Chapter-3

EXPERIMENTAL PROGRAMME

This research work is primarily, related to effect of GMA welding process parameters on mechanical properties and microstructure of IS 2062 structural steels and AISI 304 steel weldment under different conditions such as types of welding current, arc voltage, shielding gas flow rate used, types of shielding gas used, welding speed/heat input, Groove type (Single V, Double V, Single U, etc). Experiments were carried out as per the details are given below:

3.1 Design and development of a foolproof experimental set to carry out the welding work under different welding conditions.

3.2 Selection of workpiece material, welding wire, and welding processes to carry out the experimental research work.

3.3 Fabrication of samples to evaluate the tensile strength, Impact strength of the welded workpiece.

3.4 Preparation of samples for Microstructure examination, Microhardness (VHN) test.

3.5 Specimen for scanning electron microscope (SEM) and EDS evaluation.

Plan of work

Methodology

1. To determine the mechanical properties of IS 2062 & AISI 304H under different welding condition

2. Metallurgical examination of IS 2062 & AISI 304H steel weldments

Experimental approach of present research work is shown in figure 3.1.

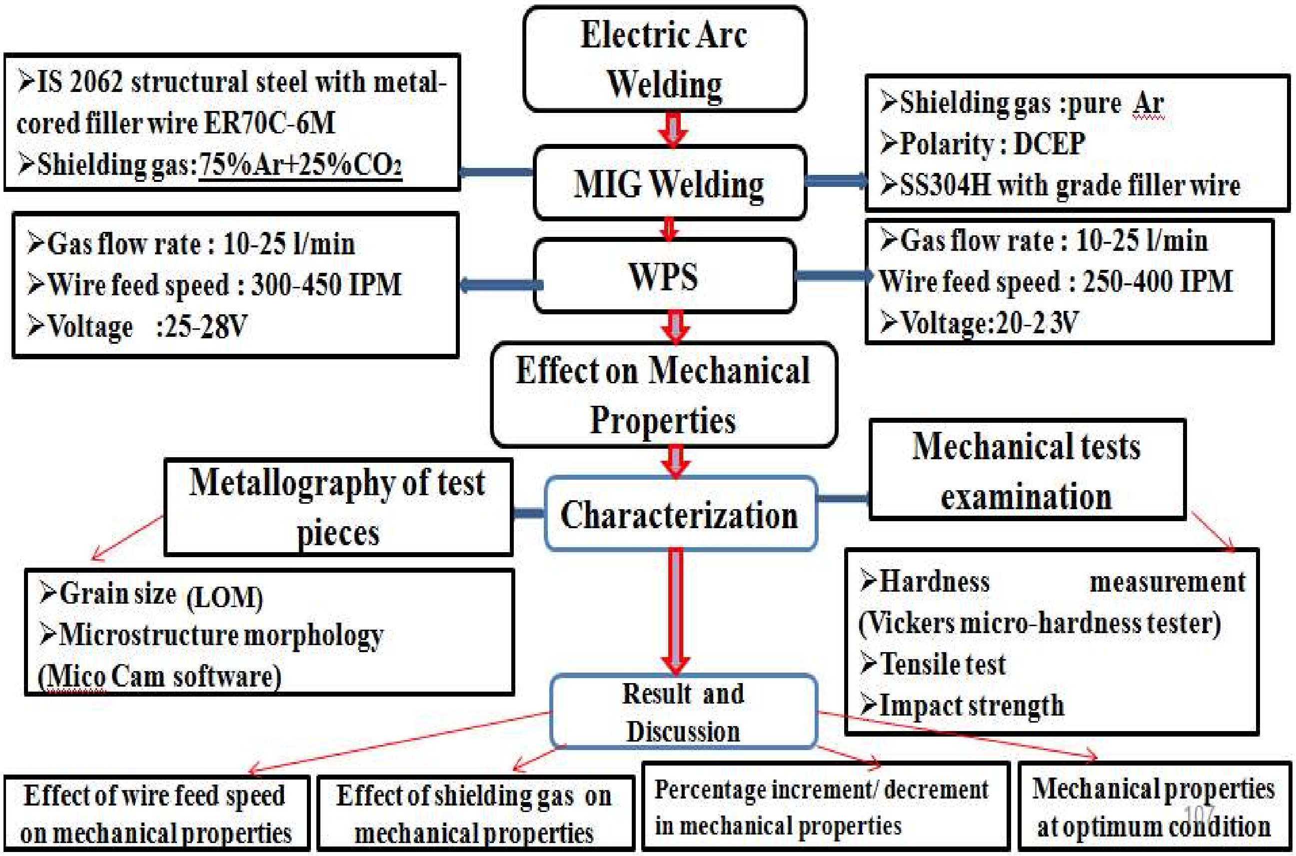

Figure 3.1 Schematic of experimental approach of the present study

3.1 Experimental setup

For welding of IS 2062 structural steel and AISI 304 steel, a foolproof set-up was designed and fabricated. Experimental set up used in this research mainly includes a power source of wave-455M CE and 455 M/STTCE, shielding gas 75% Ar+25% CO_2 cylinder, argon gas cylinder, and the welding table equipped with servo motors, and welding fixtures. The set-up so designed that it consists the following salient characteristic:

(i) The set-up does not possess any problem with performing automatic welding of test pieces.

(ii) It provides the usual penetration, arc length, welding current, arc stability, metal transfer, arc voltage, and elimination of arc below.

(iii) It is easy in the positioning of various instruments and recording of observations with the set-up.

(iv) The set-up provides a reasonable ease of welding.

3.1.1 GMA welding machine

The Semi-automatic wave-455M CE type welding machine is a fully digitally controlled GMAW/TIG power source with active and is characterized by the softest possible yet highly stable arc. It has an output of 5-570 A, is both light and robust in design. The power source is also ideally suited to portable use in many industries such as fabrication industries etc. With 121 Kg the magic wave 2200 is among the lightest among in all GMA welding machine and can be carried out anywhere. Its robust design makes it fully compatible with a construction site. It can work on a 230V connection, and can weld low, high alloys steels, aluminum, magnesium, and its various alloys and can weld nonferrous metals.

