CHAPTER 03 Experimental setup and procedure

3.1 Preamble

Activated TIG (A-TIG), Flux Bounded (FB-TIG) and Flux Zone (FZ-TIG) welding have the potential to enhance the weld penetration. To perform the A-TIG, FB-TIG and FZ-TIG welding, a fixture is developed. The present chapter discusses about the development of welding fixture, material and activated flux selection. Along with this, the chapter demonstrates the methodology adopted to prepare the test specimens for metallurgical and mechanical properties study. At last, the chapter provides the layout of the details regarding experiments.

3.2 Development of welding fixture

To perform TIG welding and its variants (A-TIG, FB-TIG, FZ-TIG), clamping is necessary to keep the plate together. During the manual welding process, it is difficult to control arc length, torch angle and torch speed which may result in poor quality of the weld. These problems are overcome by developing the welding fixture as in Figure 3.1 A-TIG/FB-TIG/FZ/TIG welding (a) setup and (b) fixture.

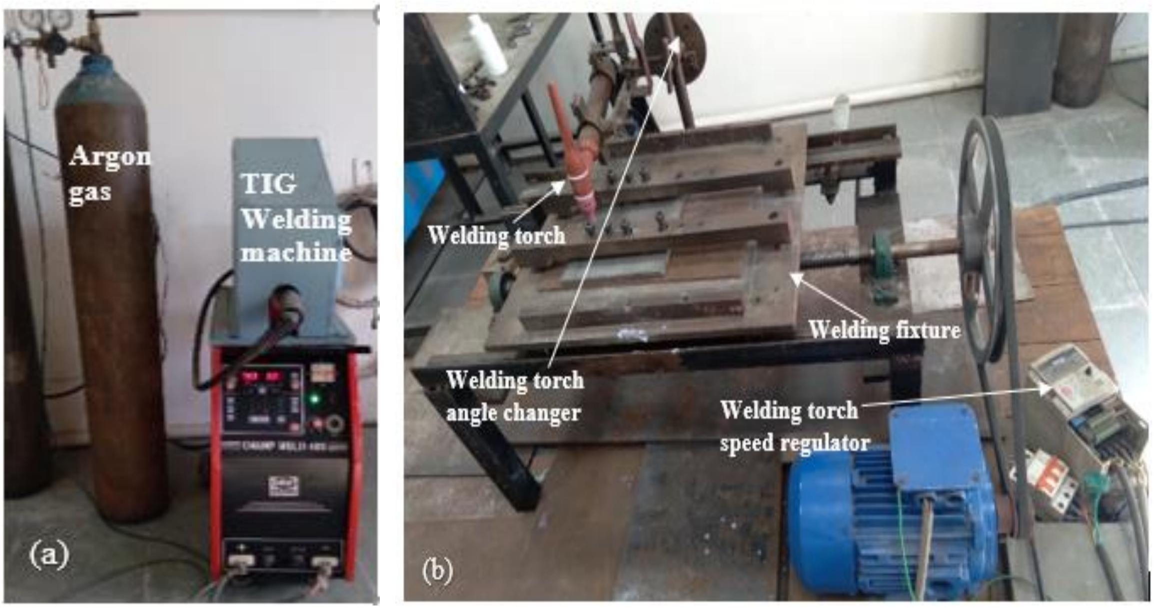

Figure 3.1 A-TIG/FB-TIG/FZ/TIG welding (a) setup and (b) fixture

The welding fixture consists of mainly a speed control unit (movable base plate). In this plate speed is control by movable plate which is place on stationary track and attached with lead screw (5mm pitch). Lead screw movement is controlled by belt and pulley mechanism which is attached with 0.5 HP induction motor. Also to vary the speed from motor to pulley variable frequency drive is attached. Torch speed is calibrated to perform the welding at predefined speed. The welding torch is clamped with the stationary track so during welding, a stable and continuous arc is formed. To change the torch angle, angle changer is manufactured on lathe machine as shown in Figure 3.2 (a) and attached to welding fixture.

