range [22]

Alloying Element	Range, %	Expected Influence on Fracture Toughness
Carbon	0 to 0.4	Marked decrease
Manganese	0.2 to 2.0	Mild increase
Phosphorus	0.01 to 0.07	Very marked decrease
Sulfur	0.01 to 0.05	Very small decrease
	0.05 to 0.15	Moderate decrease
Silicon	0.1 to 0.5	Small increase
	0.5 to 1.5	Moderate decrease
Chromium	0 to 0.5	No significant influence
	0.5 to 1.0	Small decrease
Nickel	0 to 3.0	Moderate increase
Molybdenum	0 to 0.5	Small decrease
Copper	0 to 2.0	Small increase
Vanadium	0 to 0.15	Small decrease
Titanium	0 to 0.4	Moderate increase
Aluminum	0 to 0.05	Very small increase
	0.5 to 0.1	No further influence
Boron	0 to 0.004	Small decrease
Nitrogen	0.005 to 0.04	Small decrease
Hydrogen	0 to 0.003	Significant decrease
Oxygen	0 to 0.12	Small decrease

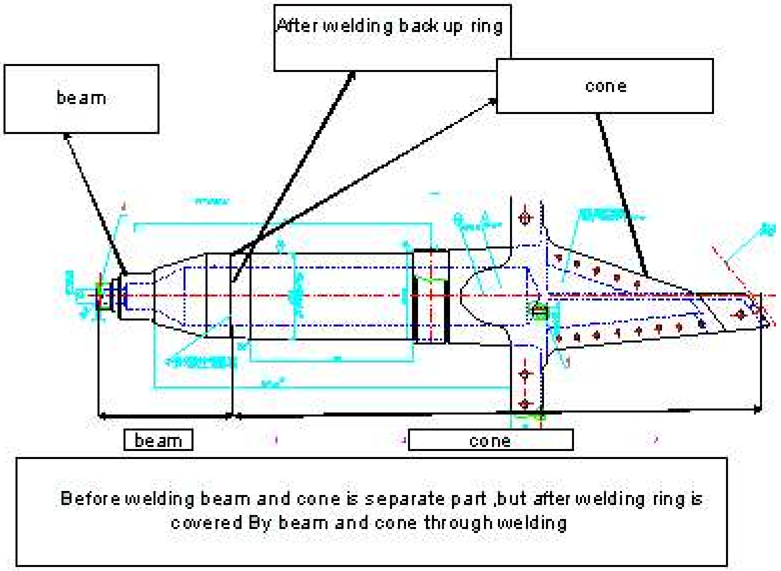
CHAPTER 4

EXPERIMENTAL WORK & RESULTS

4.1. Background

The part which is carried out for study purpose is **canard beam,** made of 30KHGSN2A-VD.sub parts of canard bean is carried out at welding shop and assemble them and comes out to be a single part that is canard beam.

When part comes under welding there is certain procedure (Russian technology) has to be followed.



Before welding beam and cone is separate part ,but after welding ring is covered By beam and cone through welding

Fig 4.1: canard beam [18]

In above figure shows that for making of canard beam, the backup ring has to fill 12-15 mm through the electrode and fillers .After tacking, root run is carried out with the help of GTAW (for defect free root) then next 4 run is welded by FCAW welding .basically it is a pipe welding but here we are doing it manually as a flat butt joint.

So it is very critical part and welding is also very critical so I wouldn't get the part for analysis so that's why I took some standard specimen of same material and started my work with them.

Welding is completed in 5 layers (one layer of GTAW and 4 layer of FCAW) .Before starting welding; backup ring should be attached with beam and cone of canard beam. then after complete assemble the ring attached between beam and cone with tack weld.

4.1.1. AFTER TACKING

Part is preheated in furnace up to (290+10) °C. For 45-50 min, then part is ready for root run or first layer of welding.Then part is fixed over the fixture and root run is started.Root run parameters are shown in table 4.1 below

Table 4.1: Root runs parameters

Process	Electrode	Filler	Current	Voltage	Gas	intensity
Argon arc welding (TIG)	Tungston Rod TU48-19-27-77….dia 2.5 mm	TU14-1-4292-87….. dia 2mm	70-120 A	10-12	argon	6-7 l/min

After root run part is directly send to furnace for the tempering and tempering temperature is (650+10) °C for 35-40 min. Then part is removed from furnace and leave it fot atm cooling Then next we check the run out in turning machine whether it is deflected or not (limit is upto 0.5mm) practically it was 0.2 mm considerable.

Then part is sent for x-ray (NDT) after X-ray test I did 2nd layer of welding by (FCAW) Before welding maintain part in the furnace at a temperature of 300 °C for 45-50 min. and electrode is maintained at 500 degree centigrade for 3 hrs there are 4 layer of FCAW welding. After each layer part go for X-ray inspection. (For radiation flaw detection)

Table 4.2: Parameters which have used in FCAW

Process	Electrode	Filler	Shielding Gas	Current	Voltage	flux
Flux cored arc welding	NIAT-3M (E-13G1XM-O-V20)	nil	Nil	120 A	12-15 v	Rutile iron powder
	Dia 3mm					
	Length 2-2.5 meter					

Before root run we did fusion run with filler dia of 1.6 mm and length (1 meter)

4.1.2. Used Electrode

Electrode which we have used specification is shown below:

GOST 346 (E-13G1XM-O-V20), AWS E7024,ISO E432RR16046,DIN E4320RR11160,EN E38ARR74

A very fast high efficiency rutile iron powder electrode giving a metal recovery of approx. 180%. Particularly suitable for fillet welds on mild steel with tensile strength up to 450 MPa. Ñan be used for welding only in flat position on AC or DC(+) current.

Used flux: The flux used is rutile based, it is acidic, T-6 classification, it produces smooth, stable arc without externally applied shielding gas.

