

MECHANICAL AND CORROSION PROPERTY INVESTIGATION OF WELDED CORTEN A588 GRADE STEEL JOINTS

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering in Mechanical Engineering

by

HEMANTH.S (37150074)

B.PRASHANT (37150139)



**DEPARTMENT OF MECHANICAL ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with Grade "A" by NAAC | 12B Status by UGC | Approved by AICTE
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119**

April - 2021



SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with “A” grade by NAAC | 12B Status by UGC | Approved by AICTE
Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai – 600 119
www.sathyabama.ac.in**

DEPARTMENT OF MECHANICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of
HEMANTH.S (37150074) , B.PRASHANT (37150139) who carried out the
project entitled “Mechanical and Corrosion Property Investigation of Welded
Corten A588 Grade Steel Joints” under my supervision from December 2020
to April 2021.

Internal Guide

Mr.J.R.DEEPAK, M.E., (Ph.D.,)

Head of the Department

Dr. G. ARUNKUMAR, M.E., Ph.D.,

Submitted for Viva-voce Examination held on 19/04/2021

Internal Examiner

External Examiner

DECLARATION

We, HEMANTH.S and B.PRASHANT hereby declare that the Project report entitled “Mechanical and Corrosion Property Investigation of Welded Corten A588 Grade Steel Joints” done by me under the guidance of Mr.J.R.DEEPAK, M.E., (Ph.D.,) is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering in Mechanical Engineering.

1.

2.

DATE: 19/04/2021

PLACE: CHENNAI

SIGNATURE OF THE CANDIDATE

ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to the Board of Management of SATHYABAMA for their kind encouragement in doing this project and for completing it successfully. I am grateful to them.

I convey my thanks to Dr.S.Prakash, M.E., Ph.D., Dean, School of Mechanical Engineering and Dr.G.ARUNKUMAR, M.E., Ph.D., Head of the Department, Dept. of Mechanical Engineering and the panel members for providing me necessary support and details at the right time during the progressive reviews.

I would like to express my sincere and deep sense of gratitude to my Project Guide Mr.J.R.DEEPAK, M.E., (Ph.D.,) for his valuable guidance, suggestions, and constant encouragement that paved way for the successful completion of my project work.

I would like to express my sincere and deep sense of gratitude to DR.K.GOBI SRAVANAN, M.E., (Ph.D.,) Scientist –C and DR.V.K.BUPESH RAJA M.E., Ph.D., Head of the Department, Dept. of Automobile Engineering for his valuable consultation and suggestions that paved way for the successful completion of my project work.

I wish to express my thanks to all Teaching and Non-teaching staff members of the Department of Mechanical Engineering who were helpful in many ways for the completion of the project.

Further, I would like to express heartfelt thanks to Mr.NIVIN JOY THYKATTUSSERRY, M.E., (Ph.D.), Project Coordinator, Department of Mechanical Engineering for timely assisting and intimation of the necessary information at the right time.

Lastly, I would like to thank MY PARENTS, FAMILY and FRIENDS for their morale support, without whome I would not have completed the project on time, during this fractious time.

ABSTRACT

Corten A588 grade steel which is popularly known by the name of a weathering steel is a high strength low carbon alloy structural steel with high atmospheric corrosion resistance. The material was developed in order to eliminate the need of painting .It is resistant to chloride corrosion cracking and stress corrosion and not easily affected by acids and sulphide conditions. It used in high pressure, temperature, marine and structural application as no maintenance required. The surface develops stable rust like appearance when exposed to weather and prevent corrosion. A significant defect in this material is that the metallurgical properties will get affected post welding due to the exposure of high temperature in and around the weld zone making it less reliable after the fabrication. In this research work we have investigate the mechanical properties such as hardness, tensile strength, bending, impact and study the corrosion of the welded Corten A588 steel joints. Furthermore, there are also several methods available for welding a single object, each with its own set of advantages and disadvantages. A method should be chosen based on its overall advantages. The current method selection protocol is intended for cases in which we need to determine which weld is better for Corten A588. The vast data from this investigation may be useful and give way to the utilization of the welded Corten A588 steel plates in the construction, automotive industry, the industries which uses the this grade of steels or wanting to explore the use of weathering steels for their application and finally the research community .

TABLE OF CONTENT

CHAPTER No.	TITLE	PAGE No.
	ABSTRACT	iv
	LIST OF SYMBOLS AND ABBEREVIATIONS	viii
	LIST OF FIGURES	xi
	LIST OF TABLES	xiv
1	INTRODUCTION	1
1.1	CORTEN A588	1
1.1.1	MAKING OF WEATHERING STEEL	5
1.1.1.1	MECHANICAL PROPERTIES	6
1.1.1.2	MICROSTRUCTURE	7
1.2	WELDING	8
1.2.1	HETEROGENEOUS WELDING	9
1.2.2	HOMOGENOUS WELDING	10
1.2.2.1	GTAW	11
1.2.2.2	GMAW	12
1.2.2.3	WELDING FILLER MATERIAL	13
1.2.3	AUTOGENOUS WELDING	14
1.2.3.1	LASER WELDING	14
1.2.3.2	AGTAW	18
1.3	WELD DEFECTS AND THEIR CORRECTION	19
1.3.1	EXTERNAL WELD DEFECTS	20
1.3.1.1	WELD CRACK	20
1.3.1.2	UNDERCUT	21
1.3.1.3	SPATTER	21
1.3.1.4	POROSITY	22
1.3.1.5	OVERLAP	22
1.3.1.6	CRATER	23
1.3.2	INTERNAL WELD DEFECTS	23
1.3.2.1	SLAG INCLUSION	23

CHAPTER No.	TITLE	PAGE No.
	1.3.2.2 INCOMPLETE FUSION	24
	1.3.2.3 NECKLACE CRACKING	25
	1.3.2.4 INCOMPLETELY FILLED GROOVE OR INCOMPLETE PENETRATION	25
	1.4 LASER BEAM CUTTING	26
	1.5 ELECTRON BEAM WIRE CUTTING	27
2	LITERATURE SURVEY	28
	2.1 WELDING	28
	2.2 COROSSION	40
3	AIM AND SCOPE	42
	3.1 AIM	42
	3.2 SCOPE	42
4	METHODOLOGY AND EXPERIMENTAL SETUP	43
	4.1 METHODOLOGY	43
	4.2 SPECIMEN PREPARATION	44
	4.2.1 GTAW	46
	4.2.2 GMAW	47
	4.2.3 LBW	49
	4.2.4 AGTAW	50
	4.3 SPECIMEN CUTTING	52
	4.3.1 LASER CUTTING	52
	4.3.2 EDM WIRE CUTTING	52
	4.4 TESTING	53
	4.4.1 TENSILE TEST	53
	4.4.2 180-DEGREE FREE BEND TEST	54
	4.4.3 CHARPY IMPACT TEST	56
	4.4.4 MICRO VICKERS HARDNESS TEST	57
	4.4.5 IMMERSION CORROSION	58
5	RESULT AND DISCUSSION	60

CHAPTER No.	TITLE	PAGE No.
	5.1 TENSILE PROPERTY	60
	5.2 180-DEGREE FREE BENDING	63
	5.3 CHARPY IMPACT	65
	5.4 MICRO VICKERS HARDNESS	68
	5.5 IMMERSION CORROSION	73
6	SUMMARY AND CONCLUSION	77
	6.1 SUMMARY	77
	6.2 CONCLUSION	77
	REFERENCE	79
	APPENDIX	84

LIST OF SYMBOLS AND ABBEREVIATIONS

%	Percentage
µm	Micron Micrometer
A	Current
AFNOR	Association French Normalization Organization Regulation
AGTAW	Autogenous Gas Tungsten Arc Welding
AISI	American Iron and Steel Institute
Al	Aluminium
Ar	Argon
ASTM	American Society for Testing and Materials
BM	Base Metal
BS	British Standards
C	Carbon
CGHAZ	Coarse grain heat affected zone
CO ₂	Carbon Dioxide
Co	Cobalt
Cr	Chromium
Cu	Copper
DIN	Deutsches Institut für Normung (German Institute for Standardization)
EN	European standards
FB	Forward Bend
Fe	Iron
FGHAZ	Fine grain heat affected zone
FSS	Ferritic stainless steel
GaAsP	Gallium arsenide phosphide
g	Gram
GMAW	Gas Metal Arc Welding
GTA	Gas Tungsten arc
GTAW	Gas Tungsten Arc Welding
HAZ	Heat affected zones
HSLA	High strength low alloy
HV	Vickers Pyramid Number

IS	Indian standard
J/m ³	Joules per meter cube
J/mm ²	Joules per millimeter
JIS	Japan Industrial Standard
J	Joules
kgf/mm ²	Kilogram Force per Millimeter Squared
kN	Kilo Newton
kW	Kilowatt
LBW	Laser Beam Welding
m/min	meter per minute
MAG	Metal active gas
mm/sec	Millimeter per second
MMAW	Manual metal arc welding
Mm	Millimeter
Mn	Manganese
Mo	Molybdenum
MPa	Mega Pascal
N/mm ²	Newton per millimeter squared
Nd:YAG	Neodymium-doped yttrium aluminum garnet
Ni	Nickel
P	Phosphorus
Q	Heat input
RB	Reverse Bend
RT	Room Temperature
Si	Silicon
SMAW	Shielded metal arc welding
S	Seconds
S	Sulfur
TIG	Tungsten Inert Gas
Ti	Titanium
UNI	Italian National Unification
UTM	Universal testing machine
UTS	Ultimate Tensile Strength
VHN	Vickers hardness number

V	Vanadium
V	Voltage
WNR	Werkstoffnummer
W	Tungsten
Wz	Weld zone

LIST OF FIGURES

FIGURE No	TITLE	PAGE No.
1.1	CORTEN A588 GRADE STEEL PLATE	2
1.2	DIFFERENT GRADES OF CORTEN AND THEIR APPLICATIONS	3
1.3	COMMON METHODS OF WELDING CORTEN A588 GRADE STEEL	9
1.4	ER70S-6 FILLER IN FORM OF (A) ROD (B) WIRE	13
1.5	TYPES OF WELD DEFECT	19
4.1	STAGES IN RESEARCH WORK	43
4.2	2MM THICK SHEET CORTEN A588 PLATE BEFORE PROCESSING FOR WELDING	44
4.3	HYDRAULIC SHEAR CUTTING OF CORTEN A588 SHEET	44
4.4	GRINDING AND POLISHING PROCESS ON SHEET	44
4.5	FINAL SAMPLE AFTER ALL PROCESSES	45
4.6	DIAGRAMMATIC REPRESENTATION WELD PLATE WITH ROOT GAP	45
4.7	DIAGRAMMATIC REPRESENTATION OF WELD PLATE WITHOUT ROOT GAP	46
4.8	PENTAGON TIG 400 MACHINE USED FOR GTAW	46
4.9	FRONT AND BACK VIEW OF GTAW PLATE	47
4.10	PENTAGON MIG 500 MACHINE USED FOR GMAW	48
4.11	FRONT AND BACK VIEW OF GMAW PLATE	49
4.12	BALLIU BELGIUM LBW MACHINE USED FOR LBW	49
4.13	LASER WELD ON PLATE	50
4.14	PENTAGON TIG 400 MACHINE USED FOR AGTAW	51

FIGURE No	TITLE	PAGE No.
4.15	FRONT AND BACK VIEW OF AGTAW PLATE	51
4.16	BALLIU BELGIUM MACHINE USED FOR LASER CUTTING	52
4.17	LASER CUTTING ON WELDED PLATE FOR DIFFERENT TESTING	52
4.18	CNC EDM WIRE CUTTING	53
4.19	EDM CUTTING ON WELDED PLATE FOR DIFFERENT TESTING	53
4.20	SERVO CONTROLLED UNIVERSAL TESTING MACHINE	54
4.21	TENSILE TEST SAMPLE DIMENSION	54
4.22	SERVO CONTROLLED UNIVERSAL TESTING MACHINE	55
4.23	BENDING TEST SAMPLE DIMENSION	55
4.24	LARYEE IZOD AND CHARPY UNIVERSAL IMPACT TESTER	56
4.25	IMPACT TEST SAMPLE DIMENSIONS	57
4.26	FIE ROCKWELL HARDNESS TESTING MACHINE,	57
4.27	HARDNESS TEST SAMPLE DIMENSION	58
4.28	CORROSION TEST SAMPLE DIMENSION	59
5.1	TENSILE GRAPH OF WELDED JOINTS	60
5.2	TENSILE TEST SAMPLES AFTER FRACTURE FRONT AND BACK VIEW	61
5.3	BEND TEST SAMPLES SHOWING SIDE VIEW, FORWARD BEND AND BACKWARD BEND	65
5.4	GRAPHICAL REPRESENTATION OF AVERAGE ENERGY ABSORBED	66
5.5	SAMPLES AFTER IMPACT TEST	67
5.6	HARDNESS GRAPH OF DIFFERENT WELDMENTS	70

FIGURE No	TITLE	PAGE No.
5.7	WEEKLY PROGRESSION OF CORROSION ON TEST SAMPLE,	74
5.8	COMPARISON OF PH AND CONDUCTANCE RATE IN DIFFERENT WELD	75

LIST OF TABLES

TABLE No	TITLE	PAGE No.
1.1	ELEMENTAL COMPOSITION AND ITS PROPERTIES IN CORTEN A588	1
1.2	CORTEN A588 USES IN VARIOUS INDUSTRIES AND PROPERTIES REQUIRED	4
1.3	CORTEN STANDARDS IN DIFFERENT COUNTRIES	6
1.4	GENERAL MECHANICAL PROPERTIES OF CORTENA588 GRADE STEEL	7
1.5	FILLER MATERIAL COMPOSITION	14
1.6	TYPE OF LASER SOURCE AND IT'S CHARACTERISTICS	16
1.7	TYPE OF WELD DEFECTS AND IT'S DESCRIPTION	17
4.1	WELDING PARAMETER FOR GTAW	47
4.2	WELDING PARAMETER FOR GMAW	48
4.3	WELDING PARAMETER FOR LASER BEAM WELDING	50
4.4	WELDING PARAMETER FOR AGTAW	51
5.1	TENSILE TEST RESULT ON VARIOUS CORTEN A588 GRADE WELD JOINTS	60
5.2	BENDING TEST RESULT ON SAMPLE	64
5.3	IMPACT TEST RESULTS ON SAMPLE	66
5.4	HARDNESS TEST RESULT ON SAMPLE	68
5.5	WEIGHT LOSS OF SAMPLES IMMERSSED IN 3.5% NACL SOLUTION FOR A MONTH	74

CHAPTER-1

INTRODUCTION

1.1 CORTEN A588

Weathering steels are Structural low alloying steels whose alloying elements as Ni, Cu, Mo, and Cr combined together makes up 3-5 percent of the total composition. The Elemental composition and its properties in Corten A588 is given in Table 1.1 [16] It has a high anti-corrosive property as it prevents the progression of corrosion by the formation of thick oxide layers on the exposed surface [1] .This is exceedingly unusual in the rest of the world, and much more so in India. Weathering steel, bridge steel, structural steel, and several other names have been given to it. This steel is long-lasting. It is a high-strength low alloy structural steel that is highly resistant to ambient corrosion.

Table 1.1 Elemental composition and its properties in Corten A588

Base element	Percentage (%)	Melting point (°C)	Property
Fe	98.095	1535	Pure iron transforms from a body-centered cubic (bcc) lattice to a face-centered cubic (fcc) lattice
Cr	0.5	1857	impart corrosion resistance and a shiny finish, when heated it burns and forms the green chromic oxide
Mn	0.36	1245	hard metal and is very brittle, hard to melt, but easily oxidized, it reacts with water and dissolves in dilute acids
Si	0.31	1410	metallic luster and very brittle, tetravalent It forms various series of hydrides, ionic or covalent properties
Cu	0.249	1083	cu-centered cubic crystalline structure, Malleable, ductile, polished, moist air it slowly forms a greenish film patina
Ni	0.197	1453	Bivalent, hard, malleable, high strength, ductility, and resistance to corrosion and heat.,

Base element	Percentage (%)	Melting point (°C)	Property
C	0.12	3500	allotropic crystalline forms, high temperatures it binds with oxygen ,property crystalline structure
P	0.106	44.1	several allotropic forms ,heated with metals, phosphorus forms phosphides,It does not dissolve in many liquids
Mo	0.021	2617	very hard transition metal,highest melting points of all pure elements, slowly attacked by acids, improves hardenability and toughness of quenched and tempered steels and increase the strength of steel at high temperatures
Al	0.018	660.37	soft and lightweight metal, high strength ,resistance to oxidation, tendency to creep under steady sustained pressure, does not flake
W	0.01	3410	resistant to attack by oxygen, acids and alkalis, highest melting point of all metals, high strength
Co	0.006	1496	hard ferromagnetic,brittle element,stable in air and unaffected by water, but is slowly attacked by dilute acids,
Ti	0.004	1660	hard and strong metal, low density and ability to withstand extremes of temperature, resistance to corrosion in seawater
V	0.003	1890	Silvery metal that resists corrosion, very tough ,shock resistant and vibration resistant.
S	0.001	115.2	Several allotropes , Improves machinability,lowers ductility



Figure 1.1 Corten A588 Grade steel plate

It contains 0.19 percent carbon by weight and 0.5 percent chromium by weight, making it resistant to corrosion. This was originally created to challenge corrosion of railroad coal wagons without the need for extra painting or layering. This involves a very low cost of upkeep. This property finds its usage on the unpainted state in bridges and buildings, it is also being used in the pressure vessels but in a small fraction due to the concerns in the toughness and the property of it after heat treatment and the type of weld being used [29]. This steel is classified as IRSM steel in India, and it was built to reduce the rate of corrosion, which used to force railway coaches to be replaced more often. The train's velocity and corrosion resistance have also improved as a result of the production of weathering steel. Weathering steels are a form of high-strength low-alloy steel with microstructures primarily composed of heavy martensite particles dispersed in a light ferrite matrix [2]. Dual-phase steels have a microstructure primarily of matrix with soft ferrite wherein the dispersed hard martensite particle are present, as it is produced by the heat treatment in an intercritical temperature which forms small pool of austenite with high carbon content leading to augmented hardenability in the ferrite matrix and later when quenched the austenite changes to martensite and resulting in an ferrite-martensite steel [8]. Different Corten grades and applications are given in *Figure1.2* [15].

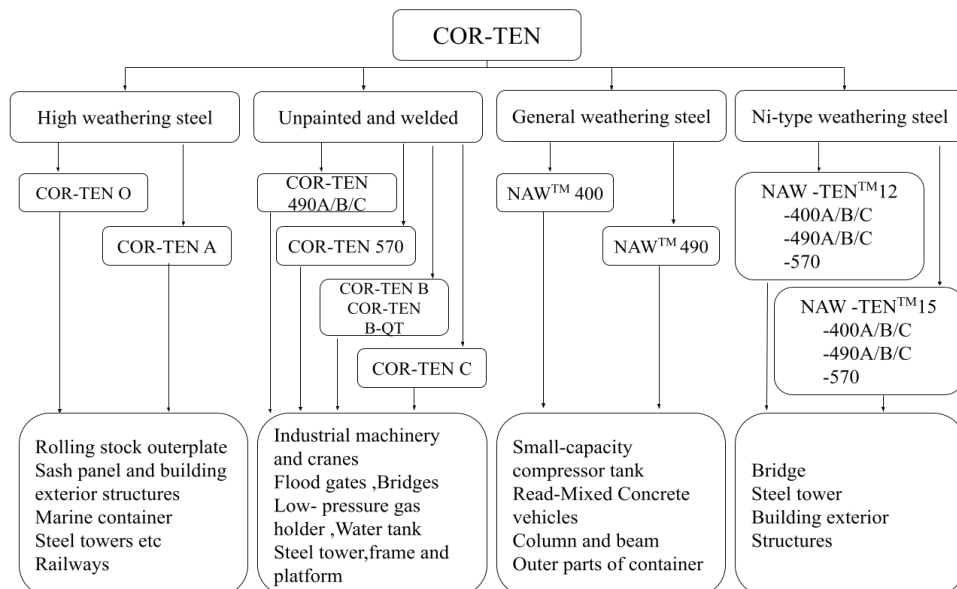


Figure1.2 Different Grades of Corten and their applications

In This study Corten A588 steel plates with thickness of 2 mm, which was shear cut with hydraulic cutting machine to an individual plate of dimension 150 mm * 300 mm and then further processed. Corten A588 is procured from sharoff steels suppliers, Chennai. The Table 1.2 gives the uses of corten A588 in various industries and the properties required by the material to be used in it.

