CHAPTER 1

Gas Metal Arc Welding

Introduction

Gas Metal Arc Welding (GMAW), by definition, is an arc welding process which produces coalescence of metals by heating them with an arc in between a continuously fed filler metal electrode and the work. The GMAW process uses shielding from an externally supplied gas to protect the molten weld pool. The GMAW process enjoys widespread use because of its ability to provide high quality welds, for a wide range of ferrous and non-ferrous alloys, at a low price. GMAW also has the following advantages such as ability to join a wide range of material types and thicknesses, ready availability of simple equipment components that are readily available, affordable [1]. GMAW is easily adapted for high-speed robotic, full automation and semiautomatic welding applications.

1.1 GMAW Process

The principle of operation of GMAW is that an electric motor feeds a consumable wire electrode at controlled speed through the welding gun and into the arc. The tip of the wire electrode melts at a rate, which is based on the amount of the welding current. The power source is designed to maintain a constant arc voltage (arc length) so that the welder / operator are able to concentrate on ensuring complete fusion of the joint. Semi Mechanized welding system, the melting electrode is pointed in the direction of the welding forehand technique which produces the best fusion characteristics. The welder must also control the speed of torch movement and all the primary welding parameters should be within the set range in order to obtain a satisfactory weld.
The application of GMAW generally requires DC+ (reverse) polarity to the electrode. During operation the process is regulated with respect to arc length and wire feed speed to obtain stable condition. The continuously fed wire is melted in the arc heat and the droplets thus formed at the wire tip are transferred to the weld pool. The way in which material is transferred from the tip of the consumable electrode into weld pool has a significant influence on the overall performance of the process [2]. GMAW is generally known as MIG (Metal Inert Gas) welding when it is shielded by inert gas and it is known as MAG (Metal Active Gas) welding when shielded by argon / CO\textsubscript{2} mixture or only CO\textsubscript{2} gas. In general the MIG process works argon, helium or their mixtures are used for shielding the molten weld pool, whereas in CO\textsubscript{2} welding process, carbon-di-oxide is used as the shielding gas. As CO\textsubscript{2} being an active gas, this process is known as MAG (Metal Active Gas) process. CO\textsubscript{2} welding is used for the welding of carbon and low alloy steels from 16 gauge (0.059 inch) to 1/4 inch (6 mm) or heavier. Carbon dioxide has become widely popular for arc shielding in the welding of steel because of low cost compared to argon. CO\textsubscript{2} welding is basically a semi automatic process, in which the arc length and the feeding of the electrode wire into the arc are automatically controlled. The CO\textsubscript{2} welding system is shown in fig.1.1.1
The filler wire is continuously fed by motor driven rolls to a welding gun where current is fed into it from a power source. The welding arc is struck between the work piece and the tip of the wire, which melts into the weld pool. The arc and weld pool are both shielded by CO₂ gas flowing from the gun.

The process is very versatile in that, by selection of the proper wire diameter and composition it can be used for welding of thin sheet as well as thick plates. CO₂ welding is extremely useful for joining thin sheets of thickness range 1.0 to 2.0 mm because it is possible to keep the heat input low to avoid excessive melting and yet ensure adequate fusion. This is achieved by selecting a combination of wire diameter, current and arc voltage which allows the use of a stable short circuiting arc [5].

CO₂ welding is also extensively used for welding of wide range of pipe sizes and applications such as Process pipe work and oil / gas pipelines. The power source is available at 250A, 400A, 600A ranges. The wire feeder feeds the wire. The wire electrode is fed continuously into the arc by the wire feed unit at a speed preset by the operator. The wire feed rate can be varied generally from 5m/min. to 20 m/min. For a given wire material and diameter, the arc current is determined by the wire feed rate.

The required voltage is selected by adjusting the voltage control knobs provided at the power source. A heater is used to heat the CO₂ from the cylinder to prevent any moisture present in it. The gas is supplied in high pressure cylinders. The welding gas has a contact tube, gas nozzle etc. The gas nozzle provides efficient shielding of the arc.

Even best welders and welding machines don't make perfect welds. Some typical welding defects that need to be found and repaired are lack of fusion of the weld and porous bubbles known as porosity inside the weld, both of which could cause a structure
to break or a pipeline to rupture. During their service, many industrial components need regular nondestructive tests to detect damage that may become expensive later [3].

To overcome this barrier the demand for sensing defects online during welding has increased in fabrication industries to achieve the desired weld quality. This thesis has attempted to design a good welding signature analyzer. It is developed for online monitoring, identifying defects and weld quality evaluation.

1.2 Background and Motivation

The quality of the weld depends on the welding parameters and heat introduced both during the welding (i.e., some welding parameters have a lesser or greater effect on the geometric shape of the welded joint) and weld joint cooling (here, the joint cools down more or less rapidly in relation to the input of thermal energy, which in turn affects the metallurgical structure of the joint, its mechanical properties and resistance to miscellaneous defects within the joint).