Table 4.3: Electrode specification

Type of electrode	rutile.
Deposition rate factor	15,0 g/A•h
Efficiency of deposition (for dia 3,0 mm)	3,3 kg/h.
Consumption of electrodes per kg Deposited metal	1,3 kg

4.1.3. Typical all weld metal chemical analysis, %

Table 4.4: Chemical Composition of Electrode

C	0,15
Mn	1,60
Si	0,20
S	0,030

4.1.4. Typical all weld metal mechanical properties

Table 4.5: Mechanical Properties

Tensile strength, MPa	490
Yield strength, MPa	390
Elongation, % .	27

4.1.5. Special properties

The electrode is very easy to strike and is ideal for short welds. OZS-3 gives smooth weld beads, and slag is easy to remove.

4.1.6. Technological features of welding

Process Keep arc short as possible withtouching tip of the electrode to the molten pool. Dry electrodes at 500°C for 3 hour.

Table 4.6: Current Range According To Electrode Diameter

Dia, mm	Length, mm	Current range, A
3,0	350	150-210
4,0	450	180-240
5,0	450	240-320

There is no CAT E part available In HAL for the analysis of canard beam. So for the analysis of the above said part of 30KHGSN2A-VD material I took 6 rectangular plates of size (110x100) mm^2 and performed the same procedure as above said and done welding, X-ray, tensile testing, bend testing, hardness check, and microstructure analysis at HAL for the same part which will be describe below:

4.2. Welding machine used for GTAW

TYPE: Model MLS -3500(invertor controlled) ;(Finland made)

- Welding current capacity: 5-400 amps;
- Steeples weight: 21 kg
- Electrode size: 1.5 mm to 6 mm

4.3. Welding machine used for FCAW

Welding Generator

Table 4.7: Welding Generator Specification

TYPE: KE	AMPS	DUTY CYCLE
	300	60%
	230	100%

OCV	86
MAX CURRENT RANGE	MIN 45 A MAX 350A
INPUT 19 KW MAX	31 A, 415 V
3 PH	50 HZ, RPM 1500

4.4. Furnace used for pre-heating and post-heating

Metco furnace

Table 4.8: Metco Furnace Specification

volts	AC	watts	AMPS	max welding temp
400/440 V	50	70/39 PH 3	110/55	1000°C

4.5. Material used

The material used for the specimen was 30KHGSN2A-VD.

4.6. Composition of material

The compositions of 30KHGSN2A-VD are as follows. Spectrometer analysis was done to find out the chemical compositions. the composition is given in the table 4.9

Figure 4.2: Sample with spectra analysis

4.6.1. Equipment used: advance spectra analyzer; Germany

Table 4.9: Chemical Composition Of Used Material

30KHGSN2A-VD	REQUIREMENT	ACTUAL
Carbon (C)	0.27-0.34	0.31
Chromium (Cr)	0.90-1.20	1.03
Manganese (Mn)	1.00-1.30	1.04
Silicon (Si)	0.90-1.20	1.11
Nickel (Ni)	1.40-1.80	1.53
S(not more than)%	0.030	0.006
P(not more than)%	0.030	0.0104

4.7. Specimen preparation

The specimen after milling was made to the size required for the welding . the size of the rectangular sample was 100x110x5 (LXWXT). Firstly I took 6 plates of (110x100) mm^2 and make 3 parts from 6 plates by tacking .and mark on plate A,B and C.(thickness of plate is 5 mm)

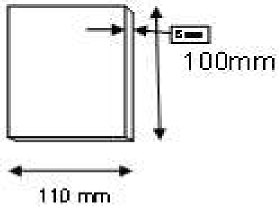


Figure 4.3: sample for specimen

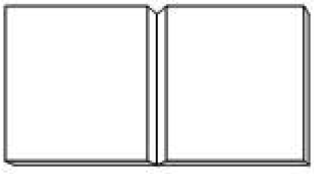


Figure 4.4: specimen for welding

Tacking parameters are as follows:

Table 4.10: tacking parameters

process	Electrode dia 2.5 mm	Filler wire dia 2 mm	voltage	Current	Qty of layer	Gas (argon)
TIG	TU48-19-27-77(Tungsten Rod)	EP331U-VI TU 14-1-4292-87	10-12 (14.5)	70-120 (113)	2 Points	6-7 litre/min (10-14) Ltr/min

Time of tacking is 1 min, after tacking cleaning is done by wire brush and rotary bit.

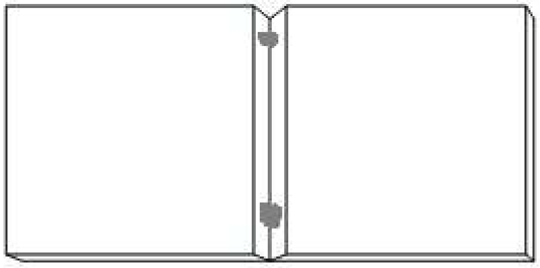
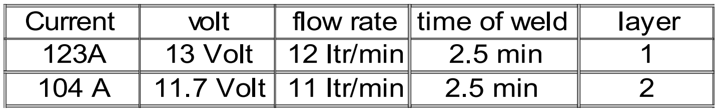


Figure 4.5: specimen after tacking

Generally tacking is done on room temperature .and there is no requirement of preheat the part. If we want to increase the current then we should increase the speed also. Otherwise more deposition will occur at one place.