The unique feature of semi-automatic wave-455M CE type GMA welding machine is that it can be easily converted into GMAW/MAG, FCAW, SMAW, TIG, and Pulse GMA welding. In this present study throughout experimental work, alternating current (AC) with square wave pattern was used.

3.2 Selection of work material, welding consumable, and welding process:

Literature survey shows that Gas Metal Arc welding is widely used for welding of ferrous and non-ferrous material such as low carbon steel, HSLA, stainless steel, aluminum and its alloys, magnesium, and its alloys, nickel, and titanium alloys in industries by choosing appropriate shielding gas, electrode, and welding condition because of its low cost of equipment, suitable for welding in all position, portable welding equipment, high deposition rate and smooth weld bead with deeper penetration. GMA welding (GMAW) was developed in the 1950s. In GMA welding the composition of a shielding mixture depends mostly on the kind of material to be welded. It was formerly known as metal inert gas (MIG) and it is a fusion welding process in which workpiece melt and re-solidify to make the joint. Hence these characteristics have made this welding operation as a perfect selection of industries for fabrication purpose.

In this experimental work among the various electric arc welding process, Gas Metal Arc welding (GMAW) (semi-automatic machine) process is mostly used because of its wide range of industrial applications such as high metal deposition rate, smooth weld bead, and the process is suitable for all position, and faster welding speed. The thick plate can be easily welded with proper penetration and no wastage of filler wire. The process can be easily mechanized for mass production, and X-ray quality of the weld.

In this research work IS 2062 structural steel and AISI 304 steel welded with GMA welding process as both materials are easily available, having good weldability and excellent mechanical properties such as tensile strength and ductility. This characteristic of IS 2062 structural steel and AISI 304 steel makes indeed to use for the structural purpose.

While selecting the filler wire for welding of IS 2062 steel and AISI 304 steel workpiece under different welding condition. It should be considered that the selected GMAW consumable (copper coated wire & shielding gas) must fabricate excellent quality weld bead profile, good mechanical properties, and excellent microstructure. For welding of IS 2062 steel an **ER70S-6M** grade filler wire of 1.2 mm diameter is used, and for shielding purpose 75% Ar+25% CO_2 gas is used. 75%Ar+25%CO_2 shielding gas provide the better results that somewhat of a compromise, giving the better weld appearance, reduced spatter, and bead control. Therefore the above said gas is used. For welding of AISI 304 steel an **ER308** grade filler wire of 1.2 mm diameters is used, and for shielding purpose pure Ar gas is used.