The quality control personnel may analyze whether the flaw is critical, major or minor, whether the flaws are inherent because of the process or whether the defects are due to the processing or service conditions.

It is of immense importance to ensure that the base material used for fabrication shall be of good quality and attested materials are used in the manufacture of space vehicles and ships, submarines, pressure vessels, power boiler components, heavy duty crane structures, bridges etc., wherein the failure of weld will lead to loss of life, money and reputation[4,7]. The impetus for undertaking this research work came during the study of non-destructive techniques for weld defect identification.
The uses of nondestructive techniques are to determine the integrity of a material, component or structure or quantitatively measure some characteristic of an object.

1.3 Advantages and Disadvantages of NDT Methods

Visual Inspection

The advantages of these tests are that they are inexpensive, portable, minimum training, minimum part preparation required and immediate results can be obtained.

Its disadvantages are that they can only identify surface discontinuities, generally large discontinuities. Further misinterpretation of scratches is also possible.

Penetrant Testing

The advantages of these tests are that they are portable, inexpensive and sensitive to very small discontinuities 30 minute or less to accomplish, minimum skill is required to conduct the test.

Its disadvantages are that it can detect surface defects only, inference of rough or porous surface with the test, need part preparation, requirement of high degree of cleanliness is required and need for direct visual detection of results is also required.

Magnetic Particle Inspection

The advantage of these tests are that they are portable, inexpensive, sensitive to small discontinuities, immediate results can be obtained, moderate skill is required, that they can be used to detect surface and sub surface discontinuities.

Its disadvantages are surface must be accessible, rough surfaces interfere with test, part preparation is required (removal of finishes and sealant, etc.), semi-directional requiring general orientation of field to discontinuity, and Ferro-magnetic materials only can be tested and part must be demagnetized after test.
Radiographic Testing

The advantages of these tests are that they are portable, inexpensive, sensitive to very small discontinuities, immediate results can be obtained, minimum part preparation is required and wide range of materials and thickness can be inspected and its disadvantages are surface must be accessible to probe; rough surfaces interfere with test, highly sensitive to sound beam discontinuity orientation and high degree of skill is required to set up and to interpret results.

Ultrasonic Testing

The advantages of these tests are that they are even though being are costly, sensitive to very small discontinuities, immediate results can be obtained, and minimum part preparation is required. Using this testing, wide range of materials and their thickness can also be inspected. Its disadvantages are the testing probe is accessible to surface, rough surfaces interfere with test, highly sensitive to sound beam discontinuity orientation, high degree of skill required for setup and interpret results

Eddy Current Testing

This test is used for detecting surface and subsurface discontinuities, obtaining immediate results and is sensitive to small discontinuities and thickness. Its disadvantages are surface must be accessible to probe, rough surfaces interfere with test, electrically conductive with materials, skill and training personnel are required and time consuming for testing large areas.

To overcome the major disadvantages of NDT methods, the demand for online welding defect identification has been increased in fabrication industries to achieve desired weld with respect to productivity and quality.
The aim of this research is to fulfill the requirement of the industrial need by developing welding signature analyzer for online monitoring, defect identification and quality evaluation and reduce the dependence on Non Destructive Examination (NDE) procedures.

1.4 Problem Definition

Weld defect is a flaw or flaws by nature or through accumulated effect that renders a part of product unable to meet minimum applicable acceptance standards or specifications. Defect is the term which relates to rejectability. Acceptance standards dictate the type of inspection and the weld is tested before giving a judgment [7].

The present day NDT techniques are consuming more time and cost for evaluation of defects. From the view point of improving the quality of the weld and for energy saving, it is necessary to have an online weld monitoring system.

Online weld defect identification has been the subject of research for the past several years. The main cause of weld defect is the variation of process parameters against the preset values. Welding process cannot be viewed with the naked eyes. The process behaviour can be understood by monitoring the online arc voltage and arc current. Any variation of process parameters such as shielding gas pressure, stand-off and torch angle are reflected in the arc voltage and arc current, hence a suitable system is required to record the online arc voltage and arc current and a software package has to be developed for online monitoring, analyzing the data for defect identification and quality evaluation [8-10]. In this work CO₂, is taken for experimentation and frequently occurring defects such as lack of fusion, burn-through, lack of shielding gas are identified.
Lack of fusion, incomplete penetration, burn-through and lack of shielding gas during welding are mainly caused due to incorrect electrode size, improper manipulation of electrodes, incorrect position of, low welding current, too rapid arc advance incorrect polarity where DC is used, slow travel speed and incorrect torch angle.