Figure 3.2 (a) welding torch angle change (b) Stirrer for mixing flux and carrier solvent

Arc length and torch angle can also be controlled using the adjustable knob. During the welding, welding torch is place perpendicular to weld plate. Direct current electrode negative (DCEN) power source is used to perform welding. A tungsten electrode having 2.5 mm diameter, grind on grinding machine to maintain 45^0 electrode tip angle. In order to maintain constant arc length during welding process, a template of 2 mm is prepared. In addition, for proper mixing of fluxes and carrier solvent rotating stirrer (rotational speed 300 rpm) also has been developed as shown in Figure 3.2(b). For easy initiation of arc copper plate is place at initial and finished point of arc. This also avoid the undercut at starting and ending point of weld metal.

3.3 Selection of material and fluxes

A 6 mm thick plate of type 2205 Duplex Stainless Steel (DSS) (UNS S32205) is used for the investigation. The chemical and mechanical properties are tested in TCR Advanced Engineering PVT. Ltd. Vadodara. The tested properties of base material are as shown in Table 3.1.

Table 3.1 Chemical composition and mechanical properties of 2205 duplex stainless steel

Cr	**Ni**	**C**	**Si**	**Mn**	**P**	**S**	**Mo**	**N**	**Tensile strength MPa**	**Microhardness HV**
22.85	5.49	0.022	0.476	1.34	0.018	0.004	3.48	0.164	720	275

Flux used in A-TIG welding and its variants are oxides, halides (chloride or fluoride) and alkaline listed in Table 3.2. Each of the flux is having different physical properties and chemical composition so they behave differently during the welding. These powders are commercially available and are used as a single component or in combination during the welding processes.

Table 3.2 Types of fluxes

Oxide	CaO, Al_2O_3, Co_3O_4, Cr_2O_3, CrO_3, CuO, NiO, SiO_2, MoO_3, Fe_2O_3, HgO, MnO_2, NiO, TiO_2, ZnO, Cr_2O_3, Cu_2O, $K_2Cr_2O_7$
Chloride	$MgCl_2$, $CaCl_2$, $KclO_4$, $LiCl$, $ZnCl_2$, Nh_4Cl, $AlCl_3$, KCl
Fluoride	NiF_2, AlF_3 CaF_2, NaF, Na_2Wo_4, BaF_2, CaF_2
Alkaline	$NaHCO_3$

The fluorides do not affect the weld bead surface chemistry. Marangoni convection movements stay centrifugal as in TIG welding and do not favor a penetration. Surinder (2015) reported that fluxes such as CaF_2, KCl, NaF containing fluorine and chlorine effect the penetration insignificantly. Whereas, Tseng (2013) observed that oxide based flux induce centripetal Marangoni convection which promotes the arc heat transfer from surface to bottom of the molten pool and create high penetration. Flux containing oxide interact with arc column electron and form plasma column more constricts and thereby reducing the anode root area. Therefore, for the present study, only oxide fluxes such as, Cr_2O_3, MoO_3, TiO_2, Al_2O_3, CaO, SiO_2 are used. All oxide fluxes are purchased used in powder form as shown in Figure 3.3. Physical properties of each selected oxide flux is describe below and shown in Table 3.3.

TiO_2: The “Titanium (IV) oxide” is the International Union of Pure and Applied Chemistry (IUPAC) name of this flux. It is also known as Titania, naturally forming oxide of titanium. When it used as a pigment, called titanium white . It’s applications are in paints, food coloring, varnishes, paper, fibers and cosmetic products. It is white in color, water-insoluble solid and odorless.

SiO_2: The “silicon dioxide” is the IUPAC name of this flux. It is also known as Silica most commonly found in nature as quartz. It is the most complex and most abundant families of materials. It’s applications are in food and pharmaceutical industries, structural materials and microelectronics (as an electrical insulator). It is white in color, solid and odorless.