3.2.1 Description of IS 2062 steel

IS 2062 steel of 10 mm of grade A is used for the general structural purpose. Previously it was known as IS226 but now as per BIS, it is known as IS 2062. It is also known as mild steel. IS 2062 Grade A is used as it is ok in bend test.

3.2.1.1 Mechanical properties of IS 2062

Mechanical properties of workpiece material i.e. IS 2062 structural steel and stainless steel 304H are listed in Table 3.1 (b) and 3.2 respectively.

Grade	Tensile Strength, MPa	Yield strength, MPa	% age elongation $5.65\sqrt{S_o}$	Toughness Joule	Bend test	Rockwell hardness

		<20 mm	20-40 mm	>40 Mm				
A	410	250	240	230	23	27	3xt (t=3times of t’)	B84
B	410	250	240	230	23	27		B82

Table 3.1(b) Mechanical properties of IS 2062 steel

3.2.1.2 Equivalent Grades of IS 2062 E250A steel

The equivalent grade of IS 2062 of different countries is listed below in Table No 3.2

EN10025(93)	EN10025(90)	DIN 17100	NFA 35-501	BS4360
S275J0	Fe 430C	St 44-3U	E28-3	43 C

Table 3.2 Equivalent grade of IS 2062 steel

3.2.1.3 Mechanical properties of AISI 304 steel

Mechanical properties of AISI 304 steel of different grades are listed in Table 3.3

S.No	Steel	Yield strength (MPa)	Ultimate tensile strength(MPa)	% age elongation	Hardness (Brinell) HB
1	304	505	515	45 Min %	215 Max HB
2	304L	505	485	45 Min %	215 Max HB
3	304H	505	515	40 Min %	210

Table 3.3 Mechanical properties of AISI 304 steel

3.2.1.4 Description of AISI 304 steel

AISI 304 austenitic stainless steel is a variation of the base of a Chromium & nickel with a ratio of 18:8. AISI 304 steel having low carbon contents. AISI 304H is a modification of AISI 304 with carbon content controlled in the range of 0.04 to 0.10 for increased strength at temperatures above about 800°F. In the annealed condition AISI 304/304H is non-magnetic but may become slightly magnetic after cold working or welding process. AISI 304L having slightly lower mechanical properties than AISI 304. Table 3.4 shows the chemical composition of different grades of AISI 304 steel.

S.No	Composition	SS304 (wt %)	SS304L (wt %)
1	Carbon	0.08 max.	0.03 max.
2	Manganese	2.0 max.	2.0 max.
3	Silicon	0.752.0 Max.	0.752.0 Max.
4	Phosphorus	0.045 Max.	0.045 Max.
5	Sulfur	0.030 Max.	0.030 Max.
6	Nitrogen	0.10 Max.	0.10 Max.
7	Chromium	18-20 Max.	18-20 Max.
8	Nickel	8-12 Max.	8-12 Max.
9	Iron	Rest	Rest

Table 3.4 Chemical composition of AISI 304 and AISI 304L steel

The different alloying elements have specific effects on the properties of a stainless steel. It is the combined effect of all the alloying, heat treatment, and, to some extends, impurities that determine the property of a certain steel grade. A Table No 3.5 shows the effect of different alloying elements in Stainless steel 304.

Alloying Element	Function
Nickel	Stabilises the austenitic structure during the austenisation treatment.
Manganese	Stabilises the austenitic structure during the austenisation treatment.
Nitrogen	Increases the tensile strength through solid solution strengthening.
Niobium	Stabilises carbon and improves the creep strength by forming NbC carbides.
Carbon	Increases the tensile strength through solid solution strengthening.
Copper	Improves the creep strength by the precipitation of a copper-rich phase. Also has an austenitic stabilizing effect.
Chromium	Improves the oxidation/corrosion resistance. Resistance increases with increasing chromium content.

Silicon	Improves the oxidation/corrosion resistance.
Phosphorus	Involved in increasing hardenability and strength.