Table 1.2 Corten A588 uses in various Industries and properties required

Industry	Properties required
Ship building	• HAZ toughness • Arrest property • High heat input weld ability • High tensile strength • Small distortion • High efficient fabrication • Corrosion resistance • Fatigue strength
Offshore structures	• High strength • High efficient welding fabrication • Low temperature toughness
Bridges	• High efficient welding fabrication • Corrosion resistance • Fatigue strength
Penstocks	• High strength • Reliability • High efficient welding fabrication
Tanks	• Higher strength • Corrosion resistance
Construction and industrial machinery	• Higher strength • Wear resistance
Railway tracks and wagons	• Lead-less

Industry	Properties required
	• High strength
Boiler Pressure vessels	• Higher strength • High efficient welding fabrication • Creep resistance
Pipe lines	• Higher strength • Low temperature toughness • Sour gas resistance
Architectures and its materials	• High strength • High heat input • High efficient welding fabrication • High toughness • Fire resistance • High corrosion resistance

1.1.1 Making of weathering steel

Smelting (furnace, electric furnace - micro-alloying treatment - Argon-LF refining - low superheat casting - controlled rolling and cooling process route are commonly used for weathering resistant steel. When smelting steel scrap with burden in furnace, according to traditional smelting procedure, after steel tapping added de oxidant and alloy Molten steel by blowing argon and then to cast, after argon is blown, temperature of molten steel by continuous casting machine cast slab The inclusion content of steel purified weathering steel is considerably reduced as a result of the addition of rare earth elements. In the Lime and Fluorspar refining process, lime and fluorspar slag are used, along with a compound deoxidizer and silicon carbide for diffusion oxygen. The top slag must be white slag before tap off. Before feeding calcium silicate, soft argon feed processing line after a period of a uniform temperature of molten steel, components, and foster inclusion floating ensure steel quality. Because weathering steel is made of copper iron, which has a low melting point, the rolling process is a crucial step in the production of weathering steel. To avoid rolling after soaking, we should strictly control the steel

temperature burning and furnace atmosphere to avoid unnecessary burning or overheating. To avoid Cu in austenite enriched crystals, billets that produce surface cracks should be scarfed at room temperature, furnace ventilation, the heating temperature control at the lower limit, billets should not be kept at high temperatures within the furnace, and the furnace should be kept in resurgence or a reducing atmosphere.

Rolling links also concentrate on temperature control of key points, cooling speed control, and the ability to control the cooling rate of the rolling process stability. The process of making the weathering steel is given in above paragraph. while the different standards of Corten in different countries are given in Table 1.3 [41].

Table 1.3 Corten standards in different countries

Country	Standard	Grade
Canada	HG	400AAT
England	BS	WR50C
European old	EN	Fe510D2KI S355J2G1W
European Union	EN	S355J2W(+N)
France	AFNOR	AFNOR
Germany	DIN,WNr	WSt52.3
India	IS	IRSM 41-97
Italy	UNI	Fe510D2K1
Japan	JIS	SMA570W
United States of America	ASTM	A588Gr.A / A600A / A600B / A600C

1.1.1.1 Mechanical properties

The typical organization of weathering steel is pearlite and ferrite; but, after weathering steel hardening, the structure of the steel is composed of ferrite and martensite, with martensite uniformly distributed irregularly like an island on the ferrite grain boundary and the axis of the island parallel to the direction of the

ferrite grain boundary. This is due to the fact that during the process of zone heating insulation growth, the original austenite transforms into martensite under its control. Because diffusion is relatively slow due to the lower heating and keeping temperature in the thermal phase zone, diffusion processes are boundary diffusion-based, thus the higher growth velocity along the austenite grain boundary ferrite, which grew to ferrite low speed, resulting in the formation of irregular, the long axis of the ferrite austenite grain boundaries parallel to the island, thus making the transition from its martensite state also showed this distribution. the following Table 1.4 illustrate the general mechanical properties of Corten A588 grade steel.

Table 1.4 General Mechanical properties of CortenA588 grade steel

Mechanical Test	Value
Brinell Hardness	170
Shear Strength	350MPa
Tensile Strength: Ultimate (UTS)	550MPa
Tensile Strength: Yield (Proof)	390MPa
Elastic (Young's, Tensile) Modulus	190GPa
Poisson's Ratio	0.29

1.1.1.2 Microstructure

Because weathering steel must have adequate strength, ductility, and toughness in addition to excellent corrosion resistance, it must also have the greatest strength and toughness. The yield ratio, strain hardening index n , and plastic strain ratio of weathering resistance steel are all related to formability. Weathering resistance steel with a low yield ratio is required for stamping forming, with the yield ratio of cold rolling steel sheet ideally less than 0.7. To achieve uniform deformation, weathering resistance steel must have a bigger strain hardening exponent n . The two-point technique of determining the tensile curve can be used to determine the value of n . Steel in plastic deformation hardening capacity is represented by the strain hardening exponent, which reflects the uniformity of the deformation process, the forming limit, and whether or not a crack is formed, among other

things. When n is enormous, the deformation is uniform. The Plastic Strain Ratio, which is determined through tensile testing, is an important indication of Steel Formability, as it indicates that under the same stress, the vertical deformation between the Thickness and Plate plane directions is distinct. [19]

1.2 WELDING

Welding is a manufacturing process which is used in order to join two different or same materials. Unlike various other processes available such as forming, casting, machining. etc., which are used in order to produce a single whole component, joining processes are used to put together different members to generate the desired complex shape. There is rarely any material available that cannot be welded, but not all the materials can be welded using the same process. Therefore, the selection of a welding process to achieve a joint of required standard and quality is necessary before undertaking any fabrication work [13].

Some welding methods are considered to be correlated with specialized uses, such as resistance spot welding, which is most commonly used in sheet metal work in the automobile industry and for the manufacturing of refrigerator shells; gas tungsten arc welding (GTAW), which is widely used in the aerospace, rocket, missile, and nuclear industries; and underwater arc welding (SAW), which is the only method used for long seams in the shipbuilding and pressure vessel fabrication. Shielded metal arc welding (SMAW), which is used for all awkwardly placed joints with complicated access or for ground welding [17]. Electron beam welding, which is mostly used for welding reactive metals. The selection of the respective processes in both of the above cases can be due to the assumption that the optimal weld output is achieved at the lowest cost, and thus cost is the primary consideration. There could be no other solution under certain circumstances, making the exercise of method selection redundant. In certain cases, though, a combination of processes may be almost as successful in obtaining the desired result. Furthermore, there are also several methods available for welding a single object, each with its own set of advantages and disadvantages. A method should be chosen based on its overall advantages. The current method selection protocol is intended for cases in which we need to

determine which weld is better for Corten A588 [43]. Common methods for welding CortenA588 is given in *Figure 1.3*.

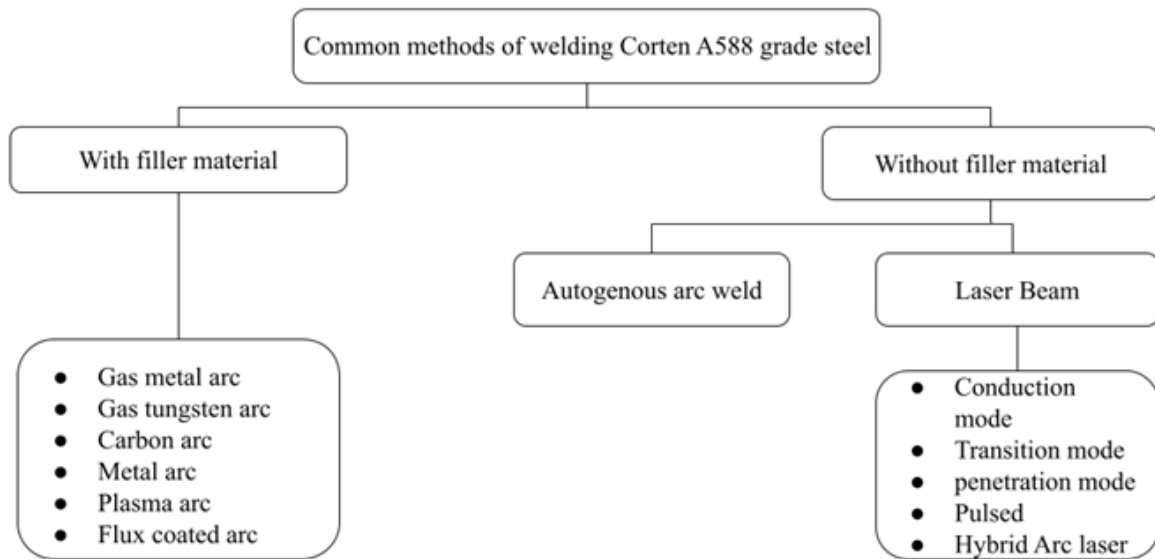


Figure 1.3 Common methods of welding Corten A588 grade steel

1.2.1 Heterogeneous welding

It is a type of weld which uses a suitable filler material to fuse the base metal together. The chemical composition of the filler material in heterogeneous welding differs significantly from that of the base materials. Welding of dissimilar or similar metals is essentially a heterogeneous operation. By using suitable filler, the properties of the weld bead can be increased to the desired degree. Filler and base plate melting points can vary considerably, so this aspect should be carefully considered before welding. To achieve a defect-free joint, the filler metal should be selected with reliability problems in mind. Heterogeneous welding can improve the joint's corrosion resistance by using corrosion-resistant filler. This is especially useful in marine applications. Residual stress and crack forming on the weld bead can be caused by an uneven rate of contraction between the molten filler and BMs during solidification so welding parameter is something we should keep in mind while performing such kind of welds.

Advantages of heterogeneous welding

- Choosing the right filler material will strengthen a number of weld properties, including stress and corrosion resistance.

- With proper edge preparation, thick plates can be welded efficiently.
- The joint's strength is superior to that of autogenous welding.
- The likelihood of crack formation during solidification is reduced due to an ample supply of molten metal.
- It is also possible to weld multiple joints such as the butt joint, lap joint, tee joint, corner joint, and so on.
- If well welded, joints are more durable and have a lower risk of failure.

Disadvantages of heterogeneous welding

- There is a high risk of weld discontinuity and crack forming due to the non-uniformity of structure between the filler and BMs.
- If the compatibility of the filler material and the base material is not sufficiently tested, faulty welding will result.
- Filler content is normally more expensive and needs more upkeep.
- Excess filler material creates high reinforcement on the weld bead, which must be eliminated by grinding after welding.
- The appearance of the weld bead is poor.
- Sputtering will happen if the process parameters aren't set correctly.[46]

1.2.2 Homogenous welding

The homogeneous welding is preferred in case of the Corten A588 because the filler material should match with the strength of the material, its corrosion property and also match with the colour of the base. The chemical composition of the filler material is similar to that of the base materials in homogeneous welding. It isn't feasible when combining fabrics that aren't compatible. Weld beads have physical, electrical, and mechanical properties that are similar to those of BMs. Chemical, electrical, and metallurgical compatibilities are inherent and apparent since the filler and BMs have the same chemical structure. The melting point of the filler is the same as the melting point of the base plates. Corrosion can be a problem in joints. Homogeneous welding would not increase the joint's corrosion resistance. The expansion and contraction rates of molten filler and BMs are almost identical. As a result, the likelihood of a crack forming on the weld bead is reduced.

Advantages of homogeneous welding

- With proper edge preparation, thick plates can be welded efficiently.
- The joint's strength is superior to that of autogenous welding.
- The likelihood of crack formation during solidification is reduced due to an ample supply of molten metal.
- It is possible to weld various joints, such as the butt joint, lap joint, tee joint, corner joint, and so on.
- If well welded, joints are more durable and have a lower risk of failure.

Disadvantages of homogeneous welding

- Joining very thin sheets is not feasible.
- Excess filler material induces reinforcement on the weld bead, which must be ground away after welding.
- The appearance of the weld bead is poor.
- Sputtering may occur while filler is present.
- Additional charges for filler content as well as its upkeep [47].

1.2.2.1 GTAW

GTAW also commonly known as Tungsten Inert Gas welding(TIG), TIG is used popularly in industries for joining materials like Mild steel , Aluminum and different types of the stainless steel alloy grades. The measurements of the parameters used for the welding plays a very important role in quality of the final product obtained after the weld in terms of the joint efficiency, mechanical properties and weld distortion. As the welding process mainly consists of heating and cooling in a non-uniform manner, the distortion is unavoidable. The welding can lead to a different kind of distortion namely longitudinal, transverse or angular distortion. Controlling distortion is one of the aspects which we should look into as it sternly affects the dimensional tolerance limit.[3].TIG welding is commonly used in several applications because of its accurate material welding, ability to weld a variety of materials, use of less amperage as compared to other welding processes, and clean welding with high control. TIG welding is a little slower than most welding processes [39].

The pulsed GTAW process is the most suitable welding type for joining materials with medium and thin thickness, e.g. stainless steel sheets and for kinds of applications where metallurgical control of the weld metal is vital. With the enhanced use of mechanized welding, the choice of welding procedure and welding process parameter must be more specified in order to ensure that the weld bead of best quality is obtained at least cost with high adherence. The welding current in a pulsed GTAW welding process is alternated between high and low temperatures for a short or long period of time, bringing the welding spot to melting point during the pulse current period and allowing the molten weld pool to cool and solidify during the background current period. The weld bead shape formed during this process will be a series of overlapping weld spot and the number of overlaps depends on the pulse frequency and welding speed during the whole process.[30]

1.2.2.2 GMAW

In gas metal arc welding (GMAW), the main source of heat is an arc generated between a consumable metal electrode and the work piece using an externally supplied shielding gas such as argon or helium [25].

GMAW is a flexible method that vastly increases the consistency characteristics of the weld joint and is widely used in the manufacture of a variety of ferrous and non-ferrous metals. The quality, productivity, and cost of a welding joint are all influenced by the GMAW welding parameters. If all of the welding parameters are in order, a perfect weld will be achieved. These parameters include arc welding current, arc voltage, welding speed, torch angle, free wire length, nozzle distance, welding location and direction, and gas flow rate [24].

Furthermore, the combined effect of different input parameters determines the level of joint strength required to satisfy the functional requirements aspects of the weld in the area of practical use [26].

The penetration depth increased as the welding current was increased but decreased when the voltage was decreased, and the penetration increased when

the arc travel rate was decreased until it reached a minimum value depending on the arc power in a previous analysis with a MIG or GMAW welding operation [31]. The conclusions of the investigation into the GMAW mechanism and the relationship between process variables and bead geometry revealed that the arc current has the biggest impact on bead geometry. The effects of electrode polarity, extension, arc voltage, welding current, power source setting, travel speed, and flux on the weld deposit region were investigated and presented [18]. Therefore, preparation of a good quality weld seems to be a challenging job. The present process selection procedure is aimed at such situations where we will be seeing which weld is best suitable for Corten A588.

1.2.2.3 Welding filler material

The filler material which we are using in this research investigation is ER70S-6. Where ER means an electrode, the 70 gives us the amount of gross tensile strength which it can provide which is of 70000 pounds per square inch, S implies it is in form of a solid, 6 tells that there is a coating present on top of the solid filler wire, in this case there is a coating of copper which acts as an deoxidizing. The *Figure 1.4* shows the filler rod in form of the wire of thickness of 1.6mm for the GMAW and in form of solid wire of thickness 1.6mm for the GTAW.

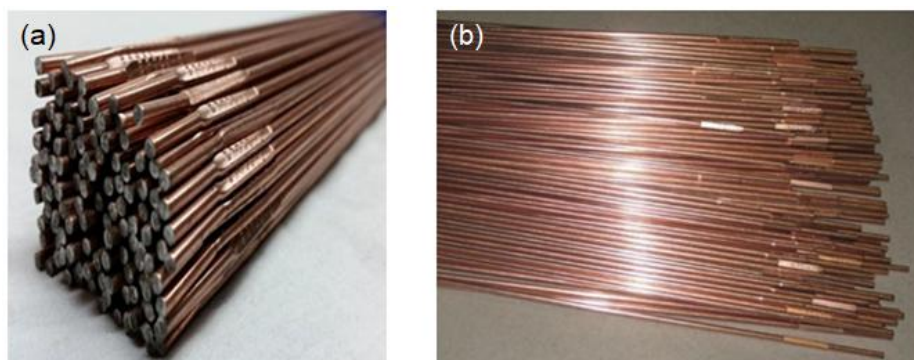


Figure 1.4 ER70S-6 filler in form of (a) rod (b) wire

This filler was selected for the welding process because the composition is nearly the same as the BM as seen in the Table 1.5. This filler is also suitable for a strong, decent weld with trouble free operation at higher temperatures and speed. It is mostly used for gas mixtures containing CO₂ and Ar.

Table 1.5 Filler Material Composition

Base Element	C	Mn	Si	P	S	Ni	Cr	Mo	V	Cu
Percentage%	0.06 – 0.15	1.40 – 1.85	0.80 – 1.15	0.025 max	0.035 max	0.15 max	0.15 max	0.15 max	0.03 max	0.50 max

1.2.3 AUTOGENOUS WELDING

An autogenous weld is a form of welding in which the filler material is either melted from the base material or has the same composition as the base material. No additional filler rod is necessary since the weld can be formed completely by melting sections of the BM.

Advantages of autogenous welding

- Only autogenous fusion welding of thin sheets is feasible.
- There is no additional charge for filler content.
- To extract hardened pieces, no post-grinding is needed.
- Processes are simple to automate.
- Appearance of the weld is good.

Disadvantages of autogenous welding

- Only a butt joint is feasible, and only if the root distance between the base pieces is held to a minimum.
- In order to achieve a sound welding, the thickness of the plates is often reduced to just 2 – 3mm.
- The joint's strength is inadequate it is less than that of the base plates.
- The welded component becomes marginally weaker when molten metal from the base plates is used to fill the small gap between plates (root gap).
- It cannot be used to join more than two pieces because the latter needs a lot of filler content.
- To achieve a sound weld, any grease, corrosion, or scale must be fully removed [45].

1.2.3.1 LASER WELDING

Laser welding is a high-tech welding process that once had very scarce practical industry usage, has now evolved as one of the most widely used metal joining processes in the industry owing to the increase in automation and demand for high production rate [27].

The foremost laser processing application in the industry is laser welding which is due to its notable advantage over the traditional processing methods in terms of the short processing time. The operation is very precise wherein the start and stop can be made very quickly. The heat-affected zone is very little because of the local treatment on the BM; this method can be employed in joining heat react-able and volatile materials. This weld can be performed in the atmospheric condition with negligible contamination employing the expedient shielding gas. The weld is performed as autogenous because of which a pleasing bead profile is obtained and no clean-up is required to post the process [5], [44]. Laser welding has a wide range of applications such as being used in underwater laser welding; this is considered as one of the best methods for deep-sea welders consequently due to the rigorous conditions. It is also used in welding of plastics and polymers, which are employed in manufacturing of the smart garments or advanced garments where Fabrics made with some content of thermoplastic fiber can be welded together instead of being stitched. In case of metals this laser can be used to weld plates with less distortion, giving it greater precision and maximizing the time saving by recovering the time used up in beating panels flat, it is used widely in automobiles, shipping, and various large scale industries [17].

Types of laser and its characteristics is given in Table 1.6 The major flaw which we come across while using the laser welding are porosity, humping and spatter. Few defects may also arise due to the small beam diameter. When welded without use of the filler material, the pieces which are to be welded are required to be adjusted next to each other without any error. Faulty beam positioning will also promote concave root surface, lack of fusion, and sagged welds. Extreme cooling rates may sometimes lead to pore development in deep welds with inadequate degassing. Modeling and experimental investigation on these parameters help in understanding this process and also the defect provoking factor and supplementing the weld quality [21].

Table 1.6 Type of Laser source and It's characteristics

Type of laser	Co2 laser	Lamp-pumped YAG laser	LD-pumped solid-state laser	Fiber laser	Laser diode (LD)	Disk laser
Wavelength (um)	10.6	1.06	about 1	1.07	0.8-1.1	1.03
Laser media	Co2 N-He mixed gas (gas)	Nd3+:Y3Al5o12 garnet (solid)	Nd3+:Y3Al5o12 garnet (solid)	Yb3+:SiO2 (solid)	InGaAsP(solid)	Yb3+:YAG or YVO4 (solid)
Average power (CW) in (kW)	50	10	13.5	100	10	16

The CO₂ laser generally has a high wavelength of 10.6 μm which is longer than the wavelength of the solid-state lasers by around 10 times. This in turn changes the interaction of the laser-produced with the materials, also the plasma, and the type of shielding gas being used in turn influence the traits of the system and its operation [38]. When we compare this type of laser with the Nd: YAG and fiber laser the quality of the beam produced is much sizable. There are two fundamental modes of welding as the keyhole and the conduction mode, wherein the significant disparity is the power density employed on the weld area [48]. The conduction setting of the system prevents the vaporization of the material with the power density applied, whereas in the keyhole settings the density of the power is sufficient enough to evoke vaporization by starting a hole cavity in the pool of the weld. In this setting, almost the entire incoming beam is consumed and the heat incorporated allows for a thicker and sharper weld [11].

A variety of defects have been found, but they can typically be controlled by choosing the correct welding speed. The existence of a variety of weld faults, such as undercutting, slumping, humping, and blow-holes, has an effect on the topography of the weld surface. Types of weld defects which we come across when we weld on daily basis and there description is given in Table 1.7.