CaO – The “Calcium oxide powder” is the IUPAC name of this flux. Calcium oxide is also known as quicklime or burnt lime which contain carbonates, oxides, and hydroxides of calcium, silicon, magnesium, aluminum, and iron predominate, such as limestone. It is widely used, in insecticides and fertilizers. It reacts with water, causes severe irritation when inhaled or placed in contact with moist skin or eyes. Its color is white to pale yellow/ gray- powder and odorless

Al_2O_3: The “Aluminium oxide active neutral Activity I - II” is the IUPAC name of this flux. It is also known as alumina, aloxite, or alundum depending on particular forms or applications. It works as an electrical insulator. Aluminium oxide is crystalline form and easily react with atmospheric oxygen, and form a thin layer of aluminum oxide on any exposed aluminum surface. It is white in color, water insoluble solid and odorless

TiO_2 SiO_2 CaO

Al_2O_3 MoO_3 Cr_2O_3

Figure 3.3 Selected single component Oxide fluxes

MoO_3: “Molybdenum (VI) oxide” is the IUPAC name of this flux. It is used in industry as a catalyst. It is used to manufacture molybdenum metal, industrial production of acrylonitrile by the oxidation of propene and ammonia.. Its appearance is white, yellow or light blue solid and is odourless.

Cr_2O_3: The IUPAC name of this flux is “Chromium (III) oxide”. It is also called Dichromium trioxide or Chromium (3+) oxide. It is one of the principal oxides of chromium and is used as a pigment. It is used in paints, inks, and glasses. Its available in powder form or in wax form. Due to dark green color its known as green compound. Table 3.3 represent the physical properties of selected fluxes.

Table 3.3 Physical properties of selected fluxes

Sr. No.	**IUPAC name of fluxes**	**Properties of flux**	**Density (g/cm^3)**	**Melting point ^{0}C**	**Boiling point^{0}C**	**DG kJ/mol**
1	Silicon dioxide	SiO_2	2.65	1600	2230	-856.67
2	Titanium dioxide	TiO_2	4.23	1843	2972	-889.52
3	Chromium(III) oxide	Cr_2O_3	5.22	2435	4000	-1053.11
4	Molybdenum (VI) oxide	MoO_3	4.69	795	1155	-668
5	Calcium oxide	CaO	3.34	2572	2850	-604
6	Aluminium oxide	Al_2O_3	3.97	2072	2977	-1582

To spread the flux on base metal, alcoholic solvent is required. The carrier solvent such as acetone, methanol and ethanol are used to convert flux into a paste. These solvent are colorless and have good spreadabilty, coverability and low boiling temperature. In the present study, to perform the A-TIG, FB-TIG and FZ-TIG welding acetone is used as a carrier solvent. Due to low boiling point, acetone evaporates at room temperature, leave the flux layer on base metal.

3.3.1 Flux selection for A-TIG and FB-TIG welding

During the A-TIG welding out of six selected oxide flux, four fluxes are selected for trial experiments. According to Ellingham diagram (Figure 3.4) flux such as Cr_2O_3, MoO_3, SiO_2

and TiO_2 have lower amount of Gibbs free energies than CaO and Al_2O_3. Therefore, the resistance towards the thermal decomposition at elevated temperature is lower with Cr_2O_3, MoO_3, SiO_2 and TiO_2 fluxes. This increases the oxygen in the weld pool. Therefore, the reversal Marangoni convection was reported in weld pool which increase the D/W ratio in weld metal (Lu, Fujii, Sugiyama, & Nogi, 2003). On the other hand, opposite effect was reported with CaO and Al_2O_3 (Lin & Wu, 2012) . Moreover, fluxes having very low Gibb's free energy (Cu_2O, Fe_3O_4) are unstable and easily decomposed during the welding. This decomposed oxygen quickly dissolved in weld pool thereby increase the oxygen level in the weld metal. But, too high oxygen level in weld pool create weak reversal Marangoni convection which is responsible for lesser penetration. Therefore, in present study, Cr_2O_3, MoO_3, SiO_2, TiO_2 are selected for A-TIG welding out of which, the best three fluxes are selected for FB-TIG welding.