After tacking, Preheat the part up to 290°C for 25 min and root run was done by consequently two layer of welding. There were certain conditions which I have adjusted for the analysis is shown below:

Table 4.11: used parameter of TIG welding



Current	volt	flow rate	time of weld	layer
123A	13 Volt	12 ltr/min	2.5 min	1
104 A	11.7 Volt	11 ltr/min	2.5 min	2

4.8. For the identification of the conditions which I have applied over samples I have given following identification:

1. **PART (A)**

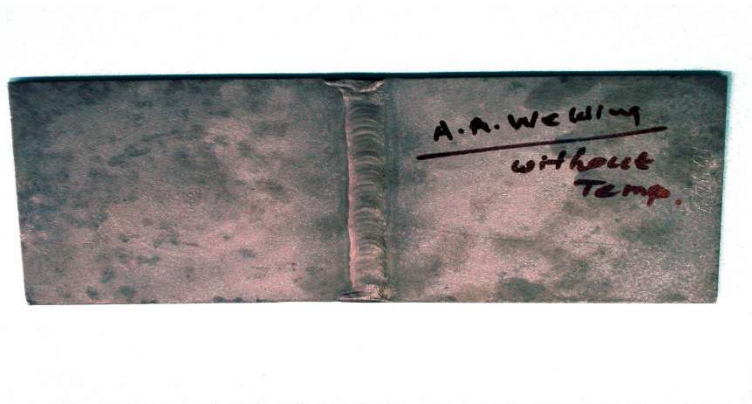


Fig 4.6: After tacking preheated (290°C for 25 min) and welding is done by GTAW (2 layer), then after welding took the part without post heat.

2. **PART (B)**

Fig 4.7: –After tacking preheated (290°C for 25 min) and welding is done by GTAW (2 layer), then after welding the part is post heated (650°C for 30 min).

3. **PART (C)**

Figure 4.8: After tacking preheated (290°C for 25 min) and welding is done (1st layer by GTAW and 2nd layer by FCAW), then after welding the part is post heated up to (650°C for 30 min).

Table 4.12: Used Parameter Of TIG And FCAW

current	volt	flow	ime of wel	layer
123A	13V	12ltr/min	2.5 min	1
120	14 V	nil	10 min	2

4.9.For TIG Welding, Root run parameter is same as the above said for the part but the Composition of filler material is same as a base metal 30KHGSN2A-VD.after completion of welding I have done the X-ray (Radiography testing) for checking the quality of the weld or defect in the weld.

4.9.1. Equipment details

Equipment name-Industrial x-ray (300kv, 5mA)

Model - MXR301, Hungery

Application -Defects in steel, casting and weldments.

4.9.2 Test Procedure

1. Firstly I went to the exposure room where x-ray setup was arranged. Room is surrounded by 20 inch thick concrete wall because of x-ray radiation property.elctron is emitted by throated tungsten is embedded in cu anode then disperse on the object .as shown in figure below schematic system of x-ray.

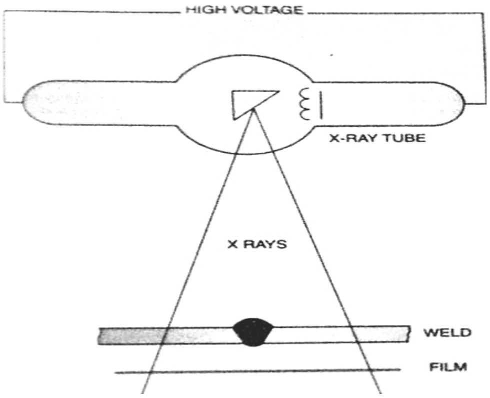


Fig .4.9: Schematic representation of x-ray system [49]

2. The film which is used for photographic image is having coating of silver bromide.

Film material – silver bromide, silver hallide

Type of film- D2 (slow film) for plastic, mg.

D4 (medium film) for Al, mg

D7 (fast film) for steel, Ti, for high density and thickness we are using.

3. Tube current is constant but x-ray time may vary. Thicknesses of samples are 5 mm.

After x-ray differential absorption on plate I found:

Penetrating power	170 kv
Time of x-ray	1.4 min
Tube current	4 mA

4. For identification of samples I have used lead identification A, B and C. Lead is more absorbent of x-ray. It looks like whitish in the film.

5. Then I removed part from x-ray machine and went to the dark room for processing

Chemical with the developer (alkaline metol hydro qunon) , fixer (acidic sodium

Thyosulphate) and preservating hardner.firstly put the x-ray film on developer which is alkaline nature up to 5 min then into water, after that put into the fixer for 5 min. after removing from fixer wash them and put into the drier (having one fan in above side and heater is in bottom side.) for 25 min.

6. After that remove the part from drier and went for the film viewer (illuminator) where magnifying glasses (lens) were there and I found following results:

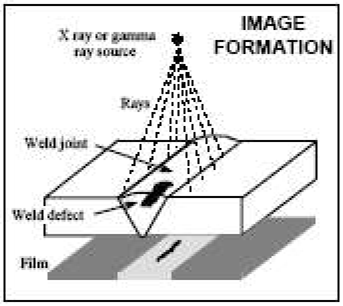
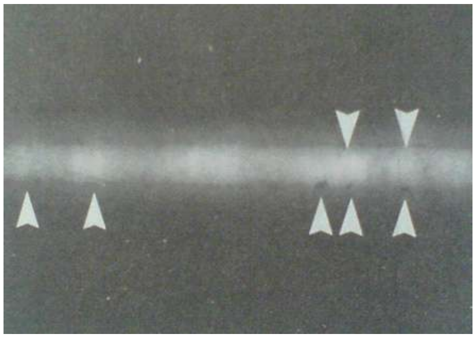


Figure 4.10: image formation in x-ray [51]

Table 4.13: x-ray results

SPECIMEN	X-RAY RESULT
A	no defect found in x-ray hence ,Welding is satisfactory
B	 Lack of fusion found in x-ray(figure 4.11)
C	no defect found in x-ray hence ,Welding is satisfactory

7. Lack of fusion between the weld beads and joint surfaces to be welded.

Elongated parallel or single , darker density lines sometimes with darker density spots dispersed along the LOF lines which are very straight in the lengthwise direction and not winding like elongated slag lines . Although one edge of the LOF lines may be very straight like LOP, lack of fusion images will not be in the centre of the width of the weld image.

8. Quantity of x-ray is the product of tube current and time of x-ray. Here 2% sensitivity expected.

After completion of x-ray testing now come to the tensile, bending and micro test. For these test; specimen should be in standard size according to the thickness of material as per Russian standard.

