Chapter 1  Introduction

1.1 Background and motivation

Gas metal arc welding (GMAW) is versatile welding process has been extensively used in the different sectors of mechanical engineering industries due to its extra ordinary capabilities such as high productivity, low cost, high quality, and can be easily adoptable for coating, cladding, hard facing and repair work of different components, in addition to welding [American Welding Society-welding hand book (1950), American Society of Metals Handbook-Welding, Brazing and Soldering (1993), Craig, E. (1991)]. Apart from this, the use of GMAW is limited for the different applications of heavy engineering pressure parts as it do not reach to the standard requirements due to limitations of its weld bead profile and mechanical properties. Most of the pressure part of the heavy engineering industry uses steel grade of SA 516 Gr. 70 wherein GMAW is found to be applicable welding process in a limited way. The limitation of GMAW in pressure vessel industries is due to not meeting requirements imposed by the standards, in regard to the morphology of the weld beads, the mechanical properties of the welds and generates defects such as lack of penetration in the weld root and lack of fusion in multi pass welding. However, application of GMAW can increase productivity, versatility and cost effects [American Welding Society-welding hand book (1950), American Society of Metals Handbook-Welding, Brazing and Soldering (1993), Craig, E. (1991), Myers, D. (2014), Ahmed, N. (Ed.). (2005), Teske and Martins (2010)].

GMAW is a fusion welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from an externally supplied gas and without the application of pressure. GMAW can be operated in semiautomatic, automatic or machine modes [Ahmed, N. (Ed.). (2005)]. All commercially important metals such as carbon steel, aluminum, copper, titanium and nickel alloys can be welded in all positions with
this process by choosing the appropriate shielding gas, electrode, and welding variables. Although the basic GMAW concept was introduced in the 1920s, it was not commercially available until 1948 [American Welding Society-welding hand book (1950)]. At first, it was considered to be fundamentally a high-current-density, small-diameter, bare-metal electrode process using an inert gas for arc shielding [Myers, D. (2014)]. Its primary application was aluminum welding with inert gas application. As a result, it became known as metal-inert gas (MIG) welding, which is still common nomenclature. Subsequent process developments included operation at low current densities and pulsed direct current, application to a broader range of materials, and the use of reactive gases (particularly carbon dioxide) and gas mixtures. The latter development, in which both inert and reactive gases are used, which, led it to the formal acceptance of the term gas-metal arc welding [American Welding Society-welding hand book (1950), American Society of Metals Handbook-Welding, Brazing and Soldering (1993), Craig, E. (1991), Myers, D. (2014), Ahmed, N. (Ed.). (2005)].

Fig. 1-1 GMAW/MCAW/FCAW arc welding process [American Welding Society-welding hand book (1950)]
Economic enhancement and increase in quality and productivity can be more effectively obtained using tubular filler wires of GMAW [Jeffus, L. (1997)]. Flux cored wire uses flux powder inside the metallic tube, while metal cored wire uses metallic powder inside the metallic tube. These process variations of filler wire is known as flux cored arc welding (FCAW) and metal cored arc welding (MCAW), for flux cored wire and metal cored wire respectively. Flux cored wires are made up for self-shielding by means of flux cloud phenomenon in addition to shielding gas characteristics. Hence, FCAW provides dual shielding such as by flux shielding and gas shielding. The flux also helps in protecting weld up to its solidification by forming slag on to the weld bead. FCAW leads to higher deposition rate, higher welding speed, high weld quality, less chances of porosity generation, low cost, low formation of spatter etc. MCAW process carries advantages of both the wires of solid and flux cored, as metal powder if filled inside a tube of metal. Higher deposition rate, high quality weld, higher electrode efficiency, high volume of electrode and better metallurgical bonding are main advantages of MCAW [American Welding Society-welding hand book (1950), American Society of Metals Handbook-Welding, Brazing and Soldering (1993), Craig, E. (1991), Myers, D. (2014), Ahmed, N. (Ed.). (2005), Jeffus, L. (1997)].

