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Experimental Investigation on the Welding of Stainless Steel and Mild Steel using GMAW

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Abstract—*Dissimilar joining of metals offers the potency to utilize the advantages of various materials and provide unique solution to engineering requirements. It has emerged out to be highly popular in recent years as the welded combination provides improved mechanical and electrical properties, low specific weight, and corrosion resistance. Although dissimilar metals can be joined by several processes, this paper mainly focuses on joining of stainless steel and mild steel by gas metal arc welding. Stainless steel and mild steel are the dissimilar metals widely used because of their improved properties in the welded combination. Experimentation is carried out by taking various input parameters such as torch angle, welding current, welding speed etc. and the corresponding output parameters such as transverse shrinkage, angular distortion, deposition efficiency; hardness and tensile strength are compared. Thus this paper depicts and compares the various properties obtained during dissimilar joining and provides a detail about them.*

Keywords: *Dissimilar metal welding, GMAC, Stainless steel, Mild steel*

1. INTRODUCTION

In the recent era of higher productivity and better quality of manufacturing goods, welding has become the backbone of manufacturing industry. Welding technique is applied to join both similar and dissimilar metals. The process of joining dissimilar metals is more complex and challenging than similar metals because of variation in physical, chemical and metallurgical properties in the materials to be joined. However, the demand for dissimilar metal joints is increasing in industries as the welded combination provides improved mechanical and electrical properties, low specific weight, and corrosion because of their enhanced properties in the welded combination. Among all the available welding processes, Gas Metal Arc Welding (GMAW) or Metal Inert Gas (MIG) welding has widespread application for joining dissimilar metals. There are many advantages in the welding by GMAW method, such as high flexibility in the welding of different metals with different thicknesses, high welding productivity, and automatic run capabilities. The weld quality in this type of welding is determined by characteristics such as the metal transfer mode and the weld geometry (Anzehaee and Haeri2011). In addition, welding parameter is a very essential factor to achieve the weld quality, productivity and cost of weld.

It is well known that the Stainless steel (SS) is one of the major materials used in industries. The metallurgical changes such as micro-segregation, precipitation of secondary phases, and presence of porosities, solidification cracking, and grain growth in the Heat Affected Zone (HAZ) and loss of materials by vaporization are the major problems which produce poor mechanical properties in SS welds (Lee and Jeng2001; Jamshidi *et al.* 2009).Thus the properties can be improved by dissimilar welding. The SS and mild steel(MS) dissimilar material joints are very commonly used in many engineering applications. However, joining of SS and MS is very critical because of carbon precipitation and loss of chromium which increases the porosity and affects the quality of joint leading to deterioration of strength (Mishra *et al.* 2014).Hence, there is a need to overcome various problems created in dissimilar metal welding of SS and MS such as risk of hardenability of the weld metal, crack formation etc. Despite such problems, because of its various advantages it is frequently used in welding of carbon steel pipes, transportation of water for household consumption and industrial purpose, coal-fired boilers and other power industry equipment. Therefore, several researches is going on in this field to meet the demand of manufacturing industries. There is a large application of joining dissimilar metals in transportation industries, aerospace, shipbuilding, railway transportation, as the weight of the vehicle is reduced (Taban *et al.* 2010). During fusion welding, chromium carbide precipitation takes place in between grain boundaries which can be avoided by friction welding (Aanthapadmanaban *et al.* 2009). Chuaiphan *et al.* (2009) investigated the mechanical and corrosive behaviour of weldments between SS and carbon steel using Gas Tungsten Arc Welding(GTAW). Karadeniz and Ozsarac (2007)investigated the effect of process parameters on the penetration in GMAW and observed that increase in welding current results in increase in depth of penetration. Long *et al.* (2009) investigated the welding distortion in butt of thin plates and observed that transverse shrinkage decreases by increase in welding speed. Pal and Pal (2010) investigated the influence of pulse parameters at various torch angles on the tensile properties of low carbon steel butt using pulsed metal inert gas(MIG) welding and found that the interface of weld zone and HAZ is the weakest area. Therefore, investigations related to GMAW of SS and MS is very much vital not only due to their wide spread applications but also due to the effect of welding parameter to achieve the weld quality, productivity and cost of weld. In the present work experimental investigation is carried out considering torch angle, welding current, welding speed etc. as input parameters and the corresponding output parameters such as transverse shrinkage, angular distortion, deposition efficiency; hardness and tensile strength are compared.