Note: Part B found correct by rework

4.10. Specimen preparation for tensile, bend and micro test

The test specimen A, B and C after machining was made to the size required for the tensile, bending and micro test. Dimensions are shown below: (thickness is 5mm)

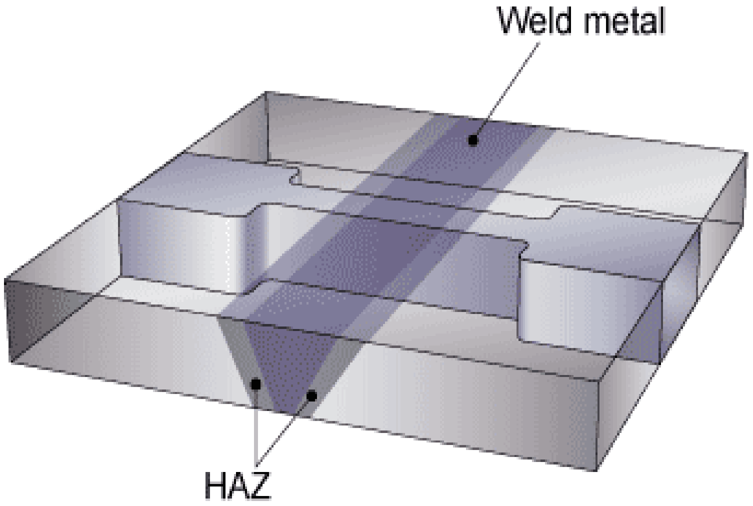


Fig 4.12: Tensile specimen from rectangular weld [28]

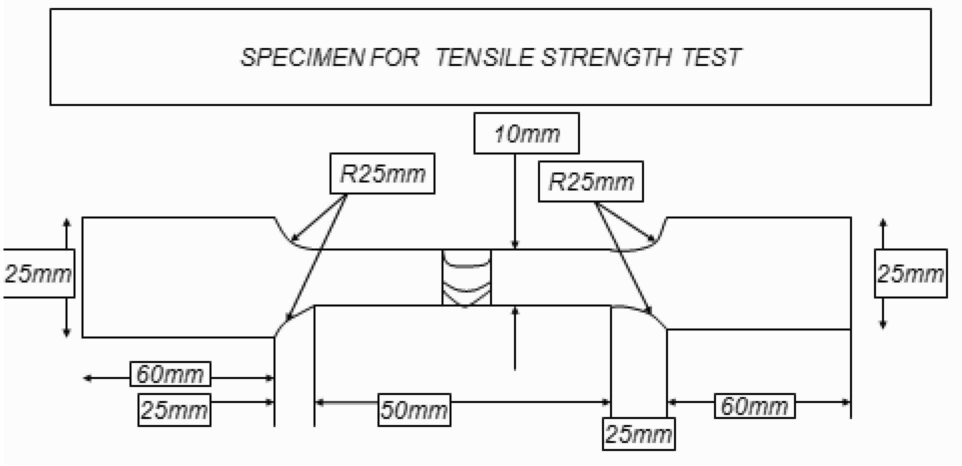


Fig 4.13: Specification for tensile test specimen

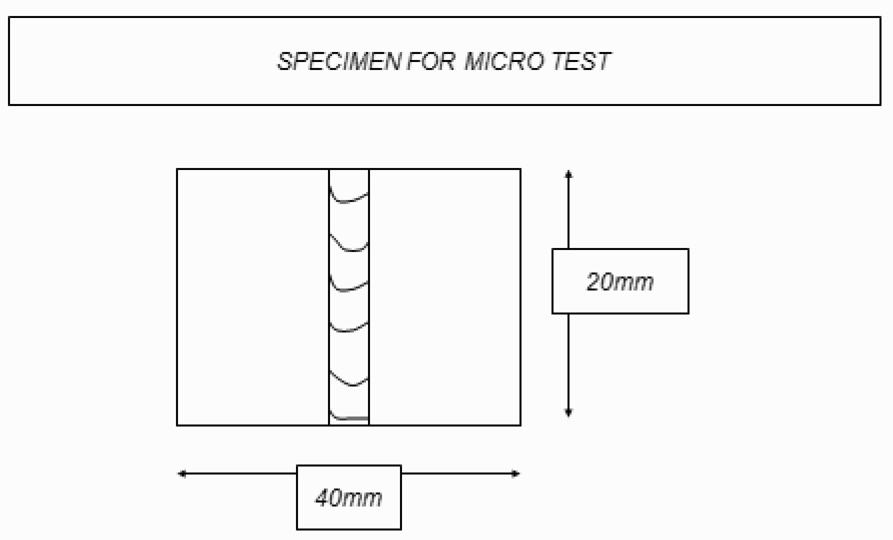


Fig 4.14: Specification for micro test specimen

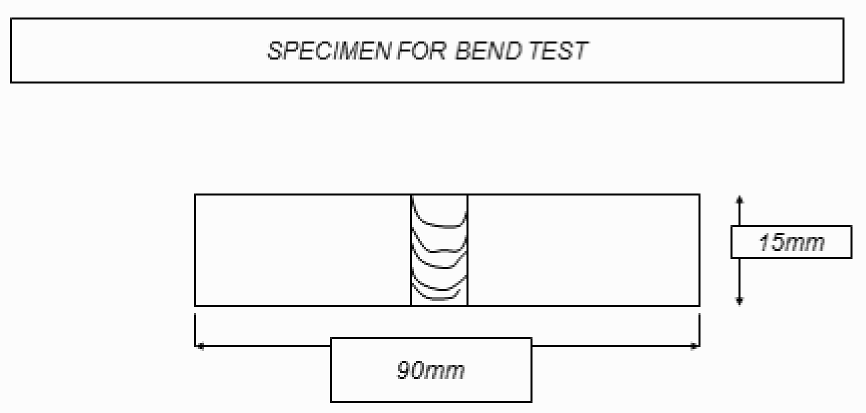


Fig 4.15: Specification for bend test specimen

The original specimens (photograph) which were used for, tensile testing, bend testing and finally for the metallographic are shown below

Fig 4.16: Sample (A, B&C) test pieces for tensile, micro and bend test

Fig 4.17: Bend test specimen

Fig 4.18: Micro test pieces for specimen (A, B &C)

Before starting the tests part is to be heat treated and for heat treatment but before gone for the heat treatment I have seen the microstructure of the micro test specimen (A,B &C) which will explain further. I have followed following steps for heat treatment as per Russian technology:

1. Preheat the part up to 650°C in chamber furnace for 15 min.
2. Then hardening up to 900 °C for 15 min on chamber furnace .then put the parts into C-11 servo Quenching oil for cooling at normal atmosphere.
3. After Quenching and cooling remove the part and clean the part.
4. Than temper at 250-300°C for 3 hours in shaft furnace (air circulation).
5. Then air cool the part till cooling.
6. After cooling the part I went for descaling process of the specimen by sand blasting.