Table 1.7 Type of weld defects and it's description

TYPE OF DEFECT	EXPLANATION OF DEFECT
Pores in the weld pool	• The keyhole collapsing too soon and does not enabling the molten metal to drain through the core of the keyhole until solidification causes pores in the weld pool. • Porosity continues to increase with rising power density and pulse time by using pulsed lasers.
Cratering	• When using pulsed lasers, the transition from conduction to keyhole welding is often followed by occluded gas pores in the root and cratering of the top surface, particularly at higher power densities. • Cratering increases rapidly as the power density and pulse time rise.
Undercutting	• It is said to be undercut when the weld's edge is lower than the weld's middle. • The height differential between the highest and lowest points on the top surface of the weld is the sum of undercutting. • Undercutting becomes more consistent at higher speeds.
Humping	• This is a longitudinal weld defect characterised by frequent weld face bumping and restraint. • The weld metal creates humps above the work piece's surface line. It can happen at a fast pace. • The shape of the weld pool is important in the creation of humping. Humping does not require total penetration to occur.
Blow-holes	• Due to keyhole instabilities, blow-holes will appear in the top weld bead, most often when the welding speed is too fast.
Drop	• This is the distance between the lower surface of the weld and the weld's protrusion.
Cracking	• Cracks were found to grow mostly in the upper portion of weldments.
Non-uniformity and surface roughness	• Surface roughness along the centerline of the top weld surface has been shown to be determined by welding speed, laser strength, pulse rate, and average peak intensity density of a pulsed laser. • When laser strength was improved, the sensitivity of the weld bead roughness to welding speed became less pronounced, and the roughness size was generally smaller.
Alloy loss and	• At high energy inputs, the substance will vaporize, with

TYPE OF DEFECT	EXPLANATION OF DEFECT
changes in chemical composition	lower melting temperature components losing preferentially. Welding speed has no impact on weld composition until a stable keyhole has formed; indicating that alloy loss is minimized once a stable keyhole has been formed.
Hardness	- The hardness of the weld pool is slightly higher than that of the actual BM. - This may be caused by a change in microstructure, precipitation, or the development of intermetallics.

1.2.3.2 AGTAW

An autogenous weld is a kind of welding in which the filler material is either melted from the base material or has the same composition as the base material. No additional filler rod is needed since the weld can be formed completely by melting sections of the BM. It's important to remember that autogenous welding isn't a basic form of welding process like MMAW, TIG, or GMAW; rather, it's one of three different types or forms of fusion welding. Solid state welding processes are typically autogenous, since no filler is used during the welding process. When compared to GTA welds, autogenous TIG welds have a higher carbon percentage in the weld fusion zone owing to a higher peak temperature due to a single pass and a faster cooling pace. The formation of martensite with a higher weight percentage of C is due to the higher strength of autogenous TIG welds. In the autogenous TIG phase, high cooling rates and heat input result in the forming of hard martensite [7].

The Advantages of Autogenous Welding

Although many welders are aware of the advantages of welding with filler wire, such as enhanced welding speed, fewer are aware of the advantages of autogenous welding, particularly when done with a dependable, hygienic system like orbital GTAW. Welding by itself:

- Creates visually appealing welds: Owing to the lack of excess material filler and irregularity in the weld void, autogenous welding processes have a smaller

propensity to produce erratic or irregular bead patterns than processes using filler wire.

- Post-grinding is not needed: There is no need to remove extra material after welding since no new material is being applied.
- Cost of filler material is eliminated: Depending on the scale of the job and the amount of filler material used, the cost of filler material may be important. Welding without the use of filler lowers welding costs and extends the life of the plant. Profitability of investment
- Best method of fusing thin sheets: Welding thin sheets offers a variety of problems, including regulating the amount of heat, the weld bead profile, and the arc start and stop all at the same time. These variables are reduced and streamlined with autogenous welding.

1.3 Weld defects and their correction

Welding defects can be classified into two types as external and internal defects where in Weld Crack, Undercut, Spatter, Porosity, Overlap, Crater, Slag Inclusion, Incomplete Fusion, Necklace cracking, Incompletely filled groove or Incomplete penetration are shown in *Figure 1.5*. The causes of these and the corrective measures is presented below.

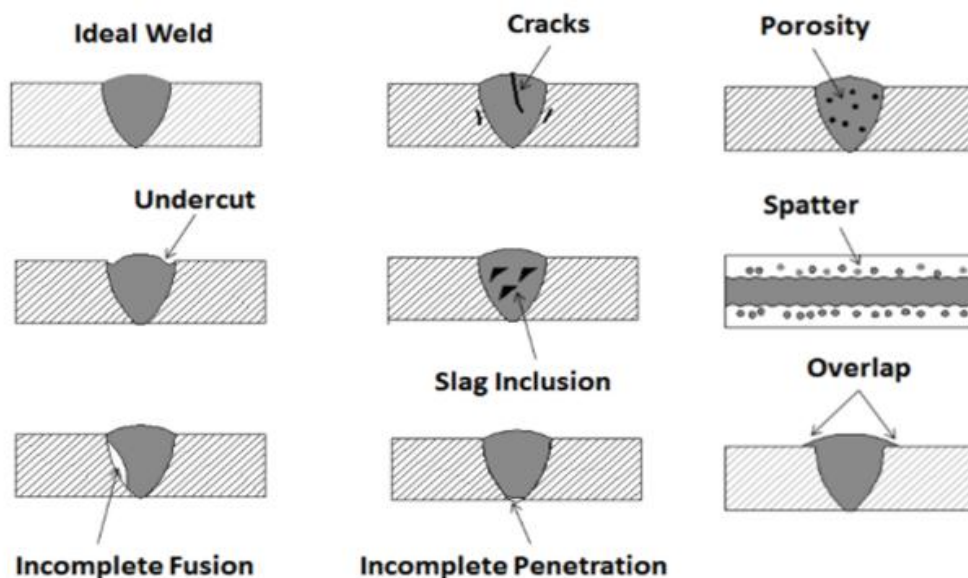


Figure 1.5 Types of weld defect

1.3.1 External weld defects

The external weld defects are Weld Crack, Undercut, Spatter, Porosity, Overlap, and Crater. The causes and their corrective measures are discussed below.

1.3.1.1 Weld Crack

Among all the other welding flaws, this is the most unwanted. Welding cracks may occur on the floor, inside the weld material, or in heat-affected areas. Cracks will occur at a variety of temperatures:

Hot Crack – This form of crack is most common during the crystallization of weld joints, where temperatures can exceed over 10,000 degrees Celsius.

Cold Crack – This type of crack happens when the temperature is very low at the end of the welding process. Several hours after welding, or even a few days later, a cold crack could appear.

Cause of weld crack:

- BM ductility is inadequate.
- The presence of residual stress on the weld metal may result in a fracture.
- The joint's rigidity, which makes it impossible for the metals to expand or compress.
- If there is a lot of sulphur and carbon in the mix, cracks will form.
- Welding ferrous materials with hydrogen as a shielding gas.

Weld crack treatments include:

- Choosing the right materials will help to minimize the chances of a break.
- Cracks may be reduced by preheating the weld and slowing down the cooling speed of the joint.
- Use fair weld joints to reduce the distance between the weld joints.
- When welding, the clamping force is gradually released, increasing the fill-to-capacity of the welding material.

1.3.1.2 Undercut

Undercut is a type of defect that happens when the base of metal melts away from the weld region, creating a groove in the shape of a notch. It lowers the joint's fatigue power.

Undercutting is caused by a variety of factors.

- This defect can occur if the arc voltage is extremely high.
- If we use the incorrect electrode or the electrode is angled incorrectly, a defect can form.
- It's also not a smart idea to use a large electrode.
- One of the causes of this defect is a high electrode speed.

Undercut Treatments:

- Shorten the arc or reduce the arc voltage.
- On the standing knee, keep the electrode angle between 30 and 45 degrees.
- The electrode's diameter should be small.
- Slow down the electrode's movement speed.

1.3.1.3 Spatter

Spatter is a defect that happens when certain metal drops are ejected from a weld and stay attached to the surface.

Spattering Causes:

- This defect may be caused by a high welding current.
- The longer the arc, the more likely it is to develop this flaw.
- The polarity is wrong.
- This defect may also be caused by a lack of adequate gas shielding.

Spatter Treatments:

- Shortening the welding arc and lowering the welding current

- Welding with the correct polarity and in accordance with the welding conditions.
- Using adequate gas shielding and increasing the plate angle.

1.3.1.4 Porosity

The situation in which gas or tiny bubbles get lodged in the welded region is known as porosity.

Porosity is caused by a number of causes.

- It happens when the electrode isn't fully coated.
- Using a longer arc will boost the odds.
- Welding currents have increased.
- The welding surface is rusted or oily.

Porosity treatments include:

- Choose the best electrode.
- Reduce the welding current
- Stopping the operation by using a narrower arc to cause the gases to exit.
- Use appropriate procedure to remove rust or oil from the soil.

1.3.1.5 Overlap

This flaw happens as the weld face reaches past the weld toe. The weld metal rolls and shapes an angle less than 90 degrees in this state.

Overlap's Causes:

- Welding process that isn't up to par.
- This defect can occur if large electrodes are used.
- Very high welding current

Overlap Treatments:

- Welding with the correct technique.
- Make use of a small electrode.

- Welding current is reduced.

1.3.1.6 Crater

It happens when the crater isn't fully filled until the arc breaks, causing the outer edges to cool faster than the crater. This creates a stress, which leads to the formation of a crack.

The crater's causes are as follows:

- The orientation of the torch is incorrect.
- Employing a big electrode.
- Welding method that isn't up to par.

Crater treatments include:

- Using a good torch angle will help to minimize metal tension.
- Using a small electrode can help to reduce crater size.
- Make sure you're using correct technique.

1.3.2 Internal weld defects

The different forms of internal welding defects Slag Inclusion, Incomplete Fusion, Necklace cracking, incompletely filled groove or incomplete penetration, their causes and remedies are discussed below.

1.3.2.1 Slag Inclusion

Slag in the weld has an effect on the hardness and metal weld ability of the given material. The weld material's structural consistency suffers as a result. Slag forms on the weld's surface or between the welding turns.

Slag is caused by a variety of factors.

- Slag is produced where the welding current density is too low to have the necessary amount of heat to melt the metal surface.
- Slag will form when the welding speed is too high.

- Slag will form if the edge of the weld surface is not adequately washed.
- Incorrect welding angle and welding rod travel rate.

Slag Inclusion Treatments:

- Increase the density of the new weld.
- Slow down the welding process so that the slag and weld pool don't mix.
- Strip the slags from previous weld layers and clean the weld edges.
- Make sure the electrode angle and travel rate are right.

1.3.2.2 Incomplete Fusion

If a welder does not properly weld the steel, the metal pre-solidifies, leaving a void that is not filled with molten metal.

Incomplete fusion can be caused by a number of factors.

- It happens as a result of the low heat supply.
- When the weld pool is immense and stretches past the arc.
- Where the joint's angle is too big.
- Incomplete fusion may also be caused by wrong electrode and torch angles.
- Incorrect bead placement.

Incomplete Fusion Treatments:

- Raising the welding current when lowering the travel speed decreases the probability of incomplete fusion.
- Decrease the rate of deposition.
- Raising the angle of the joint.
- Attempt to align the electrode and torch angle such that the plate's edges melt away.
- Properly arranging the bead so that rough points from other beads are avoided.

1.3.2.3 Necklace Cracking

It happens as electron beam welding is used and the weld does not penetrate properly. As a result, the molten metal does not drain into the hole, causing what is known as "Necklace Splitting".

Necklace Cracking Causes:

- Welding process that isn't up to par.
- It can be used in nickel base alloys, stainless steel, carbon steels, and tin alloys, among other materials.
- Using electron beam welding at a high speed.

Necklace Cracking Treatments:

- If you use the right welding technique, you will reduce the chances of your jewellery breaking.
- Welding with the correct tools.
- During the welding process, maintain a steady pace.
- Welding method that isn't up to scratch

1.3.2.4 Incompletely Filled Groove or Incomplete Penetration

These faults only exist in butt welds where the metal groove is not fully filled. It's also known as a partial penetration flaw.

The following are some of the causes of an incompletely filled groove:

- Weld metal deposition is minimised.
- Using an electrode that is the wrong scale.
- Welding method that isn't up to par.

The following are remedies for an incompletely filled groove:

- Increased weld metal deposition.
- Make sure the electrode is the right scale.
- By using proper welding techniques.

1.4 LASER BEAM CUTTING

The laser cutting process is incredibly simple and can be recapitulated as; A laser produces a high-intensity pulse of infrared light. By the use of a lens, this beam is channeled onto the work piece surface. The concentrated beam heats the material, causing a very localized melting which is generally less than 0.5 mm in diameter through the sheet's depth. A pressurised gas jet working coaxially with the laser beam ejects the molten material from the region. When some materials are used, this gas jet can speed up the cutting process by doing chemical as well as physical work. Steels, for example, are usually sliced in a jet of pure oxygen. The oxidation mechanism, which is triggered by laser heating, produces its own heat, which contributes significantly to the efficiency of the process. This small region of material removal is pushed over the sheet's surface, resulting in a cut.

The benefits of laser cutting over other types of cutting technologies have assured the development of this industry few of the benefits are as following:

- Since it is a non-contact operation, the material just needs to be gently clamped or placed underneath the beam. Flexible or flimsy fabrics can be sliced with considerable accuracy and do not distort as much as manually cut materials.
- Since the cut diameter (kerf width) is so minimal (typically 0.1 to 1.0 mm), very fine work can be performed without being constrained by the minimum internal radius imposed by milling machines and other mechanical methods.
- The whole process is CNC-controlled. This, combined with the lack of the need for complicated jiggling arrangements, makes for a simple transition from cutting component "A" out of steel to cutting component "B" out of polymer.
- While laser cutting is a thermal operation, the laser only heats a small region, and the rest of the heated material is extracted during the cutting process. As a result, the thermal contribution to the bulk of the material is minimal, heat affected areas are minimized, and thermal distortion is reduced in general.
- While a laser cutting system has a high initial investment, its operating costs are typically modest. There have been several commercial instances where a massive installation has paid for itself in less than a year.

- When opposed to rival methods, the procedure is relatively silent, which increases the working environment and the productivity of the administrative personnel. In contrast to their electronic counterparts, laser cutting devices are exceptionally safe to use.

1.5 ELECTRON BEAM WIRE CUTTING

EDM (Electrical Discharge Machining) is an electro thermal processing technique in which a thin single strand metal wire is used in combination with de-ionised water which conducts electricity to break into metal using heat from electrical sparks while avoiding corrosion.

An electrical discharge is generated between the wire or electrode and the work piece in wire EDM machining. Material is separated from the work piece and the electrode as the spark bounces through the void. Wire EDM can effectively mill complicated parts and precise components out of hard conductive materials due to the inherent properties of the process.

A non-conductive solvent or dielectric is often used in the process to prevent the sparking process from shorting out. The dielectric extracts the excess material, and the process continues.

CHAPTER-2

LITERATURE SURVEY

2.1 WELDING

(Shu Zhen et al., 2014) carried out the research on the 16 mm thick plate weathering steel of standard S355J2W+N, with hybrid laser-MAG welding and investigated the mechanical property of this welded region. The tensile hardness of the welded region to the BM where almost the same having the yield strength elongation rate and transverse tensile strength as 380.9MPa, 28.8%, 502.6 MPa for the welded region and the base 387 MPa, 30.8%, 504 MPa respectively, wherein the necking and fracture took place in the BM whereas the fractured showed plastic deformation with small or big dimple distribution, containing granular phase of the BM. The micro hardness on conducted 2mm below and above the welded region with a 200g load for a time of 10s showed that the symmetrical pattern of the shape “M” was obtained and the peak hardness was found to be on the overheated zone due to the Widmanstatten structure from the shear transformation, and the hardness of the BM to the laser was observed as at HV165-175 and HV 254.3 respectively, this is due to the high cooling rate and low heating rate during solidification after the weld. The impact strength test on different temperatures showed that it decreases with the decrease in the temperature when comparing with the BM due to slippage of the amount of ferrite in the body-centered cubic structure, during the temperature this effect is minimized but strengthens the twinning deformation, reducing the toughness. The 180 ° lateral bend test showed no crack formation on most of the tested samples, few test samples showed the crack of 0.9 mm on the transition zone of the welds [40].

(X. Y. Gu et al., 2015) experimented on a hot rolled 16 mm thick S355J2W steel plate with hybrid laser-MAG with Ar 85% and CO₂ 15% gas mixture. The investigation on the mechanical property gives us the information on it. The transverse tensile tests showed that the Tensile strength was 502.6 MPa, yield strength as 380.9 MPa, and the elongation percentage as 28.8%, the samples failed in the BM region where necking took place, whereas the heat-affected zone

was not affected, this suggests us that the plasticity and the strength over the different regions are not even and failure is due to the overmatching of the strength in the base and the heat-affected zone, also the fracture surface shows significant deformation. The micro hardness test shows that the hardness level is 280 HV and found the Widmanstatten structure present on the joint region, the hardness on the fine grain zone is lower when compared with the overheated zone whereas in this change in the microstructure was due to the cooling post-weld. The 180 ° bend test shows the formation of crack on one sample with a crack of 2mm between the two weld zones and the other samples did not show any formation of crack. The Charpy impact on the weld region on the groove showed that the absorbed energy decreases with the decrease in the temperature which can be inferred from the deformation in the fracture surface [49].

(Xiong Zhang et al., 2018) Impact toughness of different layers on a 20mm thick 16MnDR, when welded on a hybrid laser to minimize the effects of high reflectivity and spatter during the welding process, the laser welding head was tilted 5 degrees along the welding direction there were two distinct parameters that were taken into account. Welding sample 1 and 2 had currents of 220-260 amps, voltages of 24-28V, and welding speeds of 0.35-0.55 m/min, while welding sample 3 and 4 had currents of 240-280 amps, voltages of 26-30 V, and welding speeds of 0.30-0.45 m/min, respectively. During LW and HLAW, shielding gases of 100 percent Ar and 80 percent Ar + 20 percent CO₂ were used at a flow rate of 1.5 m³ /h, respectively The results of Vickers hardness tests of the joint are shown as hardness profiles. The fusion zone's hardness is greater than the base materials, with average hardness values of 438.9, 308.8, 258.7, and 234.9 HV for layers 1, 2, 3, and 4, respectively. It implies that the hardness of the weld centre decreases from layer 1 to layer 4 in general, and that it varies significantly in the interlaminar space As a result of the findings, it is clear that the welded joint's hardness distribution is also uneven. This occurrence is closely linked to micro structural in homogeneity at BM; the specimen's average yield strength and final tensile strength were 362.069 and 524.319 MPa, respectively. Furthermore, the specimen that failed at the welded joint has yield strength of 348.276 MPa and an UTS of 412.358 MPa, both of which are lower than the yield strength and UTS of the specimen that failed at the BM. Charpy V-notch impact tests specimens of layers

1, 2, 3, and 4 had impact-absorbing energies of 21.64, 18.84, 17.89, and 16.88 J, respectively. It was observed that all samples failed in the ductile fracture mode and the impact-absorbing capability of the first layer was higher than the other layers. It was also noted that the larger dimples on the fracture surface showed high energy absorption and ductility, where the small dimples showed low energy and high strength, also the layers with strong plastic deformation showed resistance to crack propagation [50].

(R. Palanivel et al., 2020) studied the 4mm A588 grade steel by the Nd:YAG laser by varying the rate of weld between 1.5–3.5 m/min and taking five different equal speed by keeping the power at constant of 3 kW. The spot size of 300 (μm) at an angle of incidence of 5° on the top surface of the study material employing the shielding gas argon with a 1.5 lpm. The tensile investigation on the different samples and the BM found that it has a strength of 585 MPa. The weld with speed with 3.5m/min has a strength of 567 MPa accounting to efficiency of 97% on the joint, marginal necking an elongation of 20.5% with the presence of the fibrous structure and a large amount of shallow micro voids, leading to less plastic flow before the fracture. The joint with 1.5 m/min has the least joint efficiency of 63% and has strength of 367 MPa and an elongation of 5.5%. The fracture was rough and flat without any micro voids indicating a brittle failure. A trend of increase in the strength of the joint with increase in the speed of weld was found for the range which was taken. The strength of the joint also increased as there was a reduction on the residual stress due to the decrementing effect of heat produced during the wedding operation. The elongation also increased with the increasing speed of the laser and the fracture location also shifted towards the BM. The joint with the highest efficiency failed in the BM while others failed on the fusion zone, while there was no observation of pores and cracks. There is an exception on some test samples taken in the close range of the highest speed where the failure can be observed on the BM. The cause of such failure can be matched with the strain localization [36].

(Devakumar D et al., 2014) has done research on 2 mm thickness plates of weathering steel of grade ASTM A242 Corten-A and duplex stainless steel which is of grade AISI 2205 were butt-welded using GTAW where argon acts as

shielding gas and E 309L was used as filler metal and investigated the mechanical property of this welded region. After welding, specimens were cooled in the air. The following are the welding parameters used to perform the GTAW. The process used 55 amps of current and 16 volts of voltage, with a filler feed rate of 0.5mm/sec and a gas flow rate of 7 liters/minute. At the BM area side, an observation of fracture occurrence was made. The strength of the weld metal is stronger than the BM among the two. Also, in a similar metal weld joint, the load value at the time of fracture during the tensile test appears to be 482 MPa. The observation states that the hardness value in the weld metal is 283HV which is high as compared to HAZ (265HV) and BM (252HV) in DSS/DSS metal weld joints. Likewise, the hardness value shows a decreasing trend in dissimilar metals from welded metal to BM joint welding. This indicates that the welded metal of 290HV hardness value is high compared to HAZ (228HV) and BM (190HV). The ratio of the sizes of the roller to the mandrel is maintained at 3:1 during the bending test. The angle of the bend maintained is 180°. The bend test was performed according to IS: 1599 – 1985 standards and the test specification during the bend test, no development of cracks were observed. There was a satisfactory ductility of the weld found in the bend tests [10].