Table 3.5 Effect of alloying elements in AISI 304 material

3.3 Experimental procedure

The IS 2062 structural steel and AISI 304 steel workpiece of 300 mm x120 mm x10 mm and 260 mm × 70 mm × 5 mm (AS per ASTM E8/8M-08) respectively having carbon and chrome and other alloying elements. Figure 3.2 to 3.4 shows the welded plate of AISI 304 steel while figure 3.5 shows the different samples cut from the welded plate. Workpieces were welded with GMA welding process under different welding conditions. For all workpiece (IS 2062 and AISI 304), reverse polarity or DCEP was used. For welding of IS 2062 steel under different welding conditions welding heat input was 3.22, 3.58, 3.88 and 4.47 kJ/mm, and for welding of AISI 304 steel plate, the heat input value was 1.89, 2.17, 2.78, and 3.01kj/mm respectively. the voltage, wire feed speed, and shielding gas flow rate were maintained in the rage of 25-28V, 7.62-11.43 m/min, and 10-25l/m for IS 2062 steel plate and 20-23V, 6.35-10.16 m/min, and 10-25l/m for welding of AISI 304 steel plates respectively. Beyond going to this range detraction in mechanical properties and very coarse grain microstructure produce.

Figure 3.2 AISI 304 plates after welding in Fixture

Figure 3.3 AISI 304 plates during welding

Figure 3.4 AISI 304 plates after weld

Figure 3.5 IS 2062 welded plate after cutting

3.4 Mechanical investigations

3.4.1 Fabrication of Tensile test specimens

Tensile test specimen fabricated as per ASTM E8/8M-08 from the welded workpiece is shown in figure 3.6 and Table 3.6 shows the dimensional details and their notation for a tensile test specimen as per ASTM E8/8M-08 standard. The flat test (I shape) specimen first cut by power hacksaw and then machined on a horizontal milling machine. To produce the arc radius of R12.5mm, test pieces machined on a vertical milling machine, this is only to avoid any stress concentration. The test pieces were so long to ensure that the neck formation should not take place near the ends. Any irregularities of the surface were removed during the machining of the test pieces.

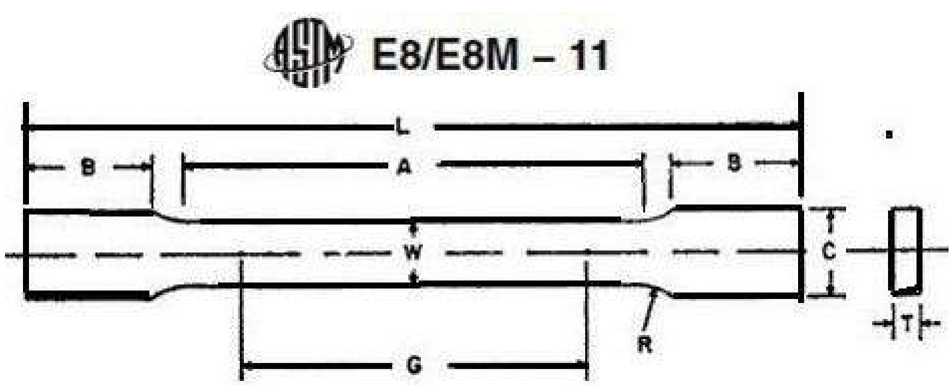

Figure 3.6 Detail of tensile test specimen as per ASTM [88]

Dimensional detail of a tensile test specimen for different thickness of plate as per ASTM is listed in Table 3.6

Dimensions				
S.No	**Standard specimens**			
		Plate Type,40mm [1.5 in] wide	Sheet Type, 12.5 mm [0.50 in] wide	6mm [0.25 in] wide
	G-Gauge length (mm)	200±0.2	50±0.1	25±0.1
	W-Width	40±2.0	12.5±0.2	6.0±0.1
	T-Thickness	Thickness of material		
	R-Radius of fillet, min	25[1]	12.5[0.5]	6[0.25]
	L-Overall length, min	450[18]	200[8]	100[4]
	A-Length of reduced section, min	225[9]	57[2.25]	32[1.25]
	B-Length of grip section, min	75[3]	50[2]	30[1.25]
	C-Width of grip section, approximate	50[2]	20[0.75]	10[0.375]

Table 3.6 Dimensional detail of tensile test specimen as per ASTM [88]

Dimensions of V-groove produced by a milling machine and the actual size of a tensile test specimen are shown in figure 3.7. All dimensions of the specimen are in mm.