Whatever procedure I have adopted as per the Russian technology and for the material 30KHGSN2A-VD (high strength low alloy steel.) and is also same for the canard beam. Only difference in the soaking time. Soaking time will change or varies according to the area cross section of the part but temperature remains same for the specific material.

Now I got the hardened and tempered test specimen for the tests. The specimens were used for hardness testing, tensile testing (UTS), bend testing and finally microstructure.

4.10.1 Hardness testing

The "Rockwell hardness tester" was used for hardness testing of the specimen .it provided the hardness value of the surface in the range from 46 HRC to 48 HRC.

CONVERSION OF ROCKWELL HARDNESS NUMBER TO TENSILE STRENGTH

Table 4.14: Rockwell hardness and tensile strength

HRC	**TENSILE STRENGTH**
	kg/mm^2
45.5	160
46.5	165
47.5	170
48.5	175
49.5	180
50.5	185
51.5	190
52	195
52.5	200
53	205
53.5	210
54	215

That means our HRC is found correct because I have earlier explained the HRC should be within 45.5 to 49.5 for this material.

4.10.2. Tensile testing (UTS)

4.10.2.1. EQUIPMENT DETAILS

Name of equipment – UTL (100KN)

Model - Instron 1195, UK

Application -Tensile, compression, load deflection test, calibration of force

Gauges, cyclic test, bend test, upsetting test, shear test.

Figure 4.19: UTL tester instron 1195(UK)

4.10.2.2. Test results

- UTL tester instron ,1195 is used to evaluate the tensile strength of standard specimen
- One by one the test specimen (A, B & C) was fixed between the jaw and operated by control panel as shown in figure above. And got following results:

  Table 4.15: Tensile Test Results

Specimen	Area (mm2)	Breaking load (kg)	U.T.S. (kg/mm2)	Locaion of fracture
A	47.30	8175	172.83	Base metal
B	49.10	5700	116.09	On weld joint
C	49.94	8350	167.19	Base metal

As per the Russian technology tensile strength of 30KHGSN2A-VD should be within 160-180 kg/mm^2. Requirement of weld is that the UTS of weld should be within 90% of (160-180 kg/mm^2). hence specimen A and C has good quality of strength but Specimen B which is already found defect in x-ray is having less strength and also failed from weld joint. The broken samples are shown below:

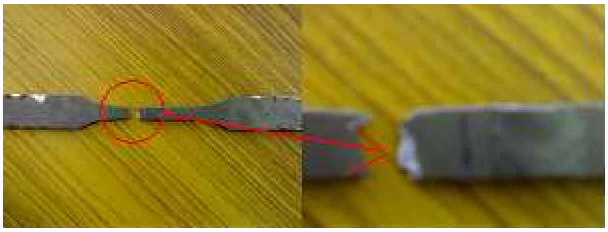


Fig 4.20: Specimen "A" after UTS

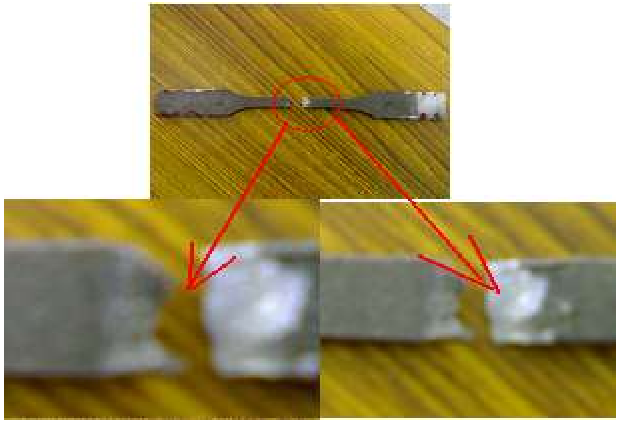


Fig 4.21: Specimen "B" after UTS

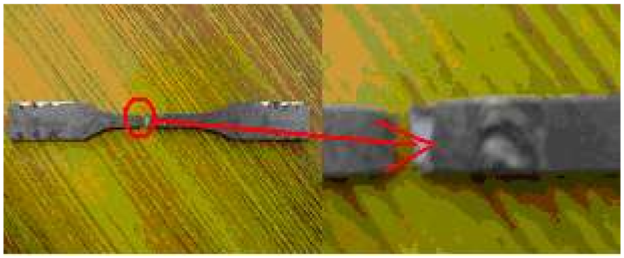


Fig 4.22: Specimen “C” after UTS

4.10.3. Bend Test

4.10.3.1. Equipment details

Name of machine (equipment): Universal testing machine

(100 KN) 10 ton

Model: Frank W Germany

Application: Bend test, tensile testing, compression test, shear test

4.10.3.2. Test procedure

- Test pieces were mounted over the UTL machine along with plunger and fixture, sample is mounted over the fixture and plunger over the weld test piece (along the weld). And these all set up between the jaws then tightly hold between the load jaws and apply the load till the fracture.
- Root face was load side and weld face was opposite side hence weld side was on tensile loading and compression load on root side.
- I got following results which are as follows:

Fig 4.23: After bending, bend test sample A,B & C

Table 4.16: bend test results

Test sample	Angle of bend	(Hardened and tempered) Bend sample after bending
A	32°	
B	30°	
C	40°	

I found more bend angle on C, it means TIG and FCAW welded part is having more stretching or ductility.