2. EXPERIMENTATION

A comparison is made on similar and dissimilar weld quality by using two different electrode wires such as ER 70S6 MS and ER 309L SS plates with the variation of major process variables (Fig. 1.)at different torch (Fig. 2.) angles using full factorial design of experiment method (Table 1). Other welding conditions are kept constant throughout the experiment. In order to investigate the quality of butt weld joint and its mechanical properties, specimen of 150×100×3 mm size is prepared. GMAW process is used in this experiment. The various input parameters such as torch angle, welding current, welding speed are shown in Table 1.

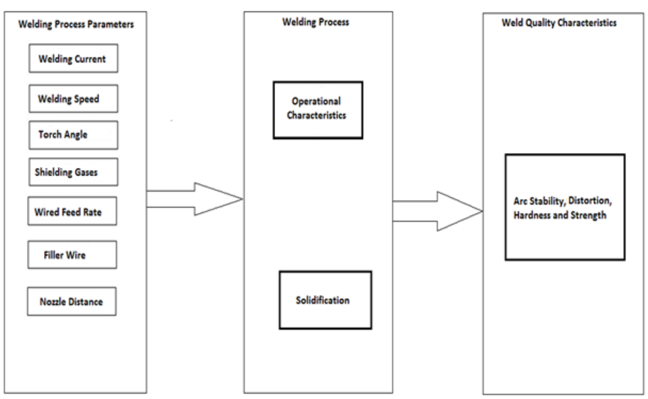

Fig. 1: Schematic illustration of GMAW process

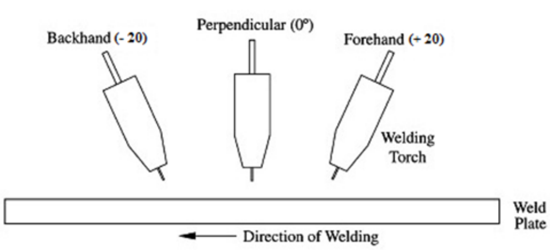

Fig. 2: Schematic representation of arc welding at different torch angle

Table 1: Experimental input process parameters

Variable parameter	Level 1	Level 2	Level 3
Torch angle (degree)	**0**	**+20**	**-20**
Welding current (Ampere)	60	80	100
Welding speed (m/min)	0.2	0.3	0.5

3. PREPARATION OF SPECIMEN

A pair of SS and MS plate has been cut in the dimension of 150×100×3 mm. The chemical composition of base metals and electrode wire is shown in Table 2 (as per mechanical hand book). Each pair of base plates is welded at points T1and T2as shown in the Fig. 3. Beads on butt joints are made in flat position using synergic GMAW welding machine. Measurement of initial length is done with Vernier caliper, weight with digital weighing machine and cross sectional angle of tack welded plate by profile projector.

Table 2: Chemical composition base metal and filler wire

Element	Materials designation			
	SS 304	**MS 1020**	**SS wire**	**MS wire**
C	0.05	0.18	0.03	0.06
Si	1	0.1	0.9	0.8
Mn	2	0.4	2.5	1.4
Cr	18	0.008	22	
P	0.04	0.06	0.03	0.02
S	0.03	0.05	0.03	0.02
Ni	8	0.007	12	
Cu			0.75	0.3
Fe	bal	bal	bal	bal

4. EQUIPMENTS USED

Table 3: Equipment list

Name of equipment	Model no.
Synergic GMAW	TS 5000
Profile Projector	801A (vertical floor type)
Rockwell Hardness Testing machine	RB-3
Universal Testing Machine	AMT IC