(i) **Lack of fusion:** As a consequence of insufficient heat or the presence of scale on the fusion face of a weld the deposited metal may remain separated from the base metal by a very thin layer of oxide. This defect is called lack of fusion. Radiographic indication of a lack of fusion is a very narrow, straight dark line, parallel to and displaced to one side of the weld image.

In case of the side wall lack of fusion it is very difficult to identify the indication. Lack of fusion involves lack of complete melting and fusion of some portion of the weld metal in a joint. It may occur either between parent metal and weld metal or between two layers of weld metal.

(ii) **Incomplete Penetration:** Failure to achieve the desired depth of melting is termed as lack of penetration. This is incomplete penetration of the weld through the thickness of the joint. This usually occurs at the root of the weld or between the deposits made from both sides of a joint. In double welded joints, lack of penetration may occur within the wall thickness as a ‘buried’ defect [12-14]. Welding current has the greatest effect on penetration.

(iii) **Burn Through or Excess Penetration:** This is a serious defect in tubular welds. This occurs because of usage of very high current and low travel speed. The net result of excess penetration in tubular welds is the reduction in bore size. Also, sharp notches are
formed by the weld metal. Normally, radiography is made use of to ascertain their presence. Use of consumable inserts restricts the excess penetration.

**(iv) Lack of Shielding Gas**

Discontinuities related to the loss of inert gas shielding are the porosity, oxide films and inclusions, incomplete fusion and cracking. In addition, the mechanical properties of high-strength steel alloys can be seriously impaired with loss of inert gas shielding.

**1.5 The Need of Welding Signature Analyzer**

In the previous sections the advantages and disadvantages of the NDT techniques are discussed. Present day non-destructive techniques do not meet the both online monitoring and assessing welding quality. Therefore a new improved technique to be developed, which, is to be user friendly to the welding personnel. This can be done by recording the online arc current and arc voltage signature and statistical evaluation of its parameters yields information about the weld nugget and also possible to know the cause of the defect by analyzing the welding signature [31]. The defects during welding can be identified with the increased processing power of modern personal computers, schemes incorporating sophisticated electrical data handling can be used. The good weld specimen signature and its statistical parameters are captured and stored as reference and subsequent weld data can be captured and compared online for defect identification. This can be achieved by incorporating software package with the welding analyzer [36]. The purpose of development of welding signature analyzer is to confirm the defect and quality by the examination of the welding current and voltage signatures and the
assumption that the variance of the weld voltage or current decreased when the welding process deviated from the optimal welding state.

1.6 Objectives of the Research Study

Based on the above problem definition the following objectives are outlined for this Research study.

1. To select suitable sensors for capturing online arc voltage and arc current
2. To select a Data Acquisition System for processing online welding data
3. To identify a versatile computer capable of operating in welding environment
4. To develop a user friendly software package for online mode for knowing the real time trend of arc current and arc voltage signature during welding.
5. To compute the statistical parameters of the recorded current and voltage signature in off line mode to find the quality of the welding

1.7 Approach to Develop Welding Signature Analyzer

The approach to develop a welding signature analyzer is shown in block diagram 1.6.1
The method of recording the arc voltage and arc current was discussed by various literatures [16-20]. The defects and quality evaluation are possible only by capturing the arc current and arc voltage during the process of welding. The online analog signals are captured by the voltage and current sensors which are digitalized and sampled in the Data Acquisition system then the samples are stored in the industrial computer in First Input to First output basis [21-23]. A software package has been developed for monitoring the welding process and to compute the statistical parameters.

1.8 Outline of Thesis

The organization of this thesis as follows.

Chapter 1 describes the background and motivation for understanding this research work. It briefly describes the problem to be solved, objectives of the research, and chosen defects to be identified.

Chapter 2 presents the literature survey of welding defects identification techniques, Statistical processing of instantaneous arc voltage and arc current data during welding, fault detection techniques and online monitoring system and frequently occurring defects and its causes is also discussed in this chapter.

Chapter 3 describes the major components of the GMAW system, characteristics, mathematical modeling of GMAW.

Chapter 4 presents the major components used to develop WSA and its specifications operation of WSA are explained. Wiring, schematic and panel dimensions are also presented in this chapter.
**Chapter 5** describes the statistical parameters used in this work and its significance, software development for online mode and offline mode for monitoring and computing statistical parameters.

**Chapter 6** The experimental setup, for online monitoring and recording. Welding signatures and their statistical values of various test results are discussed.

**Chapter 7** presents the method of fixing reference welding current signature and evaluation of welding machine and welding signature analyzer is explained. Method of computing Short Circuited Time (SCT) and Net Burning Time (NBT) are also discussed.

**Chapter 8** describes the validation test results, welding signatures and their statistical parameters are presented and identified defects and their causes are also mentioned.

**Chapter 9** presents conclusions, contribution and scope for future research work is discussed.