Apart from these benefits of different processes, limited studies are available which talks about comparisons of these three different processes of GMAW, MCAW and FCAW under the effect of different process parameters [American Welding Society-welding hand book (1950), American Society of Metals Handbook-Welding, Brazing and Soldering (1993), Craig, E. (1991), Myers, D. (2014), Ahmed, N. (Ed.). (2005), Jeffus, L. (1997)]. The operational performances and bead characteristics of GMAW, FCAW and MCAW processes are different in terms of material deposition rate, weld area, working current, etc. Fluctuations of current and voltage values are reported with basic type flux cored filler wire [American Welding Society-welding hand book (1950), American Society of Metals Handbook-Welding, Brazing and Soldering (1993), Craig, E. (1991), Myers, D. (2014), Ahmed, N. (Ed.). (2005), Jeffus, L. (1997), Norrish, J. (2006)]. In addition to this, it is reported that, the mixing of shielding gas significantly affected the properties of weld in case of MCAW and FCAW. Different shielding gases of solid wire and tubular wire variations such as, in case of FCAW and MCAW, have affected formation of spatter, material transfer rate, material deposition rate and hydrogen content inside the welds [Liao et al. (1999), Mirza et al. (2013), Mukhopadhyay et al. (2006)]. Typical construction of tubular wires makes major difference which consequently affects these
variations in the process performances and weld properties. Tubular wire like metal cored wire can carry higher amount of current due to conductive metal powder in the metallic tube construction. Higher deposition rate can be obtained in case of FCAW as the flux is low density non-metallic material. It is reported by Liao et al. (1999) that, the influence of shielding gases on flux cored arc welding and solid wire-gas metal arc welding for workpiece material of stainless steel and observed that, the tensile properties are not affected by the shielding gas while, it has affected the deposition rates and spatter remarkably. Similarly, Mirza et al. (2013) have found that, the shielding gases influences the properties of weld under tubular cored wires and solid wire. They have observed that, the performances such as spray transfer, deposition rate and hydrogen content are influenced remarkably. Mukhopadhyay et al. (2006) have observed that tubular wire provides acceptable mechanical and metallurgical properties of weld when optimum shielding gas and chemical compositions of filler wire are applied. Apart from these individual studies for comparisons of shielding gas by tubular wires and solid wire, there are few articles available in the area of hybrid multi pass welding to the best of author's information. Yuan et al. (2016) have investigated hybrid tandem welding of solid wire and flux cored wire for the fillet joint configuration. Hybridization of filler wire have improved the weld penetration significantly. Also, Yuan et al. (2012) have reported that, the low spatter formation along with deep penetration improves weld bead profile [Yuan et al. (2013) and Yual et al. (2014)]. Nevertheless, all these studies are reported as individually for specific process. Detailed comparisons on properties of welds, weld bead profiles and process performances under the effect of nearly same process parameters for GMAW, MCAW and FCAW are lacking.

Additionally, it is well documented that, the hybrid approach in welding provides extension of process parameters and additional joint capabilities. In order to eliminate disadvantages of individual process, two or more welding processes are combined. Different hybrid approaches such as laser-gas tungsten arc welding (GTAW), laser-gas metal arc welding (GMAW), laser-plasma welding, GMAW-plasma welding, GTAW-friction stir welding (FSW), laser-FSW and many more are reported in the previous literatures [Mehta et al. (2016), Cho et al. (2011), Li, C. (2009), Bagger et al. (2005), Kim et al. (2012), Song et al. (2009), Taban, E. (2008), Taban, et al. (2009)]. These welding processes are combined in two ways like hybrid processes combined at a time and hybrid welds produced by different welding processes. Hybrid processes at a time are used when two different welding set-ups are performed to obtain weld
at a same time. Hybrid welds produced by different welding processes include weld obtained with different root and filler passes. Hybrid welds of GTAW-GMAW or GTAW-SAW, GTAW-SMAW approaches are commonly used in the heavy engineering industries, wherein root run is carried out by GTAW while filler run is filled with GMAW or SAW or SMAW processes respectively. Similarly, GTAW and plasma welding are combined for the root run and filler run respectively in order to achieve benefits of speed of plasma welding and soundness of GTAW. However, application of multiple welding processes consume time for set-up change and preparations [Mehta et al. (2016), Cho et al. (2011), Li, C. (2009), Bagger et al. (2005), Kim et al. (2012), Song et al. (2009), Taban, E. (2008), Taban, et al. (2009)]. It is more convenient if weld is produced by multiple filler wire rather than multiple welding processes. Hence, it can be interesting that, the hybridization of tubular wires and solid wire or two different tubular wire can enhance process performance as well as properties of the weld. These filler wires are compared individually for the influence of the shielding gases on stainless steel welds and weld properties. It can be reported that, hybridization of multiple filler wires is novel concept and not observed in the literature so far, to the best of author’s knowledge. Therefore, it is worthwhile to implement the hybrid concept of multiple filler wires along with the individual study of GMAW, FCAW and MCAW. Based on these gap identified, following objectives have been established.