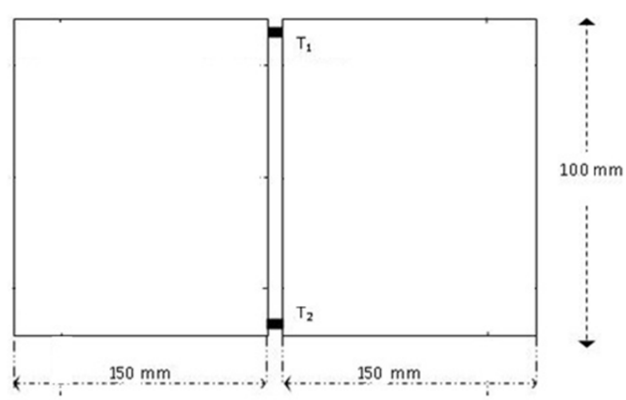

Fig. 3: Schematic diagrams for tack welding

5. DETERMINATION OF TRANSVERSE SHRINKAGE

Transverse shrinkage is expressed as the ratio of change in length due to welding to the initial length across the weld plate, as shown in Fig. 4.

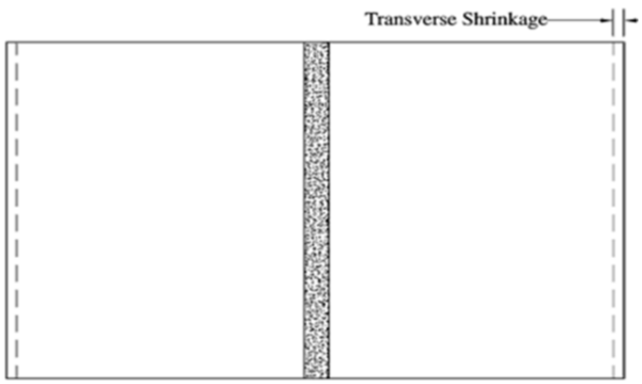

Fig. 4: Schematic representation of transverse shrinkage

Measurement is done at three different positions along the width of the plates and their average value has been calculated as per equation given below by using verniercalliper.

$$\rho_\tau = \frac{1}{3}\left[\frac{\Delta L_{11}}{L_{11}} + \frac{\Delta L_{22}}{L_{22}} + \frac{\Delta L_{33}}{L_{33}}\right] \quad \textbf{Eq. 3}$$

6. DETERMINATION OF ANGULAR DISTORTION

In a profile projector, the pair of final welded plates is fixed in the fixture in cross section position. Lens position is fixed in such a manner that ten times magnification is adjusted on the screen. The angular profile is traced from the screen on tracing paper with pencil.

The angular distortion is calculated by the difference in angles between tack welded one pair of plates and then after final welding.

Angular distortion (α_a) is expressed as

$$\alpha_a=(A_i-A_f) \text{Eq.} \quad (4)$$

Where A_i= Initial angle and

A_f=final angle

7. DETERMINATION OF HARDNESS

Hardness test is carried by Rockwell hardness testing machine of capacity 150 kg. The cross section of each weld bead sample (after cutting welded plates crosswise) is held under indenter of hardness machine. Then minor load is applied. After releasing the minor load, major load applied. Hardness is shown in the indicator to avoid fracture during the testing. Hardness is measured at weld bead, HAZ and base metal of SS and MS side.

8. DETERMINATION OF TENSILE STRENGTH

A computerized Universal Testing Machine (UTM) having capacity of 400 KN (model no AMI IC) is used as shown in Fig 6. All welded plates are cut in I shape as per rules of ASTM standards as shown in Fig. 5. One end of each specimen is fixed in the upper fixture and other end in lower fixture of the machine. Then with increase in hydraulic load,at certain load the specimen breaks.