4.10.4. Microstructure Examination

Microstructure of standard specimen of 30KHGSN2A-VD (A, B&C) and original material, before and after tempering and hardening was observed using image analysis system which shown below:

Figure 4.24: image analysis system (medimage tech. pvt. Ltd.,India)

4.10.4.1. Equipment And Consumable:

Cutting machine, belt grinder, polishing paper (emery papers) 220, 320, 400, 600, 1/0, 2/0, 3/0 grit papers.bakellite powder ,mounting press ,polishing machine ,silicon carbide powder, alumina paste, 3 to 5 % nital-etchant, alcohol etc.

4.10.4.2. Test Required:

Microstructure of standard test specimen. (A, B & C) and original material (30KHGSN2A-VD)

4.10.4.3. Procedure

Cut the pieces in standard size then prepare the surface on belt grinder .polish to fine luster using emery paper in the steps of 220,320,400,600,1/0,2/0 &3/0 grit and on polishing machine by using silicon carbide powder and finally using alumina paste to produce an even ,scratch free bright mirror like polish surface .wash and dry the specimen with water ,etch in 3 to 5% natal rinse the specimen in water ,snagged with alcohol and dried.

4.10.4.4. Result Analysis:

The test specimen were polished as per the requirements of microstructure examination and inspected under a image analyser. The structure exhibited two results for each welding joints .(one for before hardened and tempered of original material and 3 test pieces A,B and C & Second for after hardened and tempered for the same test pieces.)

(5% Nital etch)

Table 4.17: microstructure observation

Sample	**Before heat treatment**	**After heat treatment**
A	Base metal ,HAZ and weld uniformity in structure	Tempered martensite
B	Base metal , HAZ and weld Bigger HAZ observed.	Tempered martensite with some inhomogenity in HAZ area.
C	Base metal ,HAZ and weld uniformity in structure	Tempered martensite and homogenized base metal ,HAZ and weld structure. Uniform heat treatment without any abnormality.

Microstructure photographs are shown below:

Print magnification is 260µm and photo magnification is 640X (for all microstructures)

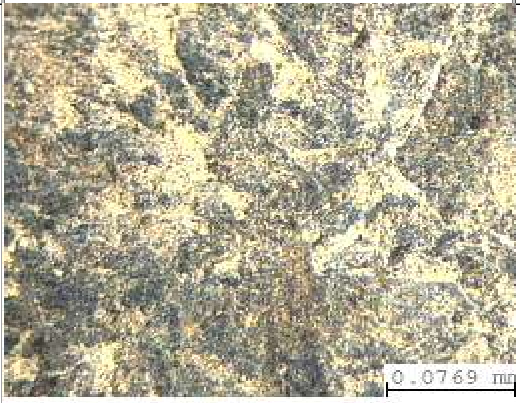
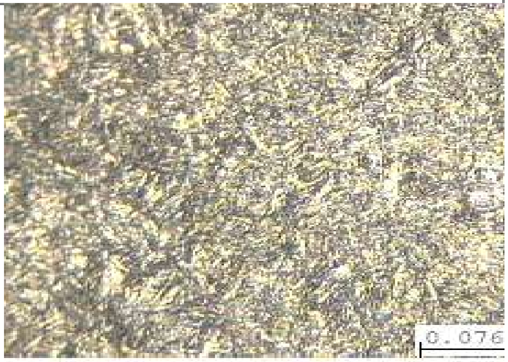
Abbreviation used:

P	PEARLITE
F	FERRITE
TM	TEMPERED MARTENSITE
RA	RETAINED AUSTENITE

Sample	before hardenning and tempering	after hardenning and tempering
Original material		

P 51.93%, F 48.07% TM 94.14%, RA 5.86%

Figure 4.25: Image of Original material before and after hardening and tempering

Sample	before hardenning and tempering	after hardenning and tempering
Base metal sample A	 Base Metal after welding	 Base Metal Sample A Tempered Martensite

P 52.58%, F 47.42% TM 88.58%, RA 11.42%

Figure 4.26: Image of base metal of SAMPLE A before and after hardening and tempering

Sample	before hardenning and tempering	Af ter hardenning and tempering
Base Metal of Sample B	 Base metal	 Base Metal Sample B Tempered Martensite

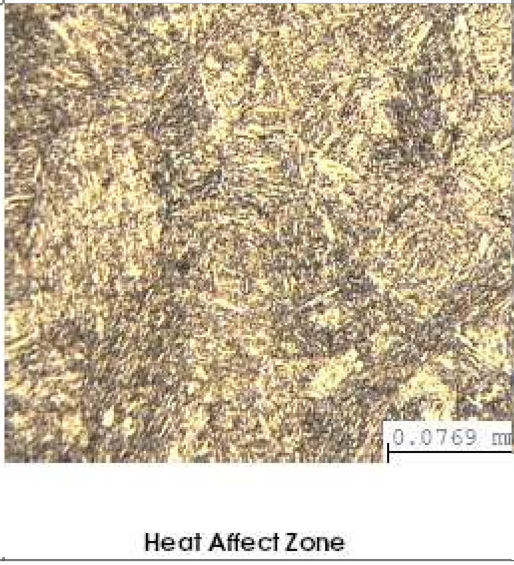
P 60.85%, F 39.15 TM 93.60%, RA 6.40 %

Figure 4.27: Image of base metal of SAMPLE B before and after hardening and tempering

Sample	before hardenning and tempering	Af ter hardenning and tempering
Base metal OF Sample C	 Base metal	 Base Metal Sample C Tempered Martensite

P 54.15%, F 45.85% TM 88.63%, RA 11.37%

Figure 4.28: Image of base metal of SAMPLE C before and after hardening and tempering

Sample	before hardenning and tempering	after hardenning and tempering
Heat affected zone of Sample A		