(S. Ravikumar et al., 2017) has studied the mechanical properties of corten steel sheet welded joints where the thickness of the sheet is 1.6 mm and the thickness of the filler rod is 2 mm which is GR-ER70S2. In this study the TIG butt joint welding was done by considering three different parameters: they are welding speed, current as 2.50mm/sec, 3.125mm/sec, and 3.26mm/sec also change in the current of 105amps, 112amps, 117amps respectively, with a constant gas flow rate 0.5 kg/cm² of an argon and carbon dioxide mixture. The tensile test is done with the welding speed of 2.50 mm/sec and current 105 amps gas flow rate of 0.5 kg/cm² and in the output result shows the UTS of 546.376N/mm², ultimate load of 6.60kN, the maximum displacement of 10.27mm, the breaking load of 4.69kN, and the yield stress of 443.709N/mm². In the tensile test the maximum elongation point is observed on the highest peak in the graph where as the sudden fall in the graph shows the point where the material breaks for the tensile load. The graph peak depicts the material's maximum elongation, while the abrupt decrease in the graph depicts the material's breakage during the tensile measure [39].

(Balamuruga S et al., 2015) researched the Corten steel of thickness less than 3mm, with MAG welding to both ends of the austenitic stainless steel plate on the floor assembly of the coaches and investigated the mechanical property of this welded region. The following welding parameters for MAG welding were used open circuit voltage of 70V, closed circuit voltage of 20V, and current of 160A. The cable feed rate, on the other hand, varied between 2.4 and 7 m/min, and the shielding gas flow rate was 12 liters/min. The temperature in the arc ranged from 5000 to 7000 degrees Fahrenheit. The speed of travel was 350mm/min. From the tensile test, we can infer the following, with the rise in filler wire size, the Peak stress is increasing. The yield strength and tensile strength of unwelded BM are 206MPa and 515MPa respectively. The elongation and decrease of unwelded BM cross-sectional area are 70 percent and 22 percent respectively. It was found during the microstructure study that the BM and weld metal interface field consists of very small heat-influenced zone regions (HAZ). Two distinct areas were observed within the small HAZ. They are Coarse-grained HAZ (CGHAZ-just adjacent to the weld metal region) Fine-grained HAZ (FGHAZ-very similar to the BM region) Hence, at four various spots, the micro hardness was calculated. There are WM, FGHAZ, CGHAZ, and BM that are unaffected. For the bend test to be carried out on both the face and root side of the specimen, UTM.180o free bend test was used. We can come to a conclusion that there is no formation of a crack [6].

(Byju John et al., 2016) carried out the research on the Corten steel plate of thickness 5mm which has undergone GMAW for three joints. During the experiment, the following welding parameters were used a gas flow rate of 15 litres per minute was used, as well as a welding speed of 35 mm and a coil feed rate of 80 mm/min, with a standoff distance of 15 to 18 mm was used . Pure CO₂, (80% Ar – 20% CO₂) and (90% Ar – 10% CO₂) all these three are used as shielding gases. Copper-coated rigid MIG/MAG wire acquiescing to AWS/SFA 5.18 ER 70 S of 1.2 mm nominal diameter is used as the filler material and investigated the mechanical property of this welded region. UTS of the welded joint where (80% Ar – 20% CO₂) was used as shielding gas composition appeared above the UTS of the BM, whereas the UTS of welded joints with pure CO₂ and (90%Ar – 10% CO₂) shielding gas compositions decided to that of the UTS of BM.

The fracture in the BM had an average value for the UTS of 531 MPa for the weld when (80% Ar – 20% CO₂) was used as shielding gas. the tensile strengths when the shielding gas is pure CO₂ is 459.10 MPa and had fracture point at weld metal, the tensile strength when the shielding gas is (90%Ar – 10% CO₂) is 460.89 MPa and had fracture point at weld metal. The impact test was carried out in the Charpy impact test machine Model: IT 30. The tests were conducted at 30o C the impact values of weld joints for the shielding gasses Pure CO₂, (80% Ar – 20% CO₂) and (90% Ar – 10% CO₂) are 73, 82, and 81 respectively. It can be inferred that the energy absorption in the weld metal increases as the CO₂ content in the shielding gas decreases because there is a decrease in the amount of Acicular Ferrite. The Vickers hardness tests were also carried out using a load of 10 Kgf. Decreasing the amount of CO₂ in the shielding gas increases the hardness of Weld Metal and this might be linked to losses in certain alloying elements such as Mn and Si resulting in a decrease in Acicular Ferrite content [4].

(D.C Saha et al., 2014) The study was performed in the 1.2 mm thick (HDGI) DP970 galvanized by hot dipping and HSLA wherein the materials are dissimilar in nature having an UTS greater than or equal to 980Mpa and 500. The welding was performed with a fiber laser with the power of 6W with a focal length of 200 mm and beam diameter of 0.6 mm were in the fiber core diameter was 0.3mm, the weld speed is varied from 12 to 16 m/min with an intermediate speed right between them with a butt weld. The tensile properties of the different weld speeds are observed as in the order of yield strength, UTS in MPa, and elongation % for the 12m/min welding speed on DP980 736MPa,1081MPa,3.9%;14 m/second on DP980 721MPa, 1085MPa, 4.8%, 16 m/sec 725MPa,1041MPa,4.7% on DP980, while the BM has 719MPa, 1097MPa, 12.9%.In the same order for the HSLA the 12 m/mm 412,534,20.0 ; 14 m/min 414,538,20.2; 16 m/min 404,530,20.0. The unwelded BM showed a property of 401,548, 20.0. These results showed that the BM DP980 had the highest ultimate strength whereas the BM showed the least yield strength, it is also observed that on changing the speed of weld the UTS decreased but the yield strength was nearly constant as of the BM. The fracture was observed in the SCHAZ from the micro hardness study; the hardness of this region was lower than the other ones when compared with the BM.While necking was not observed. In the HSLA the elongation and the UTS have not been

affected much with respect to the welding speed. The fracture took place on the BM which shows the strain localization, and a high necking was also observed before the final fracture. The dissimilar weld in fracture was observed on the HSLA in the BM region, as it was the weakest section on the weld as the plastic deformation happened only on the HSLA, while the fracture was ductile in nature. The micro hardness in the SCHAZ on welded region showed a hardness of 50 HV less than that of the DP980. The hardness in the soft region varied between 288 to 303 HV [9].

(M.J. Torkamany et al., 2012) The size of the fusion zone of the low carbon steel sheet is shown to be a determining factor in the mechanical strength of different austenitic/ferritic laser spot welds. The low carbon steel plate of 0.8mm thickness is taken and the laser welding experiment was performed on it where the laser used is Nd: YAG. The UTS and yield strength of this low carbon steel were 370MPa and 180 MPa respectively before welding. A pulsed Nd: YAG a laser power of 400 W was used for welding. Shielding gas used was of 99 percent pure argon gas with a flow rate of 5–10 l/min. The beam diameter of 0.3 ,with the frequency of 14 Hz, with an weld speed of 8.5 ms. A sharp rise in the FZ region of the low carbon steel side can be seen as the laser mean (average) power increases from 210 W to 240 W. The keyhole formation in the low carbon steel sheet at a mean power of roughly 210 W is responsible for this. The keyhole traps the laser beam and considerably increases the amount of energy absorbed from the incident laser beam. This is due to the fact that the laser beam is subjected to many processes. Because the laser beam is reflected and absorbed several times in the keyhole, this is the case (Fresnel absorption). In other words, switching from conduction to keyhole absorption increases laser power coupling efficiency by 4–5 times. The FZ (fusion zone) size of low carbon steel grows more rapidly as the heat input is increased by increasing the laser mean power. The micro hardness of the low carbon steel 170Hv. The horizontal hardness profile gained for the 240W mean power is 2.5 times more than that of the low carbon steel. The average hardness of the metal in the weld zone is significantly greater than the BM's hardness. The marten site formation resulted because of the higher hardness values of the weld nugget [22].

(Ehsan Gharibshahiyan et al., 2011) When the heat input is high, coarse grains appear in the HAZ, resulting in lower hardness values in this zone. The hardness was reduced from 160 to 148 HBN by increasing the voltage from 20 to 30 V. MIG welded Low carbon steel plate of thickness 10 mm is taken and Charpy impact test is performed on it, where the shielding gas used for welding is CO_2 and the electrode was a standard AWS-ER 70S-6 of 1mm diameter. The hardness of welded metal and its HAZ are inversely proportional to the amount of heat applied. After welding at 130 A/20 V and 180 A/30 V, a range of impact strength values of 92.3 and 40.8 kJ was obtained. At 130 A and variable voltages, there was a downward trend in effect energy. Brittle fracture behavior was observed on the fracture surface of weld metal cracked with a heat input of 8.1 kJ/cm. Transgranular fracture by quasi-cleavage and a comparatively flat surface were observed due to high heat input [12].

(Mamud Sarkari Khorrami et al., 2014) The study has been conducted on the welding two different materials namely plain carbon steel and AISI 430 of plate thickness 2mm has been used in this study. The GTAW welding was performed with the filler rod ER309L with Welding current, Arc voltage, Welding speed, gas flow rate and an arc gap of 85 A, 12V, 2mm/s, 23l/min, less than 2mm respectively and the autogenous arc weld is also performed on the with 130A current, 12V arc voltage, 4.27mm/s welding speed, gas flow rate of 12l/min and an arc gap of 1mm. The welding was also performed in a special setup with asbestos as insulator to balance the heat sink on plain carbon and copper on the AISI 430 steel to raise the heat sink is placed on both the sides of the plate to make an optimum weld as the heat conduction coefficient differs largely between the two. The longitudinal and transverse tensile strength of the welding with filler material ER309L is observed as 922 MPa UTS, energy absorption of 79.01 J/m^3 and elongation 11.93%. In Autogenous mode the absorbed energy is 53.66 J/m^3 and the UTS is 662 MPa and elongation of 10.36 %. It was found that the weld with the filler material has more energy absorbing capacity with higher ductility which is due to the presence of duplex microstructure of martensite and ferrite strengthening. But on comparing with the BM the weld has lower elongation because of the variation in the composition in the weld. In all the welds the fracture happened on the plain carbon. The hardness study on the weld revealed that the hardness on the GTAW is

385Hv and AGTAW shows 140Hv hardness in GTAW is higher because of the presence of ferritic martensitic structure. In the heat affected zone the hardness in the AISI 430 was 242Hv and 275 Hv for the weld with filler material and autogenously. There was a notable drop in the hardness after the fusion line on the AISI 430 steel. This is due to the high grain growth in the region which may be due to the higher cooling rate [23].

(Kun Yu et al., 2014) studied GH3535 which is a super alloy of low carbon steel, taken into consideration and Laser welding was performed on the 4mm thick plate. The hardness of FZ was greater than that of HAZ and BMZ, according to micro hardness findings. Tensile testing showed that the UTS of joints at room temperature, 650°C, and 700 °C was 98 percent, 97 percent, and 99 percent of that of BM, respectively. With a speed of 3.0 mm/min, the tensile properties of specimens were investigated. The tensile strength of BM and weld at room temperature is 805MPa, and 792Mpa. The tensile strength of BM and weld at 650°C is 551MPa, and 553Mpa. The tensile strength of BM and weld at 700°C is 499MPa, and 496Mpa. The strength coefficients of the joints, which are the ratios of joint strength to BM strength, are 0.98, 0.97, and 0.99, respectively. The BM elongates by 55 percent, 37 percent, and 36 percent at room temperature, 650 and 700 °C, respectively, while the joints elongate by 48 percent, 30 percent, and 28 percent, respectively, at room temperature, 650 and 700 °C. It means that laser welded joints have a lower elongation than BM joints. As-welded joints had an UTS of 497 MPa, while BM had a strength of 550 MPa at 650 °C. In FZ, all of the welded joints that were tested in tension failed [20].

(Ravikumar.S et al., 2006) Corten steel plate of thickness 1.6 mm was considered and GTA welding was performed. Different welding parameters for Corten steel sheets include welding speeds of 2.50mm/sec, 3.125mm/sec, and 3.26mm/sec, as well as currents of 105amps, 112amps, and 117amps, respectively. The shielding gas used is a mixture of Ar and CO₂ that protects the welding process from external contamination. The maximum displacement is 10.27 mm and the UTS is 546.76N/mm². The UTS and yield stress all increase as the displacement increases. The breaking load is 4.69kN. the yield stress is 443.709N/mm². The mean micro hardness at the weld zone resulted in 199.17. The average micro

hardness at the Heat Affected Zone (HAZ) is 180.46. After welding the average micro hardness resulted in 152.73. When the micro hardness values are compared the mean micro hardness of the weld zone(WZ) is the highest among HAZ and BM. The least mean of micro hardness can be observed in the BM. The peak in the graph showed the elongation , whereas the sudden decline in the graph resulted in breakage of the metal [37].

(R. Megavarnan et al., 2016) The study used IRSM41 grade mild steel with a thickness of 3.2 mm and welded using the GMAW weld with root gap of 1.5 mm on a butt weld using the shielding gas of CO_2 with flow of 10 liter per minute, ER70S6 in a wire form of diameter 1.2mm. The weld parameters used in the study is 19V voltage, 170A current, 4.3m/min wire feed maintaining an electrode stick of 10 mm and the weld speed of 100 mm/min. The tensile test along the grain flow and across it showed the strength of 508.1 and 449.47 Mpa respectively. The fracture on the test sample along the grain flow showed that the mechanical properties were high and as the alignment of the grains was in the direction where the crack could propagate through the material. The bend test performed on a mandrel of 12.8 diameters on the face and the root of the weld showed no cracks on the weld. The hardness study in both the grain flow direction showed the same hardness on the BM of 180VHN and the HAZ the hardness across the grain showed a higher hardness of 186VHN whereas along the grain flow was 187VHN which is very much comparable, but in the weld metal there was a huge change in the hardness where as the values across showed 186 VHN, along showed 190 VHN [35].

(Heng Zhang et al., 2015) performed double-pulsed GMAW (DP-GMAW) on the 5mm thickness plate of FSS. To ensure back formation, a 45° single V butt joint was created with a 2-mm preset welding gap. Pure argon was used as the shielding gas in the experiment. To keep the area above 400 °C from oxidizing, were using a flow rate of 15 L/min from the welding torch and 10 L/min from the tube behind the welding torch. ERNiCr-3 was used as a filler rod. When compared to other parts of welds, micro hardness in FZ is the lowest, ranging from 170 to 190 HV. As the indenter approaches HAZ, it rapidly increases to around 240 HV, then gradually rises to its peak value in BM, fluctuating between 260 and 280 HV.

This is due to the ERNiCr-3 filler's austenitic microstructure, which is more ductile but also less hard than ferrite, resulting in the lowest micro hardness in FZ. Previous fine ferrite in HAZ underwent enormous grain growth, resulting in polygonal ferrite. In the bending no crack formation was observed. The welded sample passed the bending test, indicating that they were ductile under DP-GMAW welding parameters that were optimized [14].

(Waghmare et al., 2019) The study was conducted on the 3mm thick HSLA ASTM A588 B-2 the welds are performed on TIG and SMAW using two different filler material E308L , E8018-B2 and ER8018-B2 , the different filler material was selected because the filler materials have different properties and the used in different industries . The weld parameters of E308L on a 3.5 mm electrode diameter for the SMAW process is 68.3 A current ,23.5 V voltage , 2.12 mm/s as welding speed and the heat input for the weld is 528.72 j/mm. In the same weld the parameters for the E8018 B-2 electrode of diameter 3.5 mm is 83.4 A current, 24.3 V voltage, and a welding speed of 2.4 m/s with heat input of 591.09 j/mm.The TIG welding of E308L used a filler with diameter 2mm and the current of 114A, 12Vvoltage, welding speed of 1.214 mm/s and heat input of 788.80 j/mm.The ER80S B-2 2mm diameter wire on tig uses a current of 188A and a 12.9V with a weld speed 1.209 mm/s and the heat input of 881.34.The tensile strength for SMAW by E308-L 513.17Mpa; SMAW by E8018 B-2 505.05 Mpa; TIG by E308-L 526.43Mpa; TIG by ER80S B-2 469.63Mpa the least strength was observed on the ER80S B-2 filler because of grain coarsening and high heat input. The impact test showed SMAW by E308-L 38 j; SMAW by E8018 B-2 40 j ; TIG by E308-L 34 j ; TIG by ER80S B-2 36 j. The E8018 B-2 has better toughness when compared to all the others this may be because of the high carbon and fine grain size present in the weld because of the filler material characteristic. The hardness distribution across the welded joint was measured using Rockwell hardness from the welded area to the BM zone. At the welded zone, HAZ, and BM, an average of four HRB readings at 100 Kgf were taken. In comparison to the HAZ and BM, the weld zone has a greater hardness. The welded part of the sample welded by SMAW with E308-L electrode had a greater hardness value, which could be attributed to a higher proportion of Ni and Cr with finer grain size. The hardness of the Corten steel welded with SMAW by E308-L in the HAZ is 184HV. The hardness of the

Corten steel welded with SMAW by E8018 B-2 in the HAZ is 153HV. The hardness of the Corten steel welded with TIG by ER308-L in the HAZ is 153HV. The hardness of the Corten steel welded with TIG by E8018 B-2 in the HAZ is 168HV. The hardness of the Corten steel welded with SMAW by E308-L in the Weld Zone is 242HV. The hardness of the Corten steel welded with SMAW by E8018 B-2 in the Weld Zone is 206HV. The hardness of the Corten steel welded with TIG by ER308-L in the Weld Zone is 192HV. The hardness of the Corten steel welded with TIG by ER80S B-2 in the Weld Zone is 183HV. The hardness of the Corten steel welded with SMAW by E308-L, SMAW by E8018 B-2, TIG by ER308-L, and TIG by ER80S B-2 in the BM (BM) showed the same reading of 148HV [42].

(R. Cortés et.al., 2018) The plates of Inconel 718 comprising the thickness of 6.35 mm were joined using gas tungsten arc welding (GTAW). A semi-auto mechanism fed an ERNiFeCr-2 filler wire with a diameter of 1.1 mm at 170 mm s⁻¹. The GTAW torch was positioned at a 15° angle to the plates' normal and displaced at a rate of 4 mm s⁻¹. As a shielding gas, a mixture of H₂ (2%), CO₂ (0.12%), He (30%), and Ar (67.88%) was used, flowing at 16.50 dm³ min⁻¹. With a potential of 29 V and a current of 356 A, an alternating current and tungsten-thorium electrode were used. Considering a thermal efficiency of 70%, these parameters resulted in a heat input of 1806.7 J mm⁻¹. An austenitic matrix, with equiaxed grains and the presence of twinning was found in the microstructure of the IN718 alloy in annealed and aged conditions, which supports the distribution of the alloying components within the matrix. When compared to the annealing condition, there is a significant presence of MC-type precipitates (where M can be Ti or Nb or even both), MoC, and M₆C (where M can be Fe, Cr, Mo, W, and Nb) in the aged condition. In the as-welded and HRPWHT conditions, the microstructure in the FZ of the welds is shown. In both cases, the usual columnar dendritic structure is visible. In annealed and aged conditions, the Vickers hardness number of the base material IN718 was 236.4±5.2 and 408.5±3.2, respectively. The hardening " and ' phases precipitated as a result of heat treatment, solubilization, and ageing, resulting in an increase in hardness. In the annealed condition of IN718 it was found that the yield strength is 430.3±5.7 Mpa, the tensile strength is 842.9±5.7 Mpa, the fracture strength is 387.7±12.7 MPa, and the elongation is 51.4±0.7%. IN718 aged sample yield strength was discovered to be 822.7±9.6 Mpa

and tensile strength was found to be 1090.3 ± 4.6 Mpa when the test was performed. The energy of a fracture is 434 ± 5.1 J m⁻³, and the elongation is 41.2 ± 3.9 %. In the welded condition of IN718 it was found that the yield strength is 371.3 ± 12.3 Mpa, the tensile strength is 660 ± 13.49 Mpa, the fracture strength is 147.6 ± 26.13 MLm⁻³, and the elongation is 25.7 ± 3.7 %. IN718 HRPWHT sample yield strength was discovered to be 719.0 ± 39.0 Mpa and tensile strength was found to be 988.0 ± 12 Mpa when the test was performed. The energy of a fracture is 246.6 ± 10.7 J m⁻³, and the elongation is 26.9 ± 2.4 % [34].

2.2 CORROSION

(Byju John et al., 2016) investigated the corrosion property of a 5 mm thick IRS M41/97 using a semi-automatic MIG welding with the shielding gas of 80% Ar – 20% CO₂ and the study area of 1.5 cm² and a scan rate of 0.25 mVs⁻¹ with the test current being –250 mV to +250 mV, a stimulant for the salty environment being 3.5% NaCl solution and calculated the rates according to the ASTM (G.102-89 of 1999) standards. It is observed that the I_{corr} , $i_{corr} = (I_{corr}/\text{area exposed})$, corrosion rate (mpy), corrosion rate was -11.899 μA , 0.793×10^{-5} A/cm², 3.5, -448.329 mV, respectively. This lies within the range when comparing it with the similar commercially available steels. The Tafel polarization is found to be aerated and neutral where in the cathodic reaction consists of the oxygen reduction ($\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^-$). This is also evident from the Pourbaix diagram of the Fe-H₂O system. The Acicular ferrite microstructure found exhibits the lowest corrosion rate and the transfer modulus and the charge transfer rate is the largest, while this layer provides protection to the steel underneath it [4].