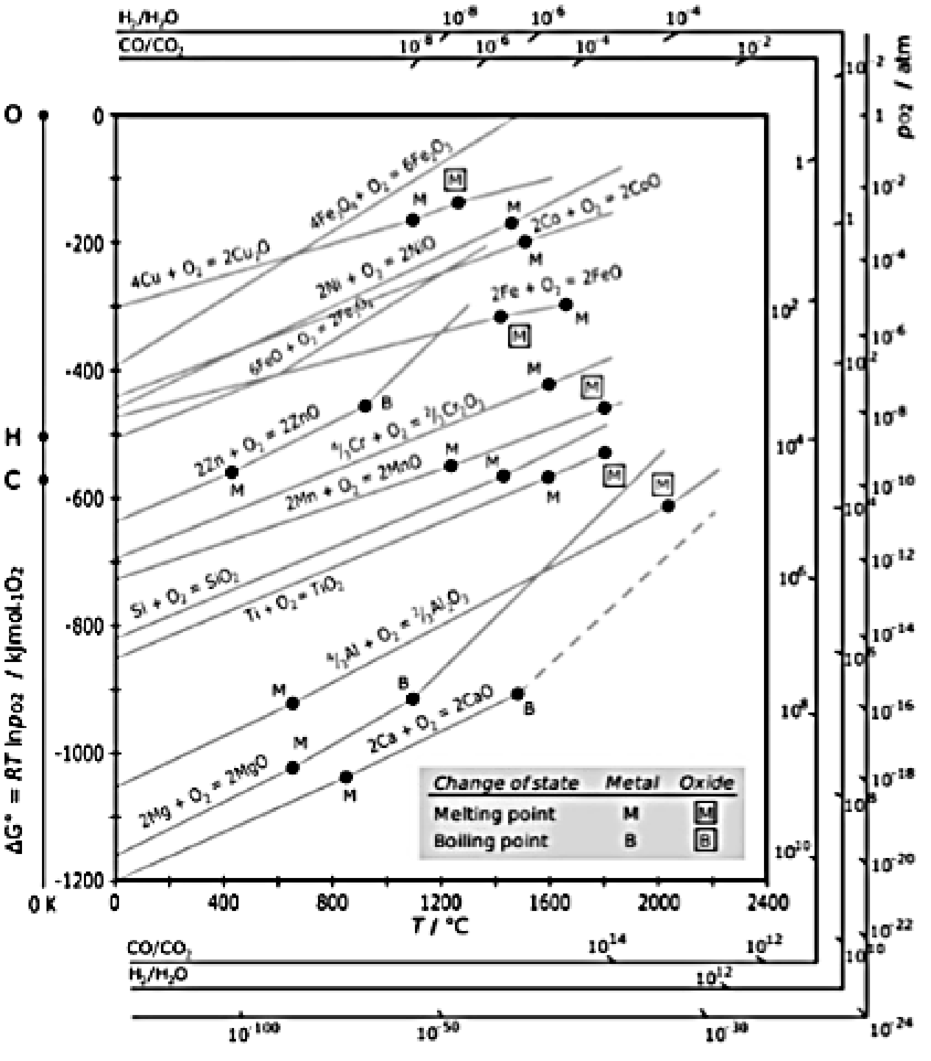

Figure 3.4 Ellingham diagram represent the various oxide metals relative stability (Mitchell, 2004)

3.3.2 Flux selection in FZ-TIG welding

During the flux selection, fluxes melting and boiling point as well Gibb's free energy of fluxes are equally important (Vidyarthy & Dwivedi, 2016). All the selected eight fluxes are having different boiling and melting point as shown in Table 3.3. Flux with high boiling and melting point choose as side region coat as its provide the insulation and thereby makes the arc column more constrict. The flux with less melting and boiling points are selected for centre region coat. This can easily evaporate during the welding, constrict the arc column due to negative ion of activated flux and reverse the Marangoni convection which is also responsible for higher penetration. From the selected oxide fluxes SiO_2 and MoO_3 is selected as inner region flux while Cr_2O_3, TiO_2, CaO and Al_2O_3 is selected as outer region flux. To perform the experiment of FZ-TIG welding different combinations of centre and side region flux are mentioned in Table 3.4.

Table 3.4 Selected Flux for FZ-TIG butt welding Trial Experiments

Sr. No.	**Central region flux**	**Side region flux**
1.	SiO_2	CaO
2.	SiO_2	Al_2O_3
3.	MoO_3	Cr_2O_3
4.	SiO_2	TiO_2
5.	SiO_2	Cr_2O_3
6.	SiO_2	TiO_2 (50%) + Cr_2O_3 (50%)
7.	SiO_2+MoO_3	TiO_2 (50%) +Cr_2O_3 (50%)

3.4 Metallurgical and Mechanical examination

The present section discusses the procedure adopted for investigating metallurgical, mechanical characteristics of A-TIG, FB-TIG and FZ-TIG welded metal. Metallurgical characteristics such as the macrostructure and microstructure study and mechanical properties i.e. tensile strength, microhadness are investigated further critical analysis has been presented in subsequent sections. Apart from this, Charpy impact test is performed at optimized A-TIG weld parameters. After welding, traverse section of weld metal is extracted for the metallurgical and mechanical characterization as shown in Figure 3.5.