Fig. 5: Tensile test specimen as per ASTM standard

Fig. 6: Universal testing machine

Then the ultimate tensile strength is calculated by, dividing breaking load by cross sectional area of weld bead as per Eq. 5

Ultimate tensile strength $\sigma t= P/A$ Eq. 5

Where,

P- Breaking load as measured with the help of UTM indicator

A- Cross sectional area of I-section welded sample

9. EXPERIMENTAL RESULT AND DISCUSSION

The primary input parameters are torch angle, welding current, heat input per weld length and welding speed are changed and the auxiliary parameters like shielding gas composition, nozzle to plate distance are kept constant. According to 3 factorial rules (L27), 27 experiments are carried out and the output parameters which include transverse shrinkage, angular distortion, deposition efficiency, hardness and tensile strength are observed.

10. WELD BEAD PROFILE

The weld bead profile for MS and SS plate combination by using different input parameters is shown in Fig. 7. There is difference in bead quality due to variation in welding speed and welding current. With increase in welding current the bead obtained is smooth and uniform because of increase in current depth of penetration. The depth of penetration increases with increase in welding speed up to a certain level and then it decreases.

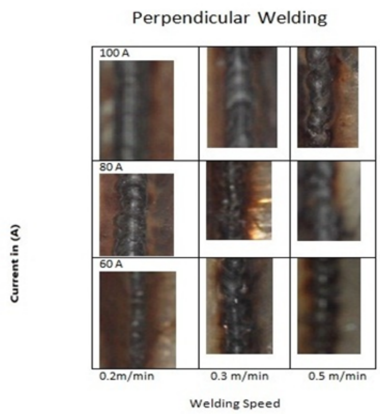

Fig. 7(a).

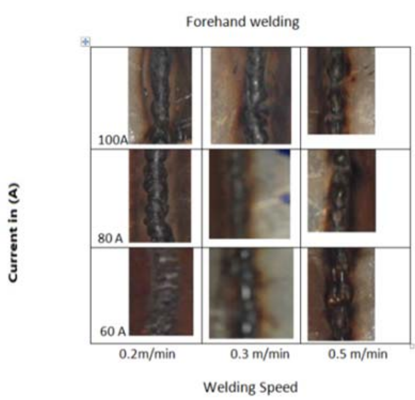

Fig. 7(b).

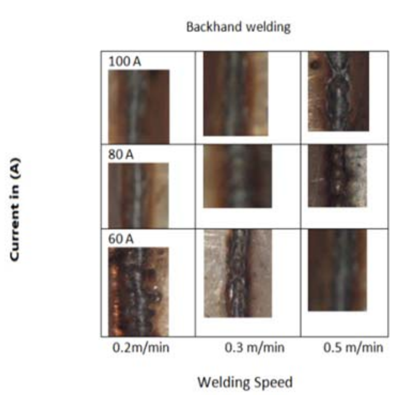

Fig. 7(c).

It is noticed that in Fig. 7 (b) bead quality is little bit inferior than in Fig. 7 (a). It is because of use of forehand welding technique. In forehand welding there occurs no arc preheating, so the depth of penetration decreases.

In Fig. 7 (c), the bead obtained is smooth and uniform in backhand welding due to arc preheating with proper gas shielding in the weld pool, which resulted into more depth of penetration with less reinforcement. Thus, it is concluded that the weld bead quality is better than forehand welding or perpendicular welding.

11. DEPOSITION EFFICIENCY

Deposition efficiency mainly depends on welding speed, feed rate, heat input and shielding gas. It increases with increase in welding speed and keeping the wire feed rate constant. But if welding speed as well as wire feed rate both are increased, then deposition efficiency decreases. It is noticed that in Fig 8 that the deposition efficiency is higher in backhand welding technique at medium current level (80A). It is because of less amount of metal deposition per unit welding time at low current. Moreover, at high current molten metal is not deposited properly and it may flow outside.