(Al-Kaseasbeh et al., 2018) observed the corrosion in 6.4 mm thick plate of A588 grade steel plate in welded condition using an SWMA with the filler material E7018, unwelded BM, and CSA coated base at a scan speed of 0.166 mV/s and a current range between from –300 mV to 1,500 mV (SCE) shows the net current in the corrosion potential which goes toward zero became more negative When the base is welded and the additional layer of the coating does not have an effect on it. The corrosion tendency of the base to weld was found as 8 times higher as indicated for E_{corr} (mV) and I_{corr} (A/cm²) for the base -735 , 5.72 , and the

welded as -739 , 48.1 respectively. The corrosion rates per year on the welded and base is 0.13 and 0.1 mm It was also found that few researchers suggested that high scan rate may affect the output of the study, but this research suggests that we evaluate the corrosion property may be evaluated quantitatively and the bare samples showed the locally formed rust spots and the welded samples showed more tendency of pinholes and damage [33].

CHAPTER-3

AIM AND SCOPE

3.1 AIM

- To provide a weld with minimal defect in base material and high strength this will be useful for the construction and the rail industry.
- To perform the hardness test on the different zones formed during welding on Corten A588 and compare the hardness values on these zones to find the effect of heat on the metal.
- To know the ductility, tensile strength and fracture strength of the welded Corten A588 by performing a bending and tensile test.
- To perform the impact test on the welded Corten A588 in order to study the amount of energy absorbed during fracture of material.
- To study the corrosion property of the welded Corten A588 in simulated condition and compare it with the unwelded plate.
- To compare the weld and find the weld with high mechanical strength and anti corrosive property for different applications.

3.2 SCOPE

- The characteristic properties of the Corten A588 graded steel when different welds are performed is obtained by which the suitable weld for specific needs can be obtained.
- A comparison between the value of the hardness, tensile, bending, impact strength and also the detailed corrosion study of various types of weld .
- This data will be majorly useful for the construction and rail industries also, this raw data can also be used in training the Artificial intelligence models which are widely being introduced in the field of metallurgy.
- The weld with mechanical strength and anti-corrosive property close to the BM is found.

CHAPTER-4

METHODOLOGY AND EXPERIMENTAL SETUP

4.1 METHODOLOGY

The various Stages in research work is given in Figure 4.1.

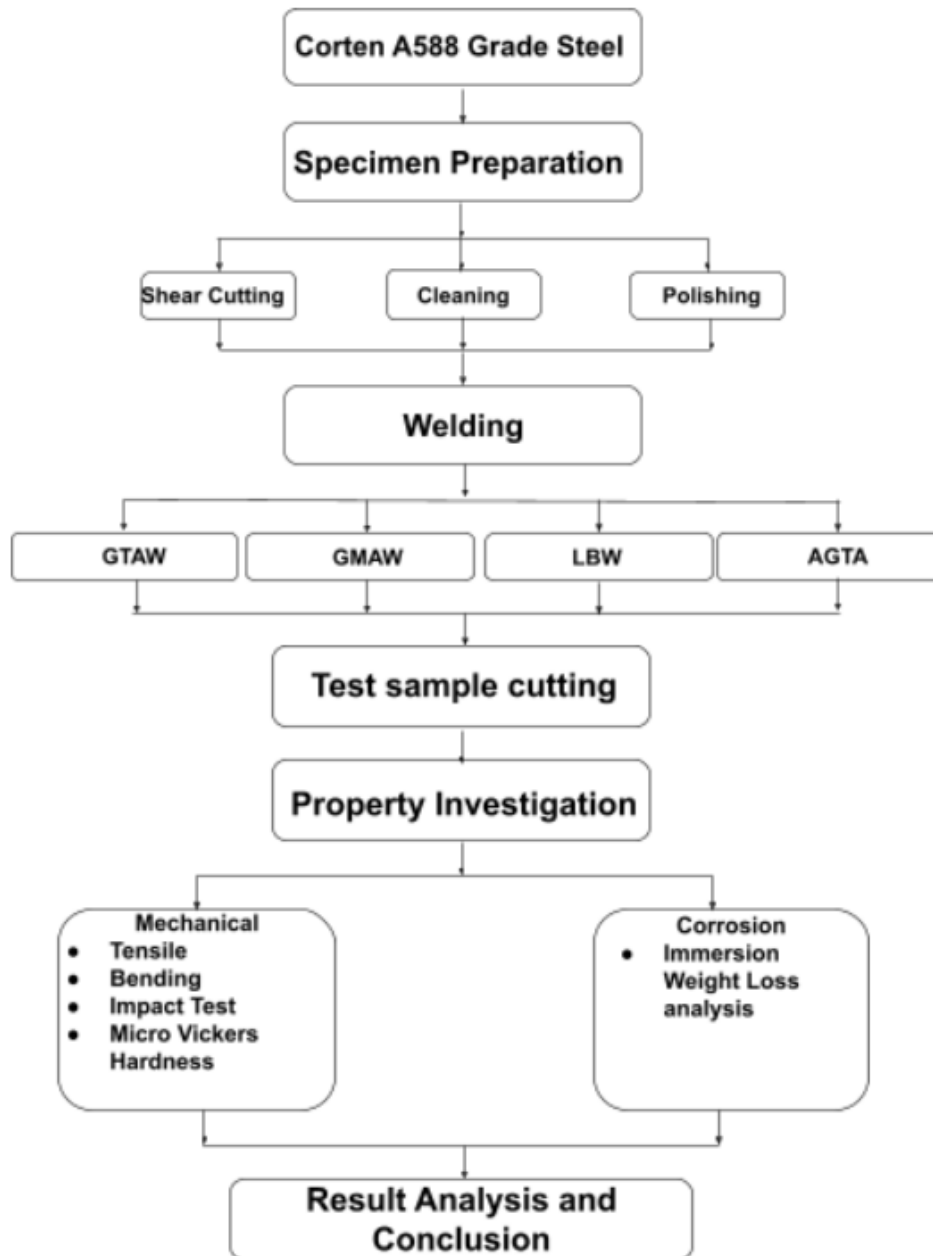


Figure 4.1 Stages in research work

4.2 SPECIMEN PREPARATION

The Corten A588 before any processing is given in *Figure 4.2* .



Figure 4.2 2mm Thick sheet Corten A588 plate before processing for welding

Before the process of surface preparation the plate was cut using Hydraulic Shear cutting machine as in *Figure 4.3* into the size 150*150 mm.



Figure 4.3 Hydraulic Shear Cutting of Corten A588 sheet

The test plate surface was prepared with the use of the (b) 120-grade emery wheel in order to remove the rusty patina on top of the specimen plate and was polished using the (c) soft wheel till it got a shiny metallic finish (a) as shown in *Figure 4.4*.

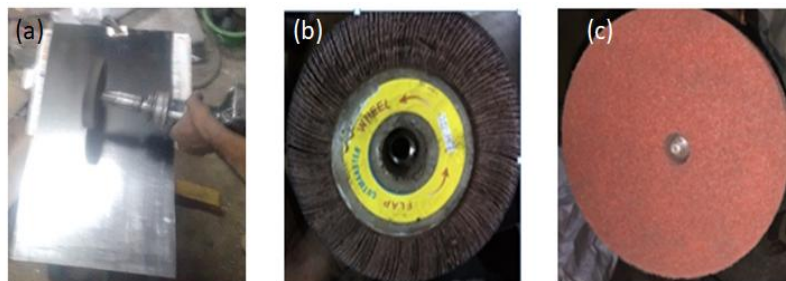


Figure 4.4 Grinding and polishing process on sheet

After grinding and polishing the plate, it was washed with acetone and subsequently dry out in the air and the final outcome of the plate before welding is shown in *Figure 4.5* .



Figure 4.5 Final sample after all processes

This plate is then welded into four different welds namely GTAW, GMAW ,LBW and AGTAW.

The square butt welding is performed on the plate with a root gap of 2mm and full penetration for GTAW,GMAW according to the *Figure 4.6*.

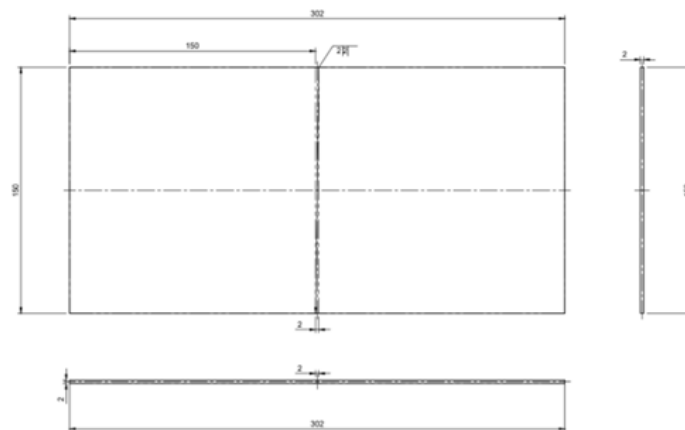


Figure 4.6 Diagrammatic representation weld plate with root gap

Similarly the square butt welding is performed on the plate without root gap and full penetration for LBW and AGTAW weld plates were prepared according to the *Figure 4.7*.

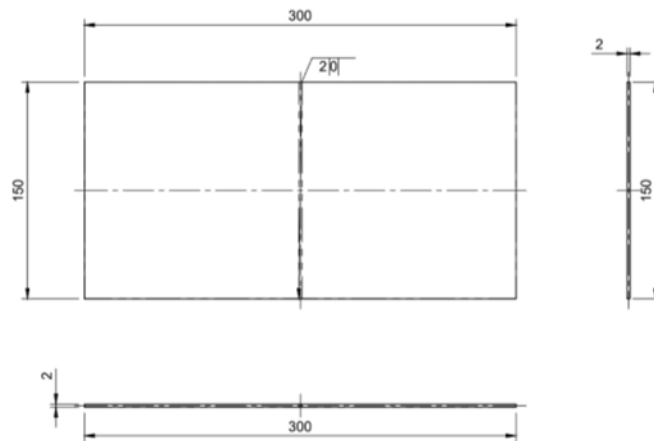


Figure 4.7 Diagrammatic representation of weld plate without root gap

After welding the plates, the specimens for examination were prepared according to ASTM standards using the shear cutting method and electron beam wire cutting. The mechanical properties of the welded joints were examined using Tensile, Bending, Impact, Hardness, immersion corrosion tests on the welded Corten A588 plate.

4.2.1 GTAW

The machine used for performing GTAW was a pentagon tig 400 in *Figure 4.8* which is present at Shakthi Fabrications, Triplicane, Chennai.



Figure 4.8 Pentagon tig 400 machine used for GTAW

Welding parameters used while performing GTAW weld on the plate is given in the Table 4.1 .

Table 4.1 Welding parameter for GTAW

Parameter	Value
Current(A)	174
Voltage (V)	18
Filler wire	ER70s-6
Filler rod dia	1.6mm
Shielding gas	Argon 80%+ CO ₂ 20%
Root gap	2mm
Heat input(Q) Joule/mm	1338.46
Weld width (mm)	4.25

The (a) front view and (b) Back view of GTAW plate is shown in *Figure 4.9*.

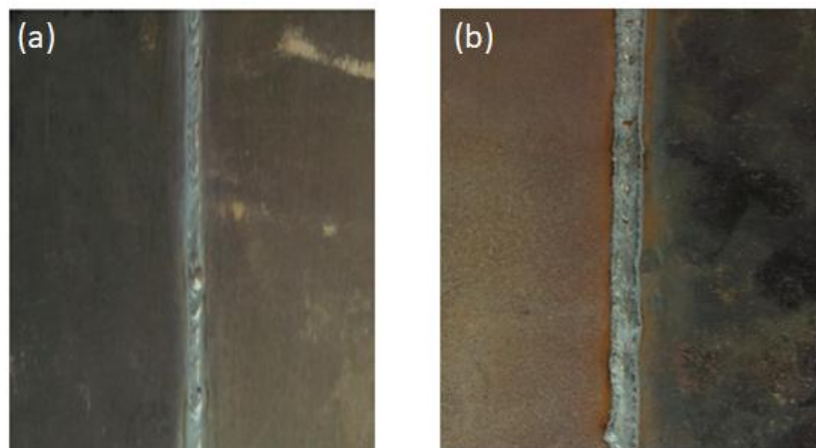


Figure 4.9 Front and back view of GTAW plate

4.2.2 GMAW

The machine used for performing GMAW was a pentagon mig 500 in *Figure 4.10* which is present at Shakthi Fabrications, Triplicane, Chennai.



Figure 4.10 Pentagon mig 500 machine used for GMAW

Welding parameters used while performing GMAW weld on the plate is given in the Table 4.2.

Table 4.2 Welding parameter for GMAW

Parameter	Value
Current(A)	170
Voltage (V)	21
Filler wire	ER70s-6
Filler rod dia	1.6mm
Shielding gas	Argon 80%+ CO ₂ 20%
Root gap	2mm
Heat input(Q) Joule/mm	1174.34
Weld width (mm)	3.25

The (a) front view and (b) Back view of GTAW plate is shown in *Figure 4.11*.

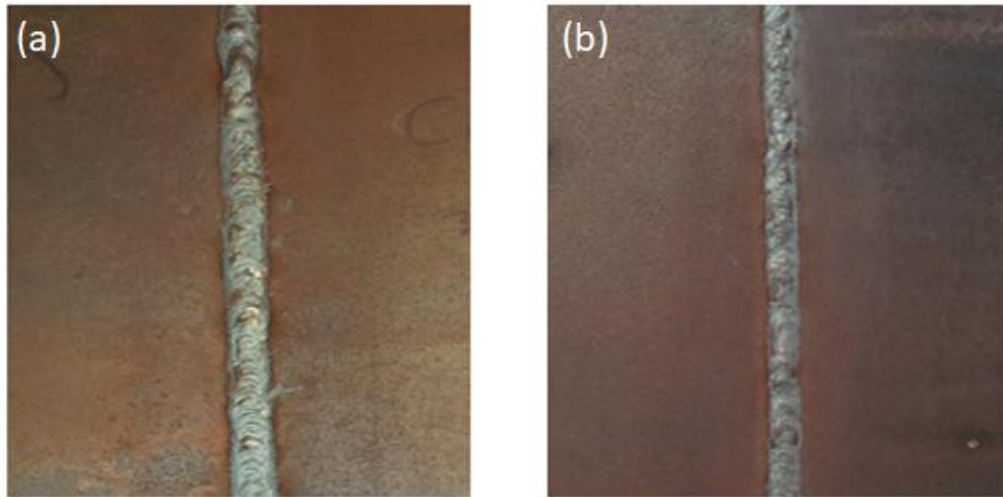


Figure 4.11 Front and back view of GMAW plate

4.2.3 LBW

Balliu Belgium laser beam 3 kW welding machine at LHB shed, *Figure 4.12*, Integral Coach Factory, Chennai, is used for this was a transverse flow, Carbon di oxide Laser. CO₂ lasers use a pre mixed gas of CO₂, Helium and Nitrogen. Nitrogen acts as a catalyst to bombard the CO₂ molecule. The excited unstable Carbon atom goes to high energy level and while returning back it emits photon. The process continues and large amounts of photons are released. Helium acts as a cooling agent. These released photons with very high energy are passing through reflecting mirrors and lenses. The welding was performed at Integral Coach Factory Perambur Chennai.

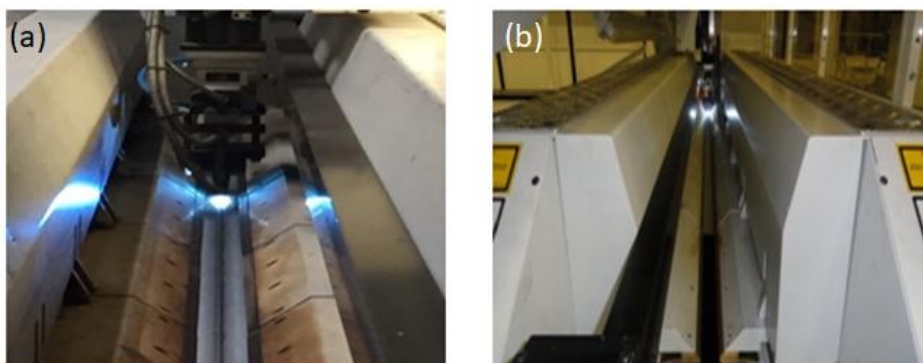


Figure 4.12 Balliu Belgium LBW machine used for LBW

Welding parameters used while performing Laser Beam Welding on the plate is given in the Table 4.3

Table 4.3 Welding parameter for Laser Beam Welding

Parameter	Value
Filler wire	No filler wire
Power output (KW)	3
Continuous power (KW)	2.29
Laser source	CO ₂ laser
Frequency (Hz)	5000
Root gap	Nil
Heat input(Q) Joule/mm	71.99
Weld width (mm)	1.6

Welded plate after Laser welding is shown in *Figure 4.13*



Figure 4.13 Laser weld on plate

4.2.4 AGTAW

Machine used for performing AGTAW welding is pentagon tig 400 which is shown in *Figure 4.14* Welding was performed at Shakthi Fabrications, Triplicane, Chennai.



Figure 4.14 Pentagon tig 400 machine used for AGTAW

Welding parameters used while performing AGTAW weld on the plate is given in the Table 4.4

Table 4.4 Welding Parameter For AGTAW

Parameter	Value
Current(A)	181
Voltage (V)	17
Filler wire	No filler
Shielding gas	Argon 80%+ CO ₂ 20%
Root gap	NIL
Heat input(Q) Joule/mm	1332.3
Weld width (mm)	4.5

Welded plates Front and Back view is shown in *Figure 4.15*

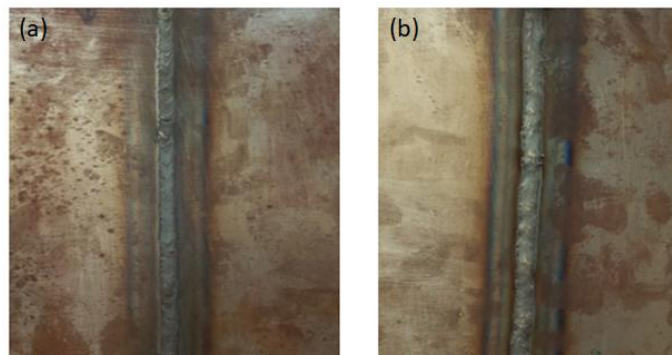


Figure 4.15 Front and back view of AGTAW plate

4.3 SPECIMEN CUTTING

Welded plate was cut using Laser cutting and EDM wire cutting for making the different test samples using the ASTM standards.

4.3.1 Laser cutting

The laser cutting was performed on the same machine *Figure 4.16*



Figure 4.16 Balliu Belgium machine used for Laser cutting

Which was used for welding it and the Laser cutting sample is shown in *Figure 4.17*. The welding was performed at Integral Coach Factory, Perambur, Chennai.

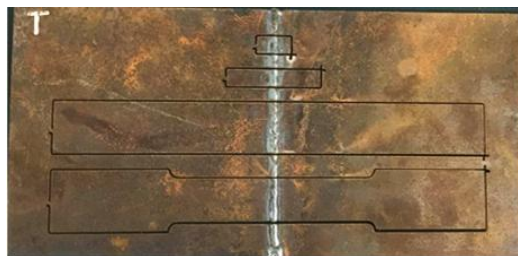


Figure 4.17 Laser cutting on welded plate for different testing

4.3.2 EDM Wire cutting

The Electron beam cutting was performed on the cnc wire cut EDM as shown in the *Figure 4.18*.



Figure 4.18 Cnc EDM wire cutting

The EDM cutted sample is shown in *Figure 4.19* EDM wire cutting was done at High Profile Engineers Mogappair West, Chennai,

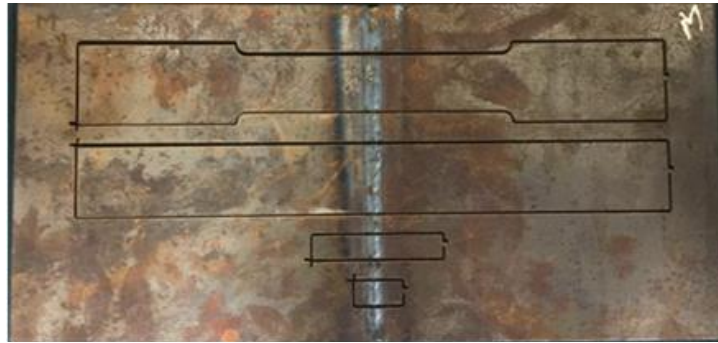


Figure 4.19 EDM cutting on welded plate for different testing

4.4 TESTING

4.4.1 Tensile test

The tensile test sample was prepared according to the ASTM - E8/E8M – 11 standards of tension test for metallic testing. The test for tensile strength and bending was performed on the Servo Controlled UTM machine Model -F100 as shown in the *Figure 4.20*. Tensile test was conducted in Micro Labs, Ambattur, Chennai.