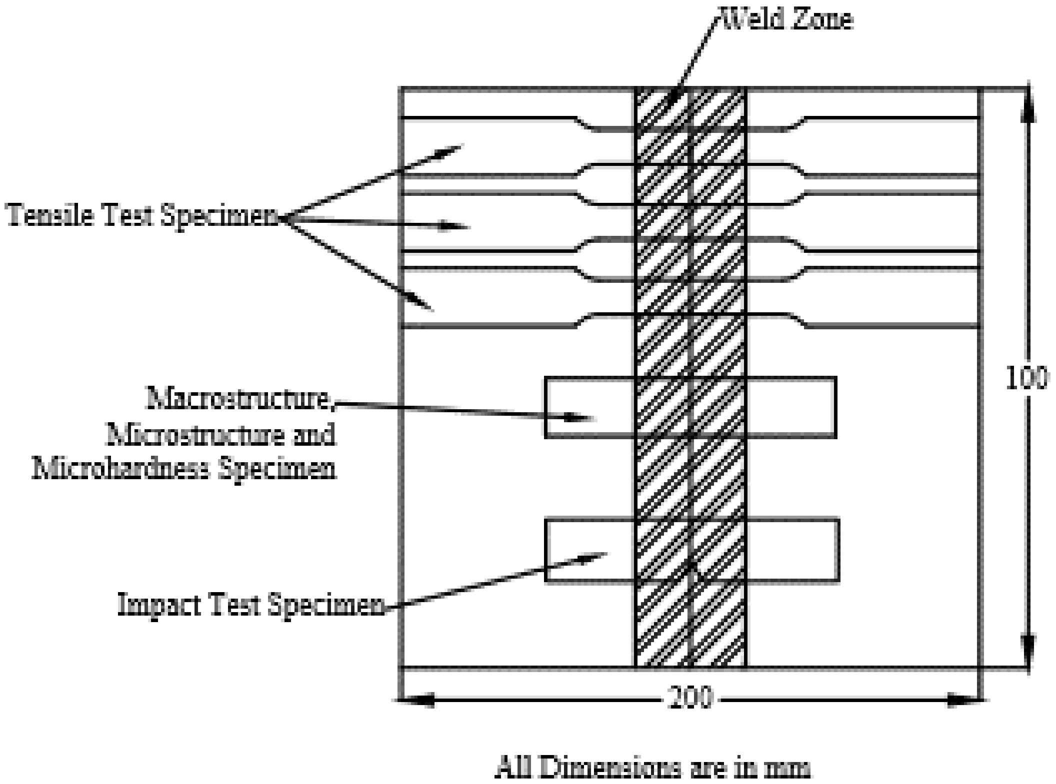

Figure 3.5 Welded joint location for microstructure, microhardness, tensile and impact specimen extraction for testing plates

3.4.1 Metallurgical examination

In order to determine the weld bead dimensions, cross-sections of central part of the welded plates are cut with the band-saw, polished on polishing machine produce a mirror-like finish. The process is followed by etching in oxalic acid solution to produce a bright surface. The weld samples macrostructure observed in stereographic microscope to ascertain weld bead dimensions. To reveals the microscopic features of welded metal under the different welding condition, optical and Scanning Electron Microscopy (SEM) is performed. To perform optical study clean and polished surface etched in Murakami's reagent. Further, polished samples SEM analysis is perform at 1000x and 500x magnification. The ferrite content is measure on base metal and weld region using Fischer Feritoscope in accordance with ASTMA799 standard, to understand the effect of weld parameters on tensile and microhardness.

3.4.2 Tensile testing methodology

To determine the mechanical behavior, the tensile tests are performed on welded metal wherein a sample is subjected to controlled tension until fracture. The tensile testing specimens are prepared on wire cut Electrical Discharge Machine (EDM). The flat tensile specimens are prepared according to the as per ASME Section IX and testing was performed at room temperature using a 1000 KN on commercially available Universal Testing Machine. In order to check the repeatability and consistency in the results three specimens are tested for each condition and each plate at room temperature. Average values were taken for analysis purpose. The dimension of the specimen for the tensile test is shown in Figure 3.6.