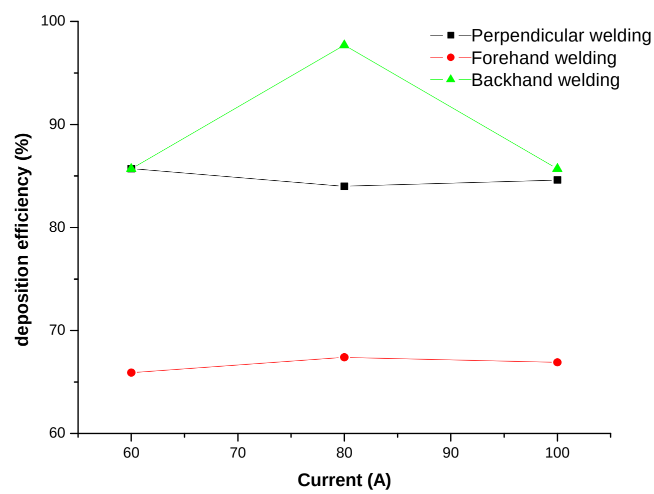

Fig. 8: Variation of deposition efficiency with welding current

12. TRANSVERSE SHRINKAGE

There is very little variation in transverse shrinkage. Generally transverse shrinkage depends on welding speed. If welding speed is slow then high amount of heat energy input is absorbed by the plates during welding. Hence transverse shrinkage decreases by increase in welding speed. Also due to non-uniform heat distribution it varies with time. With increase in number of passes the transverse shrinkage increases. It decreases with increase in wire feed rate and time interval between two successive passes in multi number of passes.

13. ANGULAR DISTORTION

Angular distortion occurs due to non-uniform transverse shrinkage. Both transverse shrinkage and angular distortion are related with heat input to the weld. It is clear from Fig. 9 that angular distortion is higher in forehand welding and lower in backhand and perpendicular welding. At high welding speed, current increases and angular distortion decreases because of high current depth of penetration. An interesting result is observed that in backhand welding, angular distortion also decreases with increase in current. It is because of over diffusion of excess depth of penetration at higher current molten metal.

14. HARDNESS

It is observed in Fig. 10 that maximum plate hardness is low in weld zone. In few plates, the HAZ of MS side hardness is low in comparison to weld zone. It is also noticed that in perpendicular and backhand welding, the welded joints have hardness little bit higher than forehand welded joints.