Figure 4.20 Servo controlled universal testing machine

Specimen Size representation of the tensile test is given in *Figure 4.21*

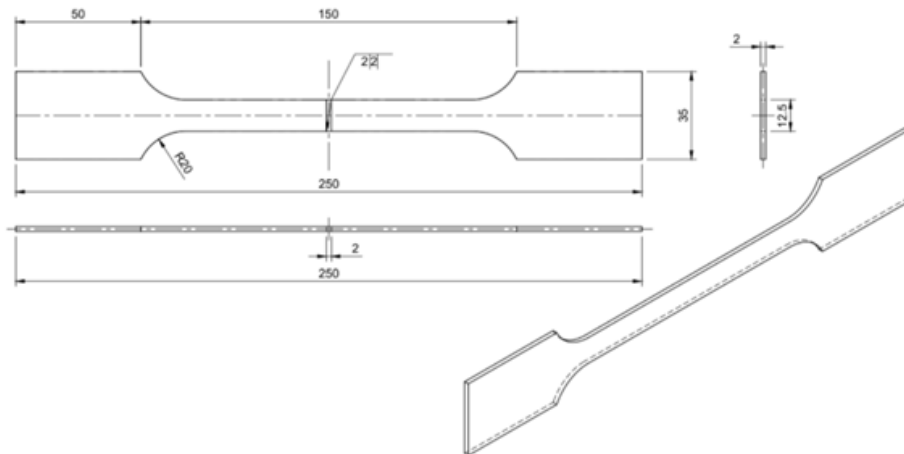


Figure 4.21 Tensile test sample dimension

The tensile testing was first performed where the test sample was first clamped on using proper fixtures on the setup and then the tensile strength was performed. The machine was switched on to perform the test and stopped when the test sample broke into two pieces while the corresponding readings were taken and stored digitally on the computer connected to it. The test was performed on five samples of all the four welds and average was taken in order to come to the final conclusion.

4.4.2 180-degree free bend test

The bending test sample was prepared according to the ASTM E190 standard.

The test for bending was performed on the Servo Controlled UTM machine Model -F100 as shown in the *Figure 4.20*. Tensile and bending test were conducted in Micro Labs, Ambattur, Chennai.



Figure 4.22 servo controlled universal testing machine

Specimen Size representation of the bending sample is given in *Figure 4.23*

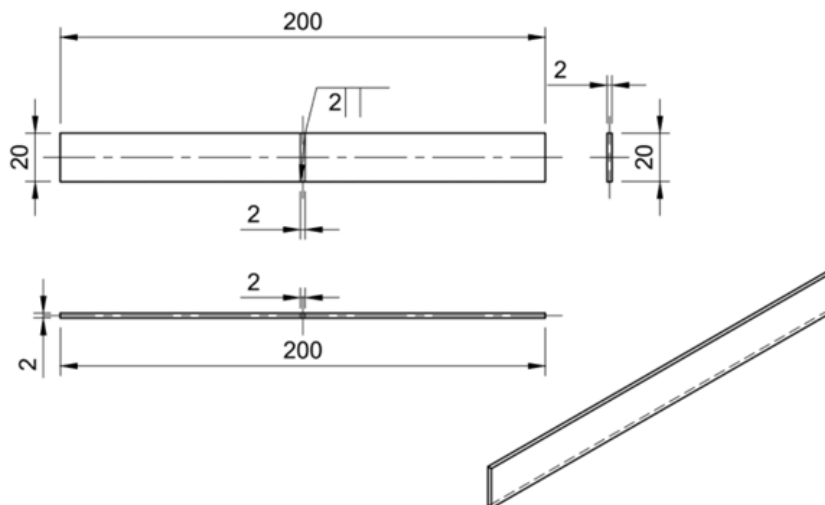


Figure 4.23 Bending test sample dimension

The mandrel of 8mm dia is used to perform the bending test. The test samples were loaded and test was performed as forward and reverse bend depending on whether the load was applied corresponding to the weld sample was bent till 180° after when the machine was stopped. The test was performed on five samples of all the four welds. The bending test samples a visual inspection is performed on the bended samples after which the results are noted.

4.4.3 Charpy impact test

The Charpy impact test was performed on the sample at room temperature, in accordance with ASTM E 23 12c requirements on a , and the test temperature was room temperature (+24°C). A pendulum impact measuring unit as shown in the *Figure 4.24* Was used to perform the Charpy V-notch test.



Figure 4.24 laryee Izod and charpy universal Impact tester

This is a standardized high strain-rate test that measures the amount of energy absorbed by a material during fracturing. The amount of energy absorbed by a substance is an indicator of its notch durability. It is commonly used in industry because it is simple to plan and execute, with fast and inexpensive performance. Find a reference for this machine name to be added. The sample was loaded on the experimental setup , after which the impact pendulum was released and the readings of the impact strength is stored on the computer attached to the setup .Test was performed on five samples of all the four welds and average was taken in order to come to the final conclusion. Impact test was conducted in Met Mech Labs, Ashok nagar,Chennai.Specimen Size representation of the Impact test is given in *Figure 4.25*.

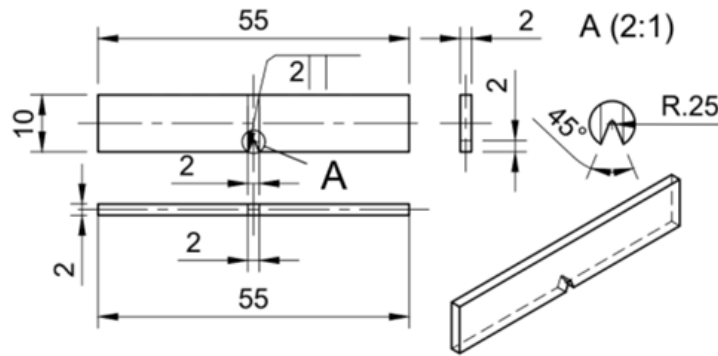


Figure 4.25 Impact test sample dimensions

4.4.4 Micro Vickers Hardness test

The micro hardness on the welded zone was conducted in the FIE Rockwell Hardness Testing Machine as shown in the Figure 4.26 with respect to the ASTM E92. Totally, fourteen micro hardness survey points have been taken at the cross section from the weld center to the BM Corten A588 Grade steel, GTAW, GMAW, LBW, and AGTAW Corten A588 Grade steel weld joints.



Figure 4.26 FIE Rockwell Hardness testing machine

Specimen Size representation of the Hardness test is given in *Figure 4.27*

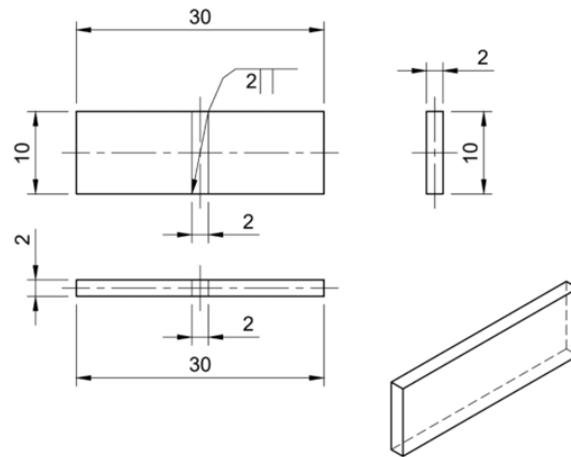


Figure 4.27 Hardness test sample dimension

The micro Vickers hardness survey is carried out by making the indentation at an interval of 0.5mm distance along the transverse plane of the weld joints with 0.5 kg load. In this, the set of micro hardness surveys is taken from (4-14) points which spread out from the base material to the Heat Affected Zone (HAZ). The second set of (2-3) points is taken from the Heat Affected Zone (HAZ) and the third set of micro hardness points (0-1) is taken on the Weld Zone (WZ). The test was conducted at Met Mech labs Ashok nagar, Chennai.

4.4.5 Immersion corrosion

The immersion corrosion test is performed in order to find how much it resists the corrosion in a simulated environment which is very much suitable for the corrosion to prorogate. The weight loss found on the test specimens gives us the rate at which the corrosion takes place on the material , this test is conducted according to ASTM – G31.

Specimen Size representation of the corrosion test is given in *Figure 4.28*

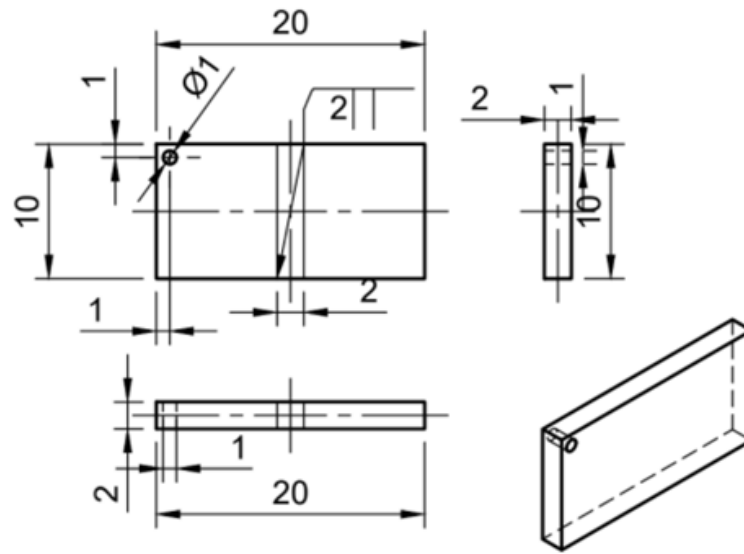


Figure 4.28 Corrosion Test sample Dimension

The immersion corrosion test was performed on all the different welds of Corten A588 grade steel using a simulated solution for the corrosive environment and where the samples were kept in the test setup for 30 days .The corrosion simulation solution used in the study was 3.5% NaCl .which was prepared by weighing the ml of distilled water and gm of NaCl and mixed together till all the solid is dissolved completely in the water .The ph of the prepared solution was measured using the electrochemical method using the pH meter before and after the corrosion. The conductivity is measured using the electrical conductivity meter before and after the corrosion test period. The weight for the sample is measured using an electronic weighing scale before and after the study. Immersion Corrosion test was done at Sathyabama Institute of Science and Technology, Chennai.

CHAPTER-5

RESULT AND DISCUSSION

5.1 TENSILE PROPERTY

The test sample was prepared according to the ASTM - E8/E8M – 11 standards of tension test for metallic testing. The tensile properties of BM and GTAW, GMAW, LBW and AGTAW Corten A588 Grade steel weld joint, viz, UTS, yield strength, percentage elongation, joint efficiency (η_{Joint}) and the location of failure has been studied and are shown in Table 5.1.

Table 5.1 Tensile test result on various Corten A588 grade weld joints

Weld	Ultimate tensile strength (kgf/mm ²)	Yield strength (kgf/mm ²)	% Elongation	Joint Efficiency (η_{Joint})(%)	Fracture location
Base Metal	484	303	22	-	Middle of the Gauge Length
GTAW	474	387	24	97.93	BM
GMAW	483	386	24	99.79	BM
LBW	480	374	21	99.17	BM
AGTAW	441	362	25	91.12	BM & WZ

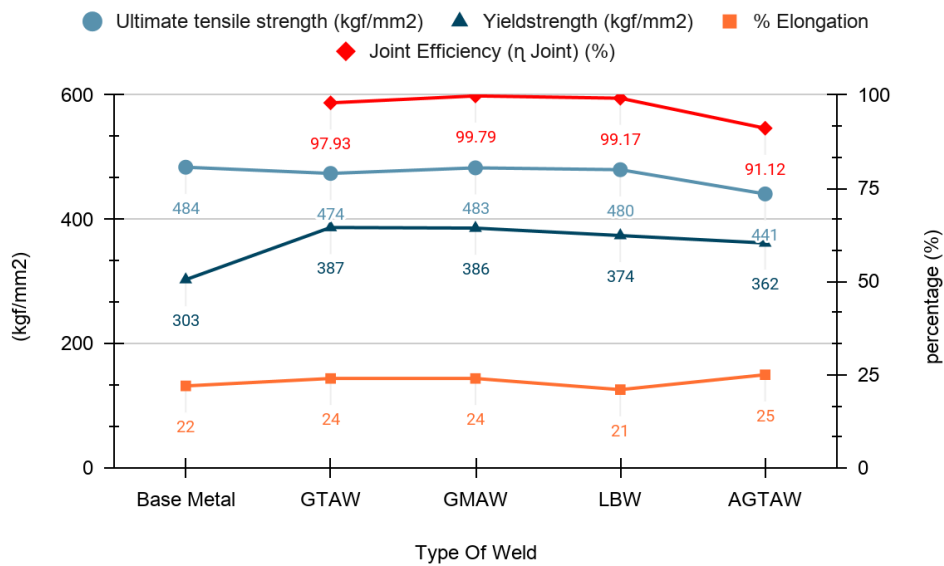


Figure 5.1 Tensile Graph of Welded joints

Tensile graph as in the *Figure 5.1* shows that the BM has the tensile strength of 484 kg/mm^2 while the yield strength is of 303 kg/mm^2 and the % of elongation is 22. The *Figure 5.2* illustrates the tensile samples before and after the test. The BM from the broke in the center of the gauge with a transverse fracture without any necking. The GTAW has the tensile strength 474 kg/mm^2 which is less than the BM making the joint efficiency as 97.9%, Making it the joint with maximum efficiency among all the welds while the yield strength 387 kg/mm^2 which is approximately 1.27 times more than the base, Which has the highest yield strength of all the joints .From the *Figure 5.2* we can say that the fracture has taken place on the BM obliquely with slight distortion and a very small necking making a ductile fracture. The GMAW shows the highest tensile strength of all welds with 483 kg/mm^2 making the joint efficiency of 99.79 % and yield strength 386 kg/mm^2 which is also similar to that of GTAW sample. The elongation % increased by 2 making it 24 %.Tensile test result on various Corten A588 grade weld joint

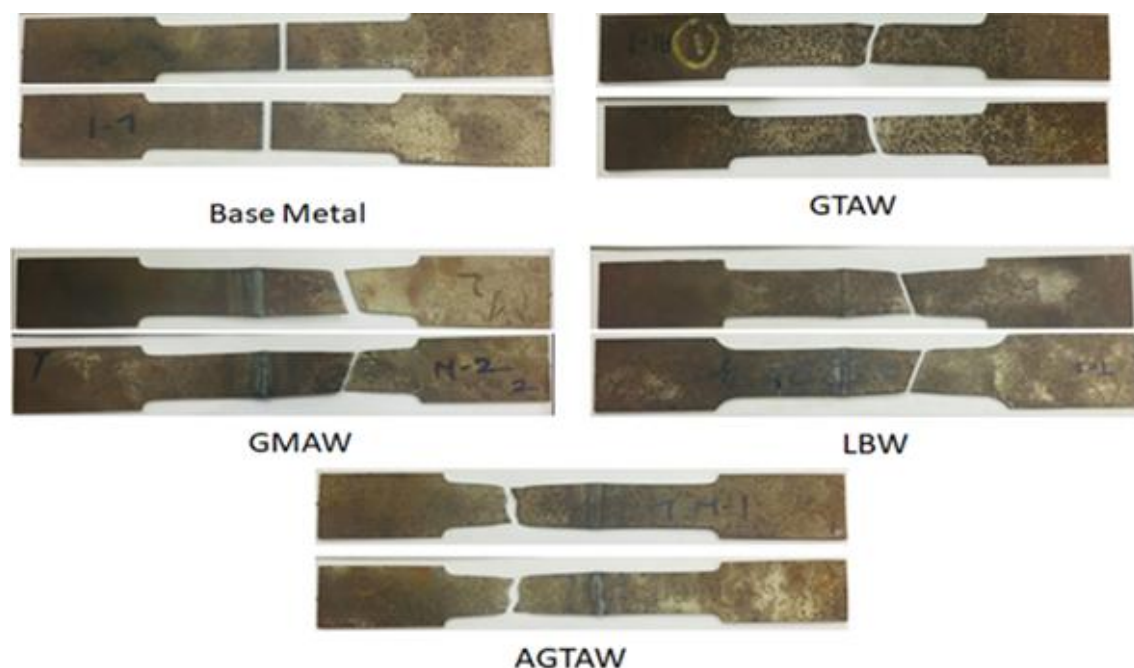


Figure 5.2 Tensile test samples after fracture front and back view

The *Figure 5.2* shows that the fracture took place on the BM where fracture was oblique with slight necking making a shear ductile fracture. The LBM has an tensile strength of 480 kg/mm^2 making the joint efficiency as 99.17 %. The yield strength is 374 kg/mm^2 which is approximately 1.234 times of the BM .The elongation

property is observed to be a minimum among all the welds as 21% which is less than the BM. The *Figure 5.2* shows that the fracture took place in the BM and with a slight necking with an oblique fracture making a shear ductile fracture. The AGTAW has a tensile strength 441 kg/mm^2 where the joint efficiency of 91.1% making it the least among all the welds. The yield strength is observed to be 362 kg/mm^2 which is approximately 1.19 times the BM which is the least among the welds but more than the BM. The elongation is observed to be 25% which is 3% more than the BM. The *Figure 5.2* shows that the fracture took place on the BM as well as the weld zone, the necking is observed to be maximum, while the fracture propagated from the BM to the weld zone steeply and then a u curve is observed starting from the weld zone to the BM and then again back to the weld zone making a highly ductile fracture.

The tensile test on the welded joints gives us an overall insight into the different strengths of the welded joint. In GTAW the UTS had some deviation from the BM while the change in yield strength increased largely after the weld was performed in turn made the yield strength and the yield point come close to each other, thus reducing the ductility overall, the elongation characteristics of the welded joint slightly increased post welding. Even with the high heat input and due to the filler material inclusion the weld width was restricted to 4.25 mm. Wherein within this zone the mechanical properties are high, which can be reconfirmed from the location of fracture taking place in the BM which may be softer than the welded region. In GMAW the tensile strength is very close to the BM whereas the yield strength is close to the GTAW weld. The ductility of the welded joint on the whole also increased from GTAW, but the elongation of the joint remained the same as the GTAW. The reason for this change in strength is associated with the decrease in weld width to 3.25mm and a lower heat input than GTAW and the change in chemistry of the welded area. In LBW we find the tensile strength of the weld very close to that of the BM.

Though the yield point is not same as the BM but the difference between the both is large increasing the ductility. The elongation is found to decrease as the weld made autogenously with a weld width of 1.6 mm having a low heat input with high concentration on the area of weld, wherein the weld zone contains the BM left after

the weld is completed. In AGTAW the tensile strength is considerably lower than than of the BM but not less than 10 percentage in total strength ,where as the trend in yield strength getting close to the UTS is found on the this weld also but the values of both is compared they lie fairly close together making it more brittle. This is caused her due to the high heat concentration on the BM and no filler was provide to compensate the burn off of the base elements on the weld with the least speed , which makes up to a very large weld width of 4.5mm.which means a gargantuan of BM is used up in welding process.

Collectively we can say that the tensile strength is reduced and yield strength is increased from the BM which implies that the brittleness is increased but the elongation parameters have shown considerable deviation from the BM. A trend in decreasing in the value of UTS is observed in all the welds sin the ogre of GTAW, GMAW, LBW, AGTAW.since most of the failure took place in the BM, the properties of the base zone should be similar to that of the unwelded material should be the same ,but we can find that this is not valid here. This may be due to the effect of filler material and the heat may have changed properties of the metal, due to the alteration made on the grain size depending up the heat dissipation after the joining process. To come in to further conclusion on what changes took place in the weld zone and the BM zone the bending ,impact and hardness test are performed.

5.2 180-DEGREE FREE BENDING

The 180-degree free bend test on the sample was conducted according to the ASTM E190 standard Bend test was applied to Corten A588 grade steel BM, GTAW, GMAW, LBW and AGTAW Corten A588 grade steel weld joints. During the test, the samples were bent in both positions at the weld location in forward and reverse for all weld configurations, thereby evaluating the bonding strength of the welded surface. The Table 5.2 shows the root bent and face bent observations made on Corten A588 grade steel weld joint

Table 5.2 Bending Test Result on Sample

Weld	Type of Bend	Mandrel dia (mm)	Angle of Bend (deg)	Observation
BASE	FB	8	180°	No cracks or fissures observed
BASE	RB	8	180°	No cracks or fissures observed
GTAW	FB	8	180°	No cracks or fissures observed
GTAW	RB	8	180°	No cracks or fissures observed
GMAW	FB	8	180°	No cracks or fissures observed
GMAW	RB	8	180°	No cracks or fissures observed
LBW	FB	8	180°	No cracks or fissures observed
LBW	RB	8	180°	No cracks or fissures observed
AGTAW	FB	8	180°	Small cracks observed
AGTAW	RB	8	180°	No cracks or fissures observed

The observation from the results of the bending test clearly shows that the weld joints for the GTAW,GMAW,LBW and the BM show no formation of cracks and fissures on the welded area . From the fracture location data obtained from the tensile strength we can also infer that the strength of the weld zone is higher than the BM as the fracture took place in the BM and not on the weld zone. The Weld joint with AGTAW has shown formation of cracks and fissure while the compression was given to the root side while the weld top was stretched, this may be because of the reduction of strength in the weld zone ,which can be seen from the results of tensile testing as the fracture has take place in the weld zone and the

BM. The forthcoming study on the impact test on the weld joint will give out the attribute of the weld. The Bending test results of the BM and weld joint are shown in *Figure 5.3* .