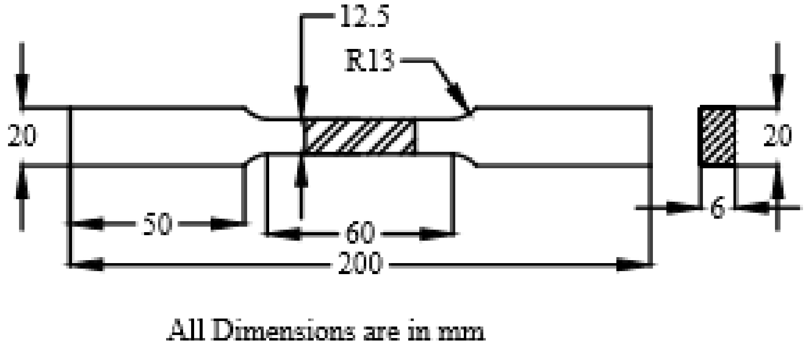

Figure 3.6 Dimension of the tensile test specimen

3.4.3 Microhardness methodology

In order to ascertain the microhardness traverse section of welded part is cut and polished as per standard procedure, applied before metallurgical observation. The microhardness of welded metal is measured using Vickers Microhardness tester at standard indentation load of 100 gf with a dwell time of 10s. The indentation for measuring microhardness is performed from the bottom to the top surface at the centre of the welded specimen. Also in few welded samples, indentations are taken at regular intervals across the transverse section at mid-thickness starting from base material on one side to other.

3.4.4 Impact testing methodology

A Charpy V-notch impact test is a dynamic test in which pendulum is struck on notched specimen and broken by a particular blow of a freely swinging pendulum. The pendulum is released from fixed height in a specially designed testing machine. For impact test samples are exerted in size 5 ×1 × 6 mm. V-notches are made exactly at the centre of the weld fusion zone on broaching machine as shown in Figure 3.7. So fracture occurred only within the fusion zones of weld samples. A dynamic Charpy V-notch impact test is performed on test equipment having range 0 to 350 Joules at optimal parameters. Prepare specimens kept under the -29^{0}c temperature and testing is performed as per ASTM A240 standard. The dimension of the specimen for the Charpy V-notch impact test specimen is shown in Figure 3.8.

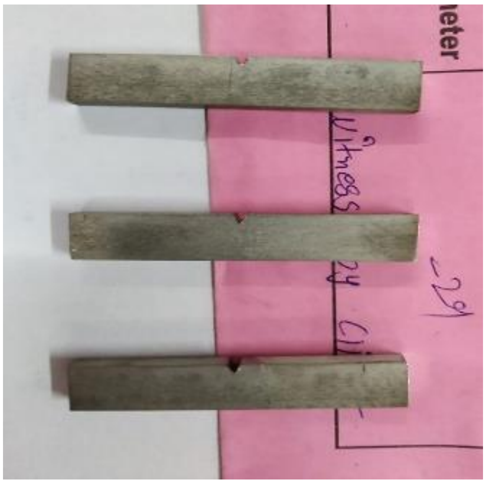

Figure 3.7 Charpy V-notch impact test prepared specimen

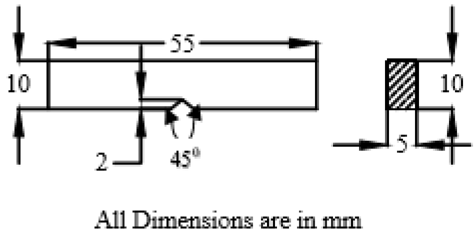

Figure 3.8 Dimension of Charpy V-notch impact test specimen

3.5 Layout of Experiments

After selecting materials and fluxes to perform A-TIG, FB-TIG and FZ-TIG welding processes, trial experiments are performed to identify the working range of input variables i.e. welding current, welding speed and the best flux. To develop the A-TIG welding process, further experiments are performed and analyzed its microstructure and mechanical properties. Moreover, propose of adapting FB-TIG and FZ-TIG welding is studied and comparison of A-TIG, FB-TIG and FZ-TIG welding processes are performed. The layout of experiments performed in A-TIG, FB-TIG and FZ-TIG welding processes are shown in Figure 3.9.