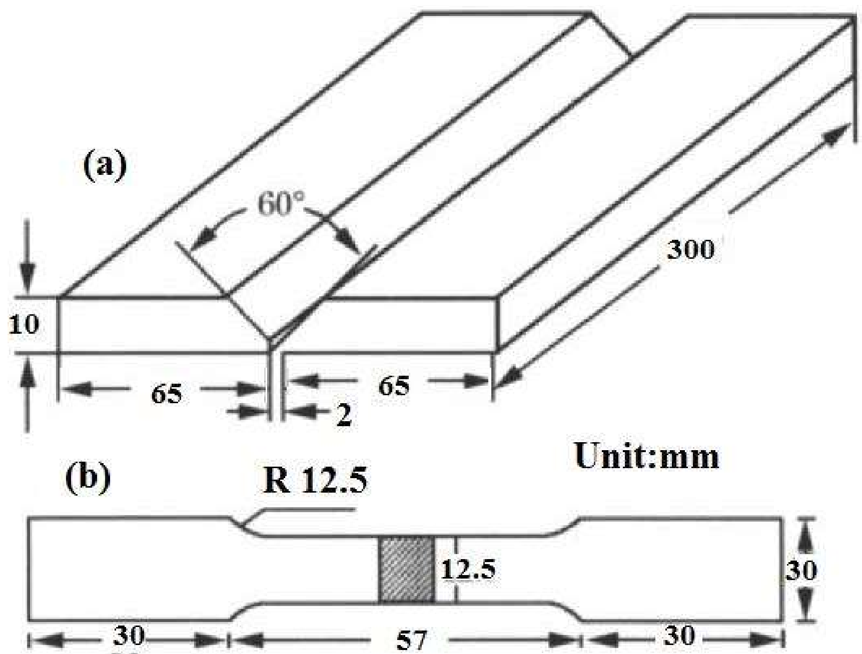

Figure 3.7 Dimensions of V-groove and tensile test samples in mm [89]

Figure 3.8 shows the actual tensile test specimen fabricated under different welding conditions for IS 2062 steel before fracture.

Figure 3.8 Actual photograph for the tensile test of IS 2062 steel

Figure 3.9 shows the actual tensile test specimens fabricated under different welding conditions for AISI 304 steel before fracture.

Figure 3.9 Actual photograph for a tensile test of AISI 304

3.4.2 Fabrication of Impact test (Charpy) specimens

To determine the Impact strength of welded piece several methods are developed. Only two methods are very common I,e Izod test and Charpy test. Charpy V- notch test piece are used in this study to determine the toughness of welded parts, and test specimens are fabricated as per ASTM A370-14 from the welded workpiece as shown in figure 3.10.Initially Charpy test specimen first cut by power hacksaw and then on a milling machine to generate an angle of 45° at the center by a milling cutter. The Charpy test method is very fast and economical. The test piece was kept on the anvil in the Izod testing machine

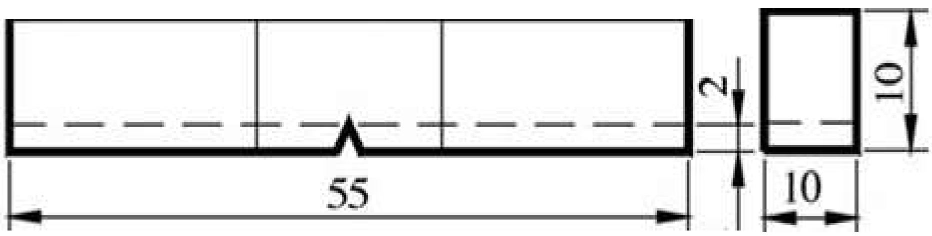

Figure 3.10 Dimensions (mm) of "sub size" Charpy V-notch test samples [88]

Fig 3.11 shows raw samples for Charpy test, whereas figure 3.12 shows Charpy test samples after fracture. All Charpy samples fractured at center.