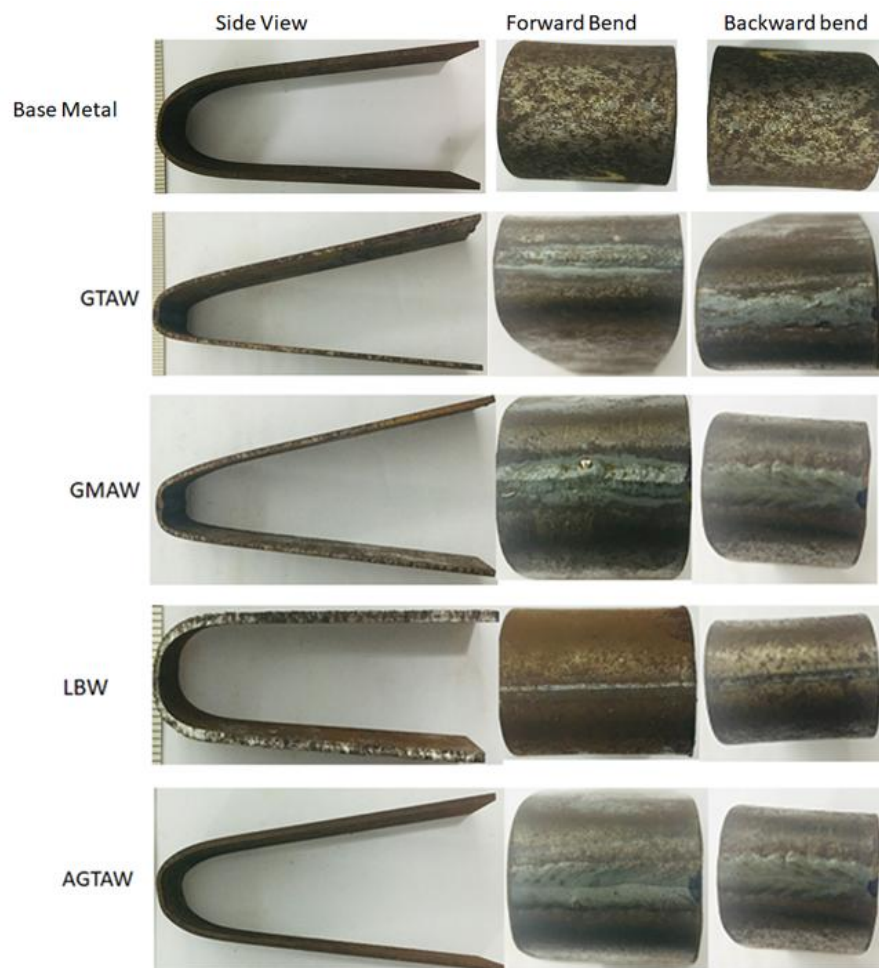


Figure 5.3 Bend Test Samples showing Side view, Forward bend, and Backward bend

5.3 CHARPY IMPACT

The Charpy impact test is conducted on the sample in the room temperature condition according to the standards in ASTM - E 23 - 12c, and the test temperature was room temperature (+24°C). Impact testing determines the relative toughness which is the resistance of the metal to fracture, after plastic deformation. The effect of impact strength of Corten A588 Grade steel weldments is shown in Table 5.3.

Table 5.3 Impact Test Results on sample

Weld	Specimen size (mm)	Test temperature (°C)	Average absorbed Energy- Joules
BM	2 x 10 x 55	RT (+24°C)	14
GTAW	2 x 10 x 55	RT (+24°C)	49
GMAW	2 x 10 x 55	RT (+24°C)	55
LBW	2 x 10 x 55	RT (+24°C)	20
AGTAW	2 x 10 x 55	RT (+24°C)	13

The graphical representation is shown in the *Figure 5.4*

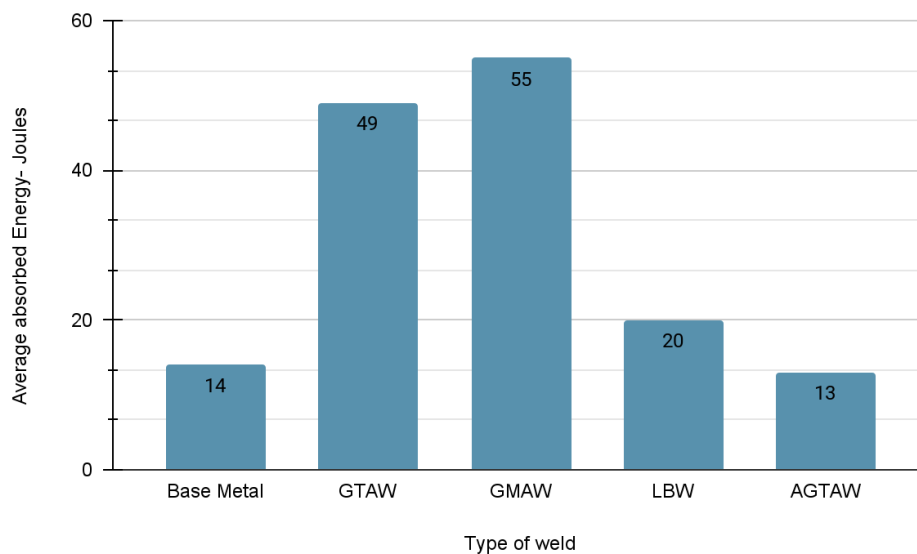


Figure 5.4 Graphical representation of Average Energy absorbed

The impact results shows us that the maximum energy absorbed by the welded sample on a sudden impact loading. The BM takes in 14 J of energy before breaking. The GTAW sample absorbs 49 J of energy which is 3.5 times higher than the BM making the joint more ductile. The GMAW absorbs the maximum amount of energy when compared to all the welded joints as 55 which is approximately 3.92 times greater than the BM. The LBM sample took in 20 J of energy which is approximately 1.42 times more than that of the BM. The AGTAW sample showed the least amount of energy being absorbed which is 1J less than that of the BM .The pictures of the samples after impact test are shown in the *Figure 5.5*.

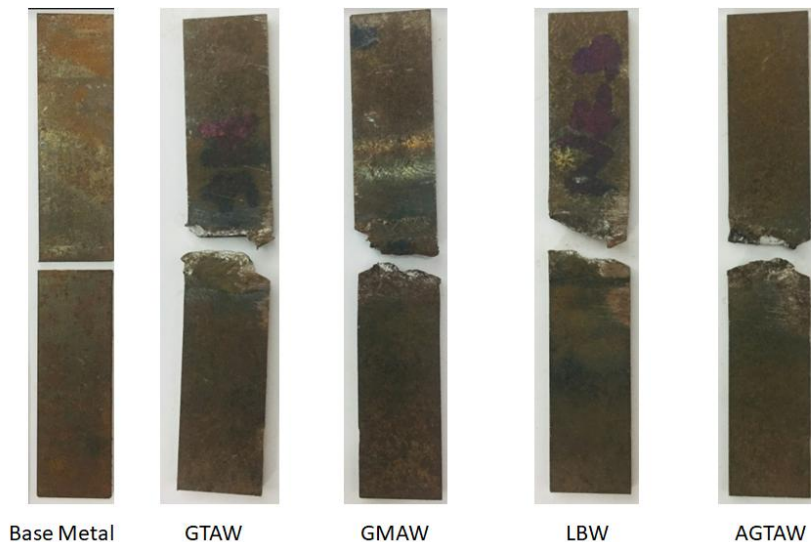


Figure 5.5 Samples after impact test

The toughness of the weld can give us more insights on the results obtained from the tensile and the bending, giving us more information on the location of failure failure.

In GTAW the toughness increased in the weld zone making it more ductile. The ductility in the weld is because of the inclusion of the filler material with the BM and then change in the elemental composition and the microstructure of the welded area, the weld could consist the elements which could withstand the heat Input 1338.46 j/mm for the weld speed of 2.34 mm/sec. In GMAW the also the toughness increased with the inclusion of filler material in the weld with the heat input of 1174.34 j/mm and a weld speed of 3.06 mm/sec . In both the type of welds the filler material is the same but as to the weld speed and the heat input provided in the welding process is different the cooling rate of the weld too changes making changes to the size and type of grain which is formed on the weld and the HAZ .

The LBW the toughness is high enough ,so as the ductility on the weld to not cause any deformation during the bending and tensile testing ,but not high as the GTAW and GMAW because there is no inclusion of the filler material as the weld is autogenous making the welded area by melting the BM with the heat input of 71.99 mm/ sec and the weld speed of 33.33 mm/sec , where the weld is made very quick with highly concentrated heat source and the very high cooling rate with

less HAZ formation .The elements which are burnt out in this process also contribute the significant hardening and the reduction in ductility by altering the grains.

The AGTAW also being an autogenous process the BM is melted to form the weld between the different plates of base material whereas to achieve this melting a high heat input 1332.3 j/mm is used with an weld speed of 2.31 mm/sec this makes the cooling process relative slow , with high heat the elements which may be lost and the HAZ should have increases when comparing with the LBW and the grain size and type over the different region changes, the effect of the same is being observed as the ductileness decreased and the weld became more brittle than the BM . Even though the weld parameters are quite similar to the GTAW the addition of the filler material makes a drastic change in terms of the composition, HAZ and grain boundary of the weld. A study on the hardness of the material across the weld area can give us the information about the effect of the heat input provided for the joining process.

5.4 MICRO VICKERS HARDNESS

Table 5.4 shows the Vickers micro hardness values of Corten A588 grade steel weldments at BM (BM), heat affected zone (HAZ) and weld zone (WZ) was done according to the ASTM E92.

Table 5.4 Hardness Test Result on Sample

Location	Distance in (mm)	GTAW	GMAW	LBW	AGTAW
(WZ)	0	257	262	402	249
	0.5	254	248	375	233
	1	259	253	353	239
	1.5	236	214	179	230
(HAZ)	2	240	226	159	197
	2.5	247	244	171	233
	3	249	236	169	240

Location	Distance in (mm)	GTAW	GMAW	LBW	AGTAW
	3.5	226	209	170	173
(BM)	4	194	185	173	210
	4.5	183	181	169	172
	5	176	186	161	169
	5.5	187	179	166	167
	6	164	176	179	174
	6.5	172	171	166	179

The hardness test results graphed in the *Figure 5.6* is given below and following inferences were made. The hardness test on the weld zone, on the center of the weld the highest hardness was observed on the LBW which was 402 HV while the lowest hardness was observed on the AGTAW which amounted with a value of 249 HV. In GTAW the hardness increases from the weld center to 259 HV on 1 mm away from it and the trend starts to decrease towards the weld zone where the hardness is observed to an 240 HV. In GMAW hardness decreases from the weld center and then increases to a value close to the weld center and then it shows a drastic decrease to the value of 214 HV and then increases to an value of 226 HV when nearing the weld zone. In LBW hardness decreases gradually from the weld center to a distance on 1mm to an hardness of 353 HV and then drastically drops after 0.5 mm towards the HAZ with 179 HV and further decrease in hardness was noticed when it 2mm away from the weld center with the corresponding value of 159 HV. The AGTAW the hardness decreases on the next indentation point, whereas it increases in the next check to 239 HV further moving

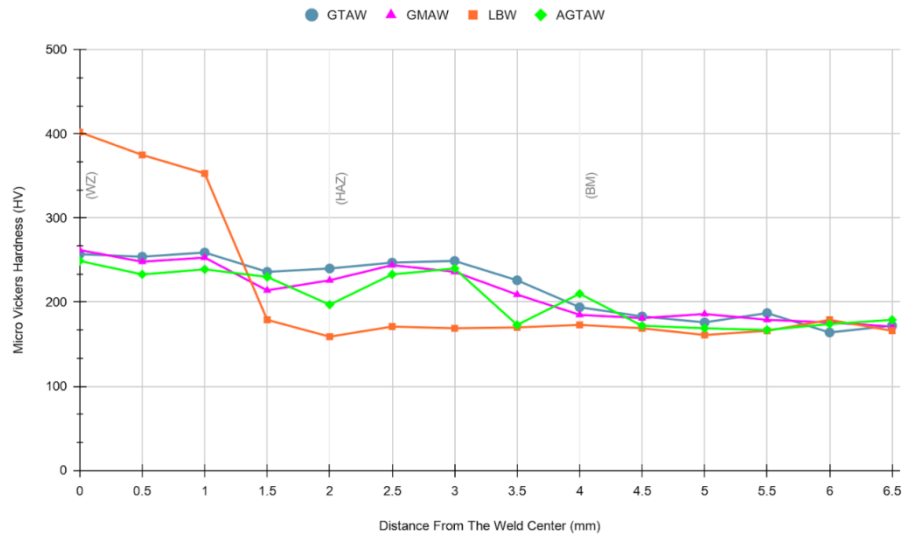


Figure 5.6 Hardness Graph of different Weldments

Towards the HAZ there was a small change at a distance of 1.5 mm and then it sharply decreases to 197 HV. As a general trend on the weld zone for all the joints except the LBW there is hardness starts decreasing from the weld center and reduces in the indentation stops right after it and increased slightly close to the hardness value of the weld center and moving further to the HAZ the hardness sharply decreased, while in LBW the weld showed the slight but sharp dip in the hardness values.

When it comes to the heat affected zone (HAZ) highest hardness was found to be present in the GTAW weld at 3mm which is 249 HV which tends to gradually increase from 240 HV which is present at the 2mm similarly the hardness value was least in LBW being 159 HV at 2 mm it is also seen that value of hardness was varying as we move towards the BM, away from the weld centerline hardness value increased from 159 HV to 171 Hv at 2.5mm and it decreased to 169 at 3mm. On the other hand when we compare it with the GMAW weld we see that highest hardness value was present at 2.5mm which is 244 HV and it gradually kept on decreasing when it moved towards the BM hardness was found to be least at the end of the HAZ at 3.5 mm which is 209 HV when it comes to the AGTAW weld we can see that highest hardness was found to be at the 3mm which tends to be 240 HZ and it tends to decrease when moving towards the BM it was found to be 173 at 3.5mm.

In the BM all the welds showed a gradual decrease in the hardness values starting from the HAZ till the end of the study area by which we can come to a conclusion that the effect of heat on the material is reduced as we move away from the centre of the weld and the characteristics of the BM is restored.

The hardness values for all the welds are found to be greatest in the region where the acme temperature is attained which is the midpoint of the weld, which comes in direct contact with the heat source and also the region where the filler material melts and fuses with the base material. In all the welds except LWB since the weld area is larger we are able to see that the weld bead has formed to a greater extent. In GTAW and GMAW the hardness values are quite close to each other as there is the addition of the filler material which has the same composition, but with the different heat input there are slight changes in the values of hardness due to the weld chemistry.

In AGTAW the hardness is slightly less due to the elements of the base material forming the weld bead without any lack of additional filler to compensate for the losses due to high heat. In the weld zone there is a formation of solid-liquid transition zone where in due to their finer grain size the hardness and the strength has increased while the ductility reduction can also be observed as progressing in this zone, the values of this can be very close to the weld center. Towards the termination of the solid liquid boundary the grain growth zone can be found to be formed which makes a steep dip in the hardness and the strength of the weld, which the ductility in this region can increase. In GTAW and GMAW this transition is quite small, so the changes in the hardness values and other strength attributes are smooth, by which we can also tell that the span of this region is small.

In AGTAW the dip in hardness was observed to be more, meaning that the Coarse-grain zone the grain size and the span of this zone was increased. So the high ductility and the drop in the strength can be observed. The increase in the hardness gradually after the Coarse-grain zone is because of the formation of the Fine-grain zone. In GTAW this transformation is smooth as the difference in the hardness level is changing sluggishly which could be because of the difference

between the grain size being very less. In GMAW this change is even more steeper which means there is a greater amount of variation in the grain size. In case of the AGTAW the grain size variegate to a finer grain size Close to that of the other weld because of this, abrupt change in the mechanical properties during this transition can be observed. In this fine grain zone another maximum is attained, moving on further to the intercritical zone the hardness decreases. In AGTAW the Fine grain zone observed is very small leading to an area of high mechanical properties. Where as in the inter critical zone the grain size again increases suddenly making the hardness and strength drop very sharp ,while ductility increases.

The trend in GTAW and GMAW is found to be transitioning at a steady pace through this zone ,not making any abrupt changes in the mechanical properties of the material .The over tempered zone is the last area in the HAZ where in the effect of heat is least after which the effect of heat can be negligible the hardness values in this zone can vary slightly, where in you cannot expect an highly notable change as compared to all the other zone within the HAZ .The size of this zone can be large and may even be unnoticed moving a long way in to the BM region. The grain size is nearly similar to that of the BM where the mechanical properties of the BM. Any slight variation within this region before the BM may be due to any splattering caused due to the weld.

In GTAW and GMAW this zone is found to be moving in a streamlined manner, while in the AGTAW there is a sharp increase and drop which is due to the heat interaction changing the grain type suddenly. In the BM region the hardness is consistent giving us the indication that there is no effect of heat hear and gives the hardness of the base material .In case of the LBW owing to the very short weld width the solid -liquid transition zone is very small and the coarse grain zone can also be found to be small with a steep hardness decrease. While there could be a very less Fine grain zone and and Inter critical zone as no spike in the hardness values could be observed. Then there is a very large over tempered zone where in the value of hardness decreases even below the hardness of the weld at the end of the weld beam where the high concentration of beam ends after this there is a small is gradual increase in the hardness of to the value of the BM .Since this

region is observed to be more the strength of the metal before this zone is also very high and the ductility of the material is greatly reduced. From the change in the hardness values in different region of the welded joint we can indirectly attribute it to the grain size of this region from which we can have an idea about the mechanical properties of grains which could be present in the region. This information can further be used to confirm about the change in the properties which has been observed in the tensile testing. In GTAW and GMAW the elongation increased because having a large coarse area with some amount of finer grain particles to provide high mechanical property and prevent the propagation of crack within the grains, the interplay of the relationship between the strength and the ductility has led to the increase in the UTS.

In the case of LBW the very steep grain size and the hardness below the BM in some areas made the elongation percentage to decrease while making the strength nearly equal which could be possible due to the possible difficulties faced in the crack propagation. Making use of the near gradual variation in the hardness and the size the fracture did not propagate in the weld zone rather it happened in the much softer BM. The AGTAW showed the maximum amount of elongation among all the welds because of the sharp change in the grain size the crack was also easier to propagate making the tensile strength less, but due to the same reason the length where the crack had to propagate has increased so the property of elongation also increased and the failure took place in the weld zone and the BM. While the other properties of the welded area have been studied in the bending and impact testing. The changes which have taken place in the weld zone and the HAZ is mainly due to the lack of proper mixing of the weld pool with the BM and heat dissipation and gain over the region of the welded BM.

Since Corten is a type of steel which was designed to have high strength capabilities with an emphasis on the corrosion resistance. The resistance towards the corrosion after the weld is also performed.

5.5 IMMERSION CORROSION

The *Figure 5.7* illustrates the different stages during the immersion corrosion test of Corten A588 grade steel, while sample in picture (a) shows the first day of sample being immersed in NaCl, while picture (b) portrays the sample after a week in the solution. The picture (c) illustrates the sample after 2 weeks of immersion in the solution, while the picture (d) glimpses the fourth week of sample in NaCl solution.

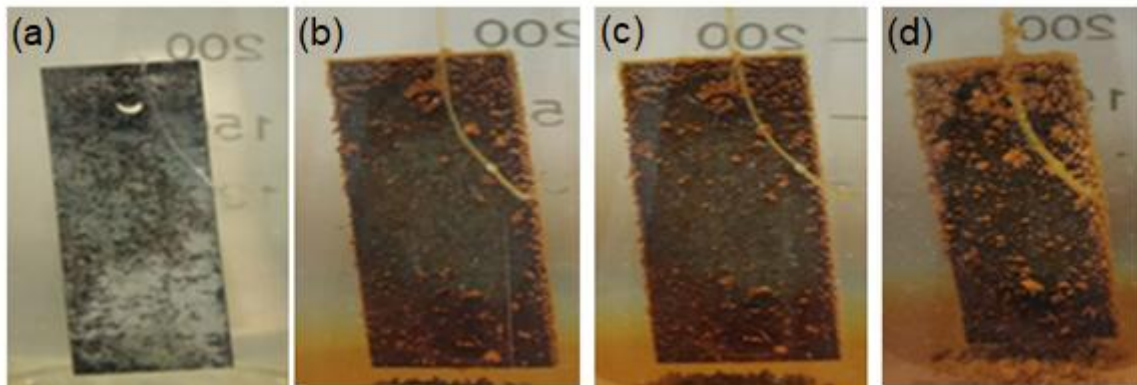


Figure 5.7 Weekly progression of corrosion on test sample

The

illustrates the results of corrosion test. After the sample plate got corroded the conductance of the welded samples decreased when compared to that of the BM.