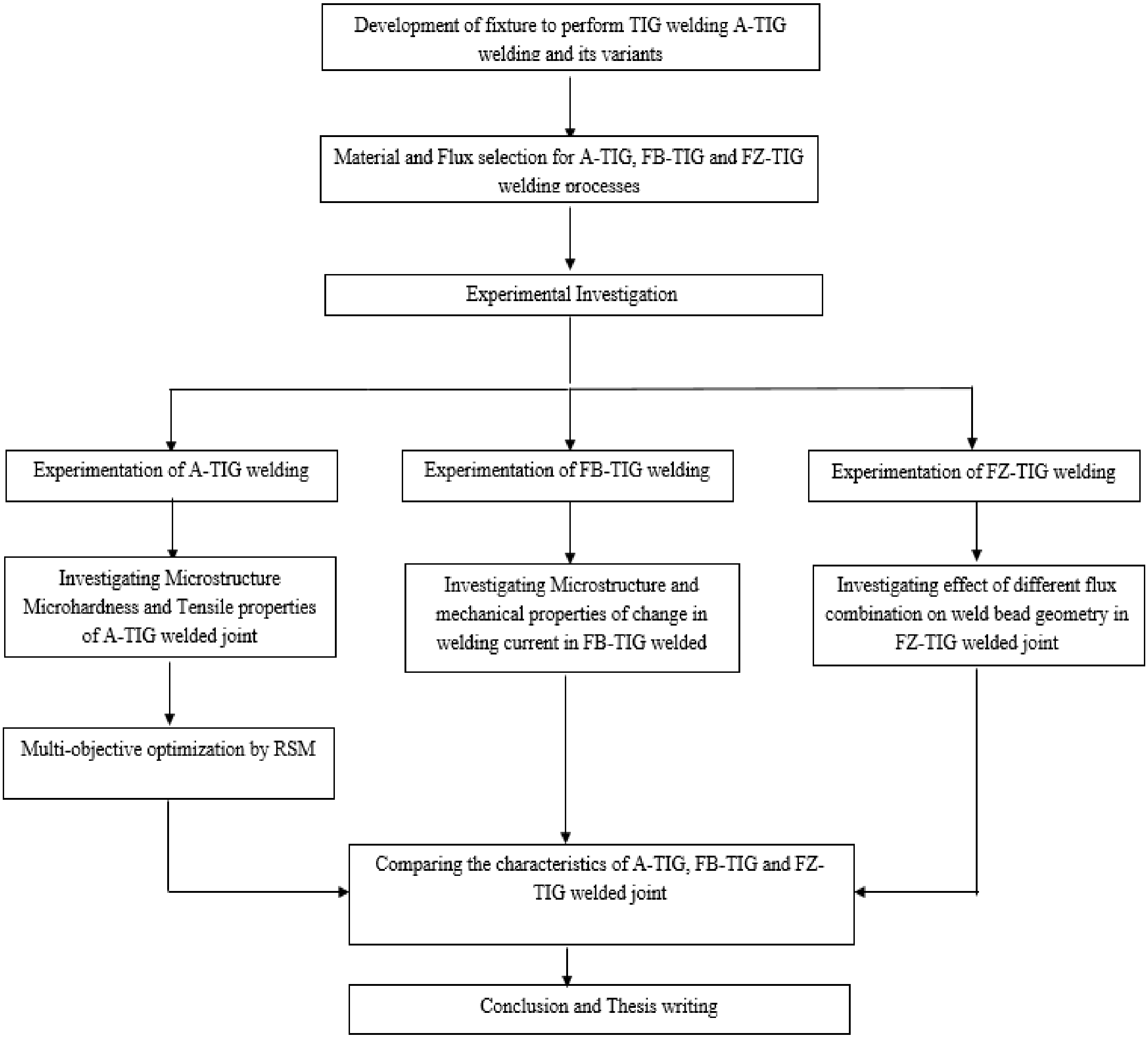

Figure 3.9 Flowchart for layout of Experiments