Figure 3.11 Actual photograph for Charpy test samples

Figure 3.12 Charpy test samples after fracture

In Charpy test, the position of V-Groove is behind the hammer and specimen kept in simple supported form Charpy testing machine consist a hammer. When there is no test piece, pendulum (Hammer) is at rest position. When test piece is there, the pendulum is at 141° position to Izod test specimen. As lever release hammer strike at the V-notch of specimen and value of toughness shown at the scale directly.

3.5 Preparation of microstructure and Vickers hardness Test Samples:

The samples for microstructural examination is prepared as per the ASTM E3-11(Standard Guide for Preparation of Metallographic Specimens) standard.

Following operations are performed on the sample.

(i) Cutting of the samples

(ii) Mold making

(iii) Belt grinding

(iv) Polishing

(v) Etching

The welded joint was in the middle of the weld to obtain the cross section of the weld. Precision diamond cutter machine was used for this purpose. Cutting using this machine is a must as to obtain the unaffected weld surface of the welded joint. These cross-sectioned samples were cut into small pieces with length about 10mm by using metacut abrasive cutting machine. This is only to make the samples easier to be cold mounted. For mounting purpose, cold setting compound powder is used with liquid to make the blocks. The cold mounted samples were ground and polished. Grinding was carried out using abrasive sandpapers that have grades such as 80,120,220, 400, 600, 800, 1000, and 1500 microns starting with the roughest till finest grade at the speed range of 200 to 300 rpm. Then these samples were polished with diamond solution followed by alumina (Alumina suspension) for microstructure examination. Light optical microscope (LOM) is used to examine the weld metal structure at 100X magnification. Two different etching solutions are used to see the structure for IS2062 and AISI 304H steel weldment. For different material, different etching solution is used. Figure 3.13 shows the different samples for microhardness (Vicker) as well as microstructure examinations.

Figure 3.13 Samples for microstructure & Vicker hardness test

Various etching solution for different steels is mentioned in Table 3.7 with their chemical name.

S.No	**Name of solution**	**Description**	**Used for**
1		98% Ethonal+2%HNO_3	IS2062
2	Glyceregia	15ml HCL+10ml glycerol+5ml nitric acid	AISI 304
3	ZIP'S Reagent	5g cupric chloride+50ml HCL+50mL H_2O	AISI 304
4	Marble's reagent	50 ml HCL+25ml saturated aqueous solution of	AISI 304

		copper sulphate	
5		Ferric chloride+cons.HCL+cons. HNO_3	AISI 304

Table 3.7 Etchants used for microscopic examination for IS 2062 and AISI 304H

The test specimens which were used for microstructure examinations, same may be used for microhardness test. Vickers hardness of weld zone was measured. Vickers hardness test was carried out as per ASTM E384-17(Standard Test Method for microhardness of materials).A series of measurement in a given pattern is made between extreme ends of the weld zone.

3.6 Material characterization

3.6.1 Vickers hardness

Samples for metallographic analysis were sectioned with a Leco VC-50 precision diamond saw and mounted in nylon conductive mounting powder. The Vickers hardness of the simulated weld zone, Heat affected zone (HAZ) regions was evaluated with a Leco M-400-H1 hardness testing machine, available at Dept. of Metallurgical Engineering, IIT(BHU), Varanasi, using a 981N (1kgf) load, in accordance with ASTM Designation E-384-08. All specimens used for the Vickers hardness testing and microstructure characterization were taken from a single sample to ensure consistency of results.

3.6.2 Light optical microscopy

A light optical microscopy is one of the most common techniques which were used to study the microstructure characterization developed in the weldment. In this experimental work, a DEWINTER monocular inverted DMI educated model is used.

3.6.3 Scanning Electron Microscopy

Scanning Electron Microscopy (SEM) is also known as SEM analysis, and SEM microscopy is used in this research work to identify the mode of fracture for tensile test specimen and Impact test specimens. The tensile test and impact test sample of IS 2062 and AISI304 steel weldments, were to further undergone the examination to understand the surface topography (texture), morphology (shape, size of particles, and grain boundaries), and extent of liquation phase along the grain boundaries.SEM study was carried out at the Central Instrument Facility Centre (CIFC) of IIT(BHU), Varanasi. The ZEISS (LEO) 1550VP is fully PC controlled SEM with light element INCA energy dispersive X-ray spectroscopy (EDS) was also used to determine the inclusion at high magnification. The EDS was used to determine the chemical composition of inclusions.