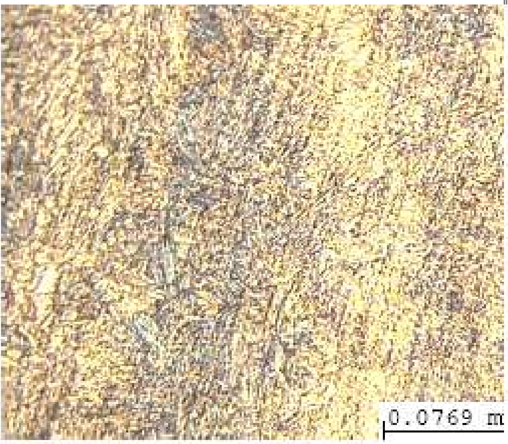
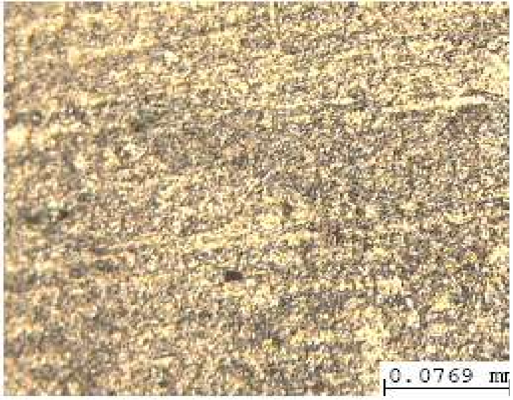
P 49.26%, F 50.74 % TM 89.90%, RA 10.10%

Figure 4.29: Image of HAZ of SAMPLE A before and after hardening and tempering

Sample	before hardenning and tempering	After hardenning and tempering
HAZ OF Sample B	 Heat Affect Zone	 Heat Affect Zone Sample B NOn uniformity in Structure

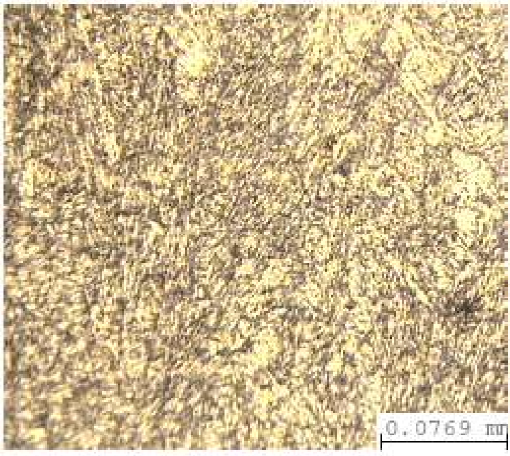
P 51.90%, F 48.10% TM 56.22 %, RA 43.73%

Figure 4.30: Image of HAZ of SAMPLE B before and after hardening and tempering

Sample	before hardenning and tempering	After hardenning and tempering
HAZ OF Sample C	 Heat Affect Zone	 Heat Affect Zone Sample C Tempered Martensite

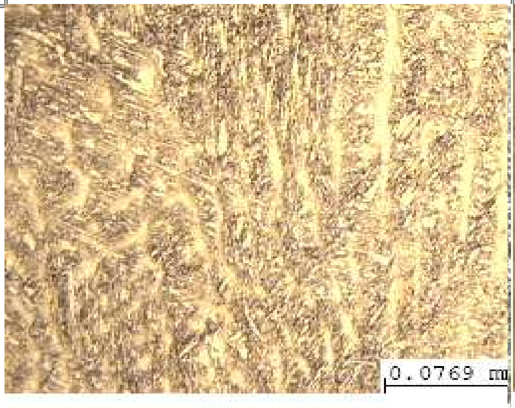
P 50.83%, F 49.17% TM 89.02%, RA 10.98%

Figure 4.31: Image of HAZ of SAMPLE C before and after hardening and tempering

Sample	before hardenning and tempering	after hardenning and tempering
Weld zone of Sample A	 Weld zone	 Weld Zone Sample A Tempered Martensite

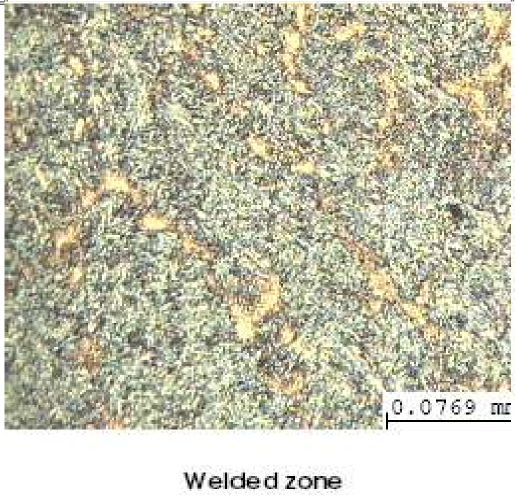
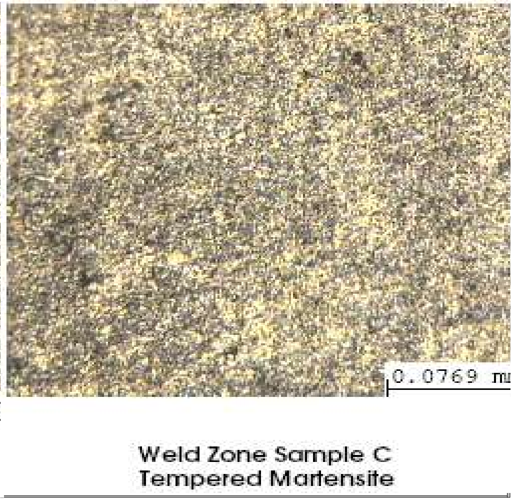
P 48.68 %, F 51.32% TM 87.04%, RA 12.96%

Figure 4.32: Image of weld zone of SAMPLE A before and after hardening and tempering