Table 5.5 Weight loss of samples immersed in 3.5% NaCl solution for a month

Samples	pH of solution		Conductance of solution		Mean Weight of Samples (gms)		Weight Difference (gms)
	Before	After	Before	After	Before	After	
Corten 588 (BM)	6.97	5.96	28.20	65.21	5.182	5.165	0.0172
GTAW	6.97	5.35	28.20	64.37	5.458	5.454	0.0041
GMAW	6.97	5.88	28.20	64.32	5.386	5.383	0.0034
LBW	6.97	5.54	28.20	64.98	5.248	5.248	0.0005
AGTAW	6.97	6.04	28.20	64.01	5.271	5.247	0.0244

Even the changes in the weight were minor, among all the welds, the highest decrease in the conductance was noticed in AGTAW when compared to the Corten A588, where minor change occurred in the Laser welded Corten A588. As there is a major conductance decline in AGTAW to the BM, the pH of the AGTAW increased to a value more than the BM. The conductance of the GMAW and GTAW are very close to that of the base material. The pH value of the non-welded Corten A588 and GTAW Corten A588 almost resulted in the same. The least pH value can be noticed for the GMAW Corten A588 plate. The graphical representation of the pH and conductance rate in different weldments is shown in Figure 5.8.

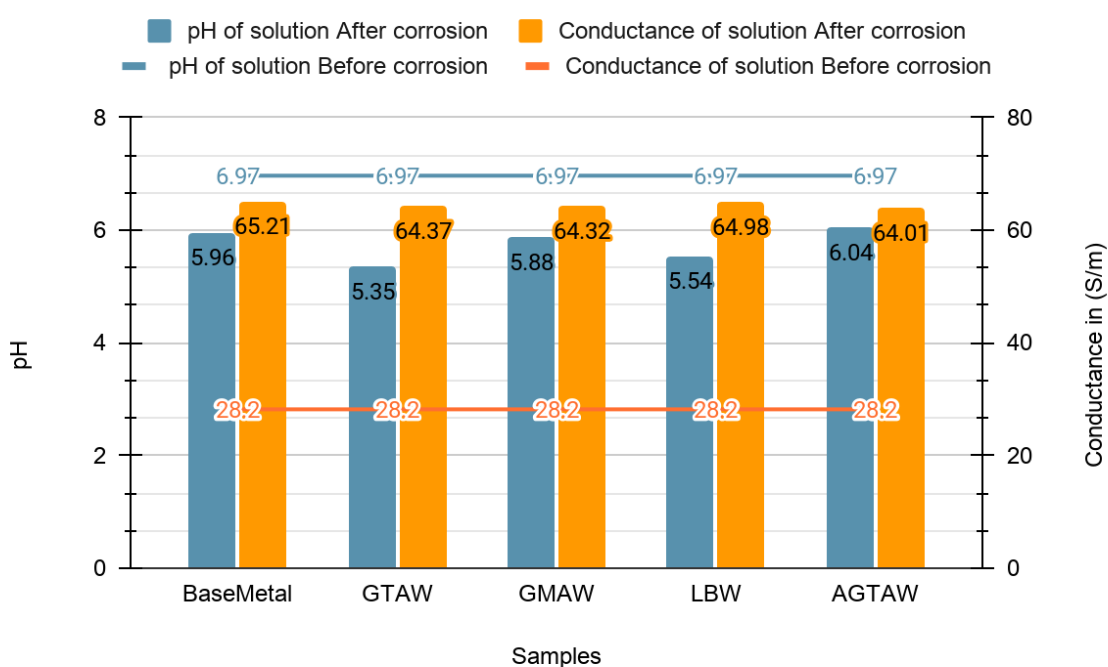


Figure 5.8 Comparison of pH and conductance rate in different weld

The weight loss in the samples after the corrosion gives us the information by which we can calculate the rate of corrosion taking place on the welded region. The corrosion rate in case of the GTAW and GMAW when compared with the BM the rate is slower, within the both we the GTAW has the fastest rate as the weld area is more and also the weld chemistry is affected because of heat and inclusion. In GMAW the corrosion rate is less even though the same filler is used as lower temperature is used for welding and the weld width is reduced because of this reason. In LBW the least corrosion rate can be observed as the weld area is

relatively small and the high heat source may have changed the elements in the weld zone where in their constituents of this are most of high corrosion resistant material and the area round it is made up of the grains which resist the corrosion. IN AGTAW the welded area is the greatest of all welds with the high heat input and no filler material to compensate any of the losses taking place during the remelting and fusion of the BM in the process welding, the rate of corrosion is highest , in fact the rate rate is even more than of the BM .

CHAPTER-6

SUMMARY AND CONCLUSION

6.1 SUMMARY

- The Weld with Highest Joint Efficiency Is GMAW 99.79% And Lowest Being AGTAW 91.12% , When Compared With BM,Where In No Joint Is 100% Efficient.
- The Weld With Highest Elongation Percentage Is AGTAW 25 kg/mm², Which Is More The The Base And Lowest Being LBW 21 kg/mm², Which Is Less Than The Base , When Compared Among The Welds And BM.
- The Yield Strength Is Noted to Be More Than of the BM and the Maximum Being 387 kg/mm² In GTAW And Least Being 362 kg/mm² For AGTAW.
- The Impact Toughness Is Found Maximum For GMAW As 55 J And Minimum As 13 J For AGTAW ,Where The BM Was 14 J.
- During the Bending Test All The Test Samples Except AGTAW Showed No Crack Or Fissures ,Even Though A Small Crack Was Formed On AGTAW It Is Negligible And Can Be Fixed When Grinding.
- The Micro Vickers Hardness Showed Higher Hardness On The Weld Zone And Then Decreasing In The HAZ And BM .
- The Highest Hardness Is Shown By LBW As 402 HV In The Weld Zone And Lowest Of 249HV In AGTAW.The peak hardness of all welds are observed on the weld centre.
- The Hardness On The Various Zone Changes Due To The Varying Amount Of Heat Distribution On The BM Produced during the Welding Process.
- The Weld Which Showed Greater Resistance To Corrosion Was LBW and the least resistance in AGTAW, which is due the higher HAZ.

6.2 CONCLUSION

Based on the experiments the obtained results we can compare the mechanical properties and the rate of corrosion of the of GTAW,GMAW,LBW,AGTAW performed on Corten A588.This research gives us a quantative comparison of the mechanical properties of between the welded joint and the BM. A further the study

on the metallurgy and the microstructure of these welded joint can give away the exact changes which take place on the BM post the welding process, This studies can further help us to optimize the weld parameters and even help to select a different filler material with which this metal can be joined with minimal changes to the mechanical and the corrosion properties.

REFERENCE

- [1] A. Artigas, A. Monsalve, K. Sipos, O. Bustos, J. Mena, R. Seco, N. Garza-Montes-de-Oca, Development of accelerated wet–dry cycle corrosion test in marine environment for weathering steels, *Corrosion Engineering, Science and Technology*. 50 (2015) 628–632.
- [2] A. Ruggiero, L. Tricarico, A.G. Olabi, K.Y. Benyounis, Weld-bead profile and costs optimisation of the CO₂ dissimilar laser welding process of low carbon steel and austenitic steel AISI316, *Optics & Laser Technology*. 43 (2011) 82–90.
- [3] Atma Raj M.R, Joy Varghese V.M., “Determination of Distortion Developed During TIG welding of low carbon steel plate”, *International Journal of Engineering Research and General Science* Volume 2, Issue 5, September, 2014 (00)
- [4] B. John, S. Paulraj, J. Mathew, The role of shielding gas on mechanical, metallurgical and corrosion properties of corten steel welded joints of Railway Coaches using GMAW, *Advances in Science and Technology. Research Journal*. Vol. 10 (2016).
- [5] B.S. Yilbas, A.F.M. Arif, B.J. Abdul Aleem, Laser welding of low carbon steel and thermal stress analysis, *Optics & Laser Technology*. 42 (2010) 760–768.
- [6] Balamuruga S., Vasiga, D., Gokulanathan, L. 2015 “Stainless steel of AISI 304 to Corten steel joint using MAG welding process”, *International Journal of Current Research* Vol. 7, Issue, 12, pp.24693-24700 (00)
- [7] C. Pandey, M.M. Mahapatra, P. Kumar, N. Saini, Comparative study of autogenous tungsten inert gas welding and tungsten arc welding with filler wire for dissimilar P91 and P92 steel weld joint, *Materials Science and Engineering: A*. 712 (2018) 720–737.
- [8] C. Zhang, D. Cai, B. Liao, T. Zhao, Y. Fan, A study on the dual-phase treatment of weathering steel 09CuPCrNi, *Materials Letters*. 58 (2004) 1524–1529.
- [9] D.C. Saha, D. Westerbaan, S.S. Nayak, E. Biro, A.P. Gerlich, Y. Zhou, Microstructure-properties correlation in fiber laser welding of dual-phase

- and HSLA steels, *Materials Science and Engineering: A*. 607 (2014) 445–453.
- [10] Devakumar, D., D. B. Jabaraj, and VK Bupesh Raja. "Investigation on microstructure and mechanical properties of similar, dissimilar metal weld joints by gas tungsten arc welding." *International Journal of Mechanical and Production Engineering* 2, no. 5 (2014): 23-8.
- [11] E. Assunção, L. Quintino, R. Miranda, Comparative study of laser welding in tailor blanks for the automotive industry, *Int J Adv Manuf Technol*. 49 (2010) 123–131.
- [12] E. Gharibshahiyan, A.H. Raouf, N. Parvin, M. Rahimian, The effect of microstructure on hardness and toughness of low carbon welded steel using inert gas welding, *Materials & Design*. 32 (2011) 2042–2048.
- [13] Gosh A, Mallik AK. *Manufacturing science*. New Delhi: Affiliated East-West Press; 1986. (00)
- [14] H. Zhang, S. Hu, J. Shen, L. Ma, F. Yin, Microstructures and mechanical properties of 30Cr-4Mo ferritic stainless steel joints produced by double-pulsed gas metal arc welding, *Int J Adv Manuf Technol*. 80 (2015) 1975–1983.
- [15] http://www.steelnumber.com/en/steel_composition_eu.php?name_id=887#
- [16] [#">https://www.lentech.com #](https://www.lentech.com).
- [17] I.A. Ibrahim, S.A. Mohamat, A. Amir, A. Ghalib, The Effect of Gas Metal Arc Welding (GMAW) Processes on Different Welding Parameters, *Procedia Engineering*. 41 (2012) 1502–1506.
- [18] I.S. Kim, J.S. Son, I.G. Kim, J.Y. Kim, O.S. Kim, A study on relationship between process variables and bead penetration for robotic CO₂ arc welding, *Journal of Materials Processing Technology*. 136 (2003) 139–145.
- [19] J.P. Niu, Y.J. Li, L.X. Zhao, Y. Han, W.M. Gao, The Research Situation and Development Trend of Weathering-Steel, *Applied Mechanics and Materials*. (2015).
- [20] K. Yu, Z. Jiang, C. Li, S. Chen, W. Tao, X. Zhou, Z. Li, Microstructure and Mechanical Properties of Fiber Laser Welded GH3535 Superalloy, *Journal of Materials Science & Technology*. 33 (2017) 1289–1299.
- [21] Laser Welding Process – A Review of Keyhole Welding Modelling, *Physics Procedia*. 78 (2015) 182–191.

- [22] M.J. Torkamany, J. Sabbaghzadeh, M.J. Hamed, Effect of laser welding mode on the microstructure and mechanical performance of dissimilar laser spot welds between low carbon and austenitic stainless steels, *Materials & Design*. 34 (2012) 666–672.
- [23] M. Sarkari Khorrami, M.A. Mostafaei, H. Pouraliakbar, A.H. Kokabi, Study on microstructure and mechanical characteristics of low-carbon steel and ferritic stainless steel joints, *Materials Science and Engineering: A*. 608 (2014) 35–45.
- [24] N. Ahmed, *New Developments in Advanced Welding*, Elsevier, 2005.
- [25] N. Ghosh, P.K. Pal, G. Nandi, GMAW dissimilar welding of AISI 409 ferritic stainless steel to AISI 316L austenitic stainless steel by using AISI 308 filler wire, *Engineering Science and Technology, an International Journal*. 20 (2017) 1334–1341.
- [26] N. Ghosh, P.K. Pal, G. Nandi, R. Rudrapati, Experimental investigation of TIG welding of austenitic stainless steel with change in composition of filler material, in: *Proceedings of the National Conf. on Recent Trends in Manuf. Science and Technol. Kolkata, 2013*, pp. 27–35. (00)
- [27] Nippon Steel Corporation, (n.d.). <https://www.nipponsteel.com/>
- [28] Ohkita, Shigeru, and Hatsuhiko Oikawa. "Latest advances and future prospects of welding technologies." *Nippon steel technical report 95* (2007): 2-10.
- [29] P. Dhaiveegan, N. Elangovan, T. Nishimura, N. Rajendran, Weathering Steel in Industrial-Marine-Urban Environment: Field Study, *Mater. Trans*. 57 (2016) 148–155.
- [30] P.K. Giridharan, N. Murugan, Optimization of pulsed GTA welding process parameters for the welding of AISI 304L stainless steel sheets, *Int J Adv Manuf Technol*. 40 (2009) 478–489.
- [31] P. Sathiya, S. Aravindan, P.M. Ajith, B. Arivazhagan, A.N. Haq, Microstructural characteristics on bead on plate welding of AISI 904 L super austenitic stainless steel using Gas metal arc welding process, *International Journal of Engineering, Science and Technology*. 2 (2010).
- [32] Pense, Alan W., "Mechanical Property characterization of A588 Steel Plates and Weldments" (1987). *ATLSS Reports*. 87-07.

- [33] Q. Al-Kaseasbeh, Z. Lin, Y. Wang, F. Azarmi, X. Qi, Electrochemical Characterization of Steel Bridge Welds under Simulated Durability Test, *J. Bridge Eng.* 23 (2018) 04018068.
- [34] R. Cortés, E.R. Barragán, V.H. López, R.R. Ambriz, D. Jaramillo, Mechanical properties of Inconel 718 welds performed by gas tungsten arc welding, *Int J Adv Manuf Technol.* 94 (2018) 3949–3961.
- [35] R. Megavarnan, G. Rajamurugan, R. Shanmuga Prakash, Comparative Study on Mechanical Properties of GMA Welded IRSM41 Mild Steel Plate Based on Grain Flow Direction, *Applied Mechanics and Materials.* (2017).
- [36] R. Palanivel, I. Dinaharan, R.F. Laubscher, Microstructure and mechanical behavior of Nd:YAG laser beam welded high strength low alloy steel joints, *Optik.* 208 (2020) 164050.
- [37] Ravikumar, S., J. Vishal, K. Vigram, and AN Ganesh Babu. "MATERIAL CHARACTERISTIC STUDY OF COLD ROLLED GRADED THIN SHEET BY USING TIG WELDING PROCESS FOR RAIL COACHES." (2006).
- [38] S. Katayama, *Handbook of Laser Welding Technologies*, Elsevier, 2013.
- [39] S. Ravikumar, J. Vishal, K. Vigram, A. N. Ganesh Babu 2017 "MATERIAL CHARACTERISTIC STUDY OF COLD ROLLED GRADED THIN SHEET BY USING TIG WELDING PROCESS FOR RAIL COACHES", *ARPN Journal of Engineering and Applied Sciences*, VOL. 12, NO. 19, pp. 5527-5531 (00)
- [40] S. Zhen, Z. Duan, D. Sun, Y. Li, D. Gao, H. Li, Study on microstructures and mechanical properties of laser–arc hybrid welded S355J2W+N steel, *Optics & Laser Technology.* 59 (2014) 11–18..
- [41] S355J2W(+N) / 1.8963 - SteelNumber - Chemical composition, equivalent, properties, (n.d.).
- [42] U. Waghmare, A.S. Dhoble, R. Taiwade, J. Verma, H. Vashishtha, Prediction of HAZ and other mechanical properties of welded joints of HSLA A588-B of jet blast deflector, *WJE.* 16 (2019) 438–444.
- [43] V. Ravisankar, V. Balasubramanian, C. Muralidharan, Selection of welding process to fabricate butt joints of high strength aluminium alloys using analytic hierarchic process, *Materials & Design.* 27 (2006) 373–380.
- [44] W.M. Steen, J. Mazumder, *Laser Material Processing*, Springer Science & Business Media, 2010.

- [45] What is Autogenous Welding? – Examples, Advantages & Disadvantages, Minaprem.Com. (n.d.).
<http://www.minaprem.com/joining/welding/introduction/what-is-autogenous-welding-examples-advantages-and-disadvantages/>.
- [46] What is Heterogeneous Welding? Examples, Advantages & Disadvantages, Minaprem.Com. (n.d.).
<http://www.minaprem.com/joining/welding/introduction/what-is-heterogeneous-welding-examples-advantages-and-disadvantages/>.
- [47] What is Homogeneous Welding? Examples, Advantages & Disadvantages, Minaprem.Com. (n.d.).
<http://www.minaprem.com/joining/welding/introduction/what-is-homogeneous-welding-examples-advantages-and-disadvantages/>.
- [48] What is Welding Defects – Types, Causes and Remedies? – The Welding Master, (n.d.). <https://www.theweldingmaster.com/welding-defects/>.
- [49] X.Y. Gu, Z.Z. Duan, X.P. Gu, X.H. Zhang, Y.L. Xie, D.Q. Sun, Microstructure and mechanical properties of laser-MAG hybrid welded thick-section weathered steel joint, *Int J Adv Manuf Technol.* 81 (2015) 825–831.
- [50] X. Zhang, G. Mi, S. Li, X. Hu, C. Wang, Y. Zhang, Study of microstructural inhomogeneity and its effects on mechanical properties of multi-layer laser welded joint, *Int J Adv Manuf Technol.* 94 (2018) 2163–2174.

APPENDIX

Plagarism Report

MECHANICAL AND CORROSION PROPERTY INVESTIGATION OF WELDED CORTEN A588 GRADE STEEL JOINTS

ORIGINALITY REPORT

17%

SIMILARITY INDEX

7%

INTERNET SOURCES

11%

PUBLICATIONS

5%

STUDENT PAPERS

PRIMARY SOURCES

1

Jian Ping Niu, Yu Jian Li, Li Xin Zhao, Yu Han,
Wei Min Gao. "The Research Situation and
Development Trend of Weathering-Steel",
Applied Mechanics and Materials, 2015

Publication

2%

2

www.theweldingmaster.com

Internet Source

1%

3

V. Ravisankar, V. Balasubramanian, C.
Muralidharan. "Selection of welding process to
fabricate butt joints of high strength aluminium
alloys using analytic hierarchic process",
Materials & Design, 2006

Publication

1%

4

J.R. Deepak, V.K. Bupesh Raja, Gobi
Saravanan Kaliaraj. "Mechanical and corrosion
behavior of Cu, Cr, Ni and Zn electroplating on
corten A588 steel for scope for betterment in
ambient construction applications", Results in
Physics, 2019

1%

Paper acceptance

Materials Today: Proceedings
Laser Welding of ASTM Corten A588 grade steel - A Case Study
--Manuscript Draft--

Manuscript Number:	MATPR-D-21-04209
Article Type:	SI: FRESM'21
Keywords:	Laser welding; Carbon Dioxide Laser; CortenA588; Weathering Steel; mechanical properties; Welding
Corresponding Author:	J R DEEPAK James Raj, BE - ME - (PhD) Sathyabama Institute of Science and Technology Chennai, INDIA
First Author:	J R DEEPAK Deepak, BE - ME - (PhD)
Order of Authors:	J R DEEPAK Deepak, BE - ME - (PhD) V K Bupesh Raja PRASHANT BHUMIREDDY HEMANTH SOUNDARARAJAN
Abstract:	Corten A588 is a high strength low carbon alloy structural steel with high atmospheric corrosion resistance. A significant defect in this material is the metallurgical properties gets affected post welding process due to the exposure of high temperature in and around the weld zone making it less reliable after the fabrication. Laser welding is an autogenous method and where the weld zone is considered to be less. Carbon dioxide laser beam welding is performed on the thin sheet of Corten A588 grade under optimal condition. The mechanical property such as tensile, impact, bending and hardness of the welded joint is evaluated on the standards set by the ASTM. The result obtained from the research aims to give detailed information about drawbacks which are face during carbon dioxide laser welding.

From: fresm2021 - <fresm2021@cmrit.ac.in>

Date: Mon, Apr 12, 2021 at 8:37 AM

Subject: Acceptance and Registration Notification for Paper Id: MATPR-D-21-04209

To: <deepakcape@gmail.com>

Dear J R DEEPAK James Raj

We are glad to inform you that your paper titled " Laser Welding of ASTM Corten A588 grade steel - A Case Study" (Paper Id: --- MATPR-D-21-04209 -----) has been **PROVISIONALLY ACCEPTED WITH REVISIONS** for online presentation and publication in the " Materials today Proceedings " through FRESM'21 to be held online organized by Department of Mechanical Engineering, CMR Institute of Technology, Bengaluru, India & Core-Facility Centre for Photochemistry and Nanomaterials Gyeongsang National University, South Korea during **April 23-24, 2021**.

Kindly incorporate reviewers comments via the Materials today Proceedings editorial manager website. **During revision please ensure that the similarity index in the revised paper should not exceed 15% (Excluding Reference)**

Please note that the **final acceptance** will be received from Materials Today Proceedings after the successful submission of your **Revised paper & registration** process. Also, it is mandatory for any one of the authors to **present** their respective papers during the allotted session.

Now you are requested to proceed with the **REGISTRATION PROCESS**. Registration fee must be paid through **ONLINE** mode only.
The registration fee details