1.2 Aim and objectives

The aim of the present investigation is to analyse GMAW, FCAW and MCAW for SA 516 Gr. 70 for its properties comparisons. The novel concept of hybrid filler wire under the effect of different combinations of GMAW, FCAW and MCAW is settled as another aim of this investigation. The assessment of weld quality is evaluated by means of mechanical and metallurgical analyses such as tensile test, hardness test, toughness test, microstructural study and energy dispersive X-ray spectrograph. The specific objectives defined as follows:

To investigate and compare the gas metal arc welding for solid wire filler and tubular filler wires such as flux cored wire and metal cored wire keeping same filler for root and filler pass.
To implement the concept of hybridization in multiple filler wire gas metal arc welding. These investigations include nine different combinations of weld with three different filler wires of solid wire, flux cored wire and metal cored wire. Further objectives are elaborated as under.

- Investigations on properties of hybrid welds of root pass as solid wire and filler pass as solid, flux and metal cored wire respectively.
- Investigations on properties of hybrid welds of root pass as flux cored wire and filler pass as solid, flux and metal cored wire respectively.
- Investigates on properties of hybrid welds of root pass as metal cored wire and filler pass as solid, flux and metal cored wire respectively.

To investigate and compare the mechanical and metallurgical properties of weld obtained through hybridization of multiple filler wires.

To set-up the effect of hybrid welds on actual performance and properties of gas metal arc welded joints.

1.3 Scope and significance

The present work is proposed to study the variations in the process performances, weld properties and develop comprehensive understanding on comparisons of GMAW, MCAW and FCAW for SA 516 Gr. 70 base material. It is also envisaged that, the insights on comparisons of weld properties (such as mechanical and metallurgical properties) will be suggested by the present investigation. Novel developments such as hybridization of filler wire of GMAW will be implemented and its detailed information will be acquired. Comparisons on different hybrid combinations of multi filler hybrid weld will be made for its mechanical and metallurgical properties. Best combination of hybrid filler wire will be suggested by this investigation.
1.4 Limitations

Present investigations are focused on experimental investigations on GMAW, FCAW and MCAW for SA 516 Gr. 70 carbon steel workpiece material of 10 mmm thickness. Butt joint configuration with V groove is fixed for the present study.

The presented investigation is conducted for experimental work only.

Selection of process parameters are carried out by bead on test of same material.

1.5 Layout of thesis

The present work is presented here as in the form of THESIS. The structure of thesis is divided into five number of chapters. Description of each chapter is mentioned as under.

Chapter 1 presents the background, motivation, problem statement, aim, objectives and structure of the thesis related to the topic.

Chapter 2 provides detailed description on available literatures on comparison of GMAW, FCAW and MCAW. Process benefits and characteristics are also presented from previous literatures.

Chapter 3 describes experimental part. Experimental procedure, description on materials, selection of process parameters, testing procedure and characterisation methods are presented this chapter. Procedures performed for mechanical and metallurgical testing are mentioned as per respective standards.

Chapter 4 presents results and discussions parts. The results obtained under the objectives mentioned of the present work are presented here. Analysis of the results for GMAW, FCAW and MCAW as well as hybrid filler wires are presented and compared for its results and discussions.
Chapter 5 provides conclusions for the present work and future work possible under the topic of hybridization of GMAW, FCAW and MCAW and individual effects.