Sample	before hardenning and tempering	Af ter hardenning and tempering
Weld zone OF Sample B	 Welded zone	 Weld Zone Sample B Dissociated Structure

P 56.55%, F 43.45% TM 38.96%, RA 61.04%

Figure 4.33: Image of weld zone of SAMPLE B before and after hardening and tempering

Sample	before hardenning and tempering	Af ter hardenning and tempering
Weld zone OF Sample C	 Welded zone	 Weld Zone Sample C Tempered Martensite

P 50.47%, F 49.53% TM 88.32 %, RA 11.68%

Figure 4.34: Image of weld zone of SAMPLE C before and after hardening and tempering

4.11. Microstructure result of base metal, HAZ and weld zone

Table 4.18: Microstructure results

SAMPLE	CONDITION		Original Sample	A	B	C
BASE METAL	Before hardenning and tempering	% P		52.58	60.85	54.15
		% F		47.42	39.15	45.85
	After hardenning and tempering	% TM		88.58	93.60	88.63
		% RA		11.42	6.40	11.37
HAZ	Before hardenning and tempering	% P		49.26	51.90	50.83
		% F		50.74	48.10	49.17
	After hardenning and tempering	% TM		89.90	56.22	89.02
		% RA		10.10	43.73	10.98

WELD ZONE	Before hardenning and tempering	% P		48.68	56.55	50.47
		% F		51.32	43.45	49.53
	After hardenning and tempering	% TM		87.04	38.96	88.32
		% RA		12.96	61.04	11.68
Original sample	Before hardenning and tempering	% P	51.93			
		% F	48.07			
	After hardenning and tempering	% TM	94.14			
		% RA	5.86			
P	Pearlite					
F	Ferrite					
TM	Tempered Martensite					
RA	Retained Austenite					

CHAPTER 5

DISCUSSION

In the present work the effect of TIG welding and FCAW welding at different conditions studied. Spark spectrograph analysis is found conforming to requirement for chemical composition

TIG welding without post heat is giving more strength than post heated one. Basically TIG welding is used for defect free root hence there is no need of post heating after TIG welding in root. After root run FCAW was used for further run .and it is also satisfactory and found acceptable.

Sample B of GTAW welded (without post heated after welding) exhibited reduction in UTS than sample A. tensile strength of sample C of GTAW and FCAW welded is found 167.09 kg/mm^2. So the results were found within the limits that is 160 to 180 kg/mm^2, for UTS. The specifications mentioned for UTS and the position of the fracture only to be recorded. The cross joint strength is usually required to exceed the minimum specified UTS of the parent metal. In most situations the weld metal is stronger than the parent metal - it is overmatched - so that failure occurs in the parent metal or the HAZ at a stress above the specified minimum, so FCAW and TIG welded part C has good strength in weld than base metal and the bend test is also showing maximum stretching or ductility and fractured bend surface shows small crystal structure which is sign of a good weld.

Martensite is the hardened microstructure that form in an austenized steel when cooled at a rate too fast to permit the nucleation mechanism by which pearlite is formed as shown in figure 4.29 as the austenite transform to martensite , carbon is trapped as solute atoms as an interstitial solid solution. When base metal of sample A,B and c is compared with original metal the formation of pearlite is more than original one .as a general rule when alloy steel is slowly cooled to produce a microstructure containing pearlite , the percentage of this phase likely to be present can be approximated by multiplying the carbon content by 125.

Microstructure of pearlite and ferrite typical of high strength steel containing 0.31 % carbon in figure 4.34: steel had been cooled slowly in air and transformation on passing through its weld zone produced a microstructure consisting of about 50.47% pearlite (dark patches) and 49.53% ferrite (light colored grains).lamellae in the pearlite are too fine to be plainly resolved in each nodule at the magnification employed for the photomicrograph(natal etchent; original magnification : 640X)

Range of remained austenite is allowd as per Russian technology is 15% not more than this.if retained austenite is more than 15% then strength is less because of during quenching RA is converting into martensite which is hard , tough and required face. RA reduces the hardness but small amount cannot effect the structure but more than certain limit it may be increases brittlensess so there would be chances of strain induces transformation of austenite to martensite. When compairing the microstructure of base metal, HAZ and weld zone before hardening and tempering than I found uniform pearlite and ferrite in sample A &C and I found bigger HAZ in sample B.

And after hardened and tempered I found more retained austenite in weld zone and HAZ zone in sample B (61.04% & 43.73%) hence there would be chances of cracking. finally sample B failed in X-ray test also. our requirement is tempered martensite I got tempered martensite in weld zone ,HAZ, and base metal of sample A not better than C because I found Tempered martensite and homogenized base metal ,HAZ and weld structure. Uniform heat treatment without any abnormality in GTAW followed by FCAW (Sample C).

CHAPTER 6

CONCLUSION

A concise study of welding of 30KHGSN2A-VD has been done and the conclusions are as follows:

Joint subjected to TIG welding with post heating suffer degradation in mechanical properties such as UTS, ductility, and found inhomogenity in base metal, HAZ and weld structure. C-Cr-Mn-Si-Ni steel plate used for the weldment was carbon content 0.31,then the procedure with small beads and low heat input is risky to carry out because the rapid cooling rate create a hardened microstructure in the HAZ which would be susceptible to cracking .

The analysis of results reveals that Gas Tungsten arc welding (root run) followed by FCAW is suitable. The microstructure of Sample C was found better compared to Sample A and found Tempered martensite and homogenized base metal, HAZ and weld structure. Uniform heat treatment without any abnormality and concluded that this can be used for welding material 30KHGSN2A-VD.

Earlier SAW was used. Flux, hopper and machine adaptable but too costly. That's why started to finding the methodology.FCAW is cheaper compared to SAW and cost of fabrication is less for manufacturing of aircraft.

The methodology obtained through this experimentation, is implemented and found suitable for welding, this has further improved productivity, productivity increases is expected to be 15% minimum.

6.1. Future scope:

The methodology described here could have a great future if its done under ideal laboratory conditions and with proper equipments.

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