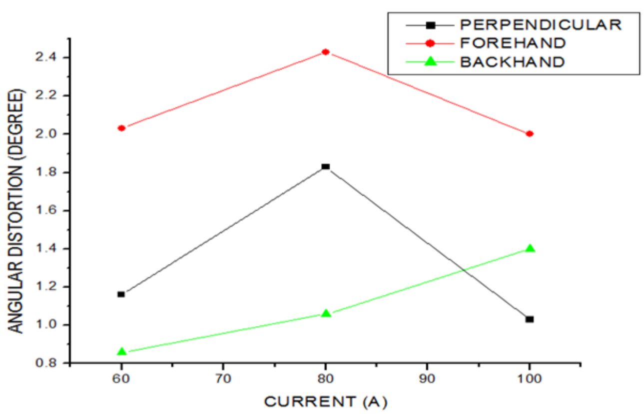

Fig. 9: Variation of angular distortion with current

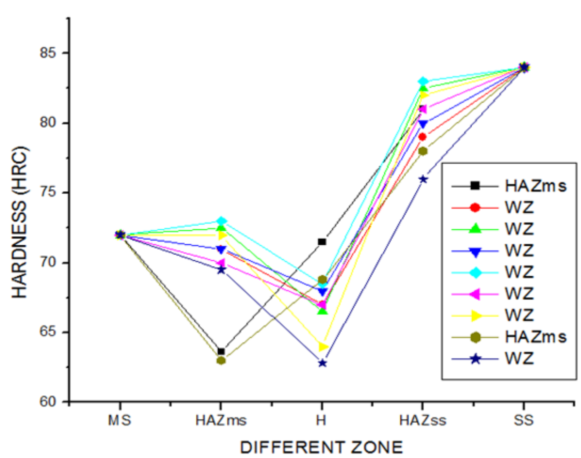

Fig. 10: Variation of hardness in different zone of plates

15. TENSILE STRENGTH

Fig. 11 clearly shows that that tensile strength is higher in backhand welding at medium level of current and lower in forehand welding. It is because of full depth of penetration at backhand welding. It is also observed that tensile strength is higher for high welding speed. Due to uniform high current, metal is highly deposited, and high welding speed heat content is developed in the system. Also the tensile strength is higher in backhand welding due to arc preheating which results in full depth of penetration. Generally, maximum failure occurs in weld bead because it has low hardness and few of them in HAZ of MS side.

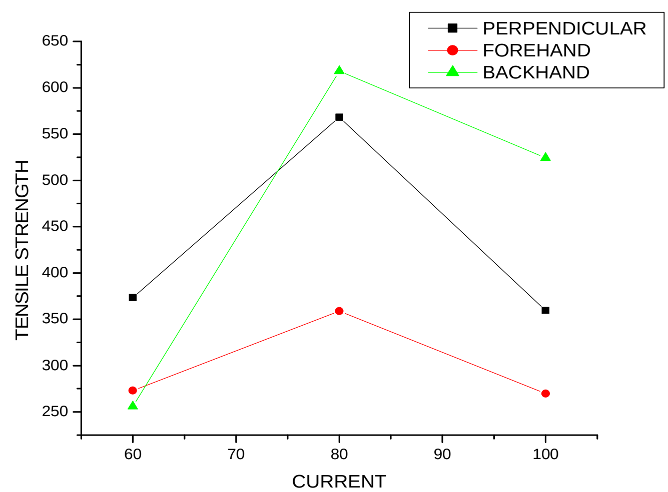

Fig. 11: Variation of Tensile strength with current

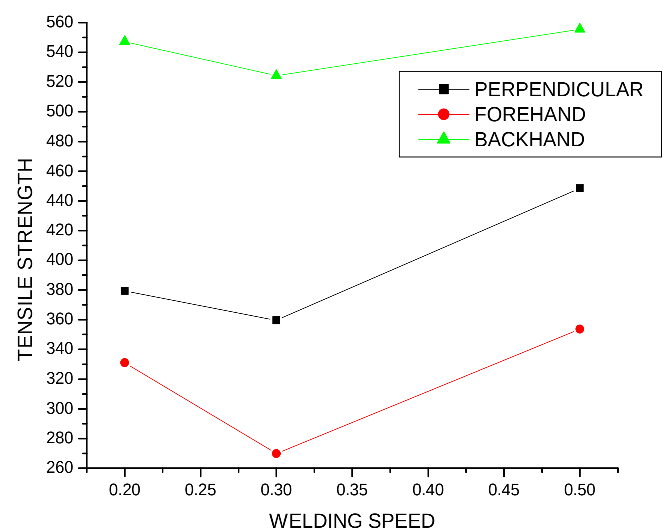

Fig. 12: Variation of Tensile strength with welding speed

16. CONCLUSION

In the experiment, for joining SS with MS the filler wires used are ER 70S6 and ER 309L. However, it is observed that SS filler wire is highly efficient than MS filler wire. It has low transverse shrinkage as the length of the plate is very high. It is analyzed that the deposition efficiency is higher in backhand welding at medium level of current i.e around 80 Ampere. But angular distortion is higher in forehand welding in comparison to backhand and perpendicular welding. It is concluded that hardness is low in weld zone in comparison to HAZ and base metal. In few plates weld zone hardness is higher than HAZ in MS side. Tensile strength is found to be higher in backhand welding. Most of the failures in tensile test take place in the weld zone. Few failurestake places in HAZ of MS side. Generally all the failures are found to be in that zone whose hardness is minimum than other zones. Hence, hardness variation, depth of weld penetration and weld bead profile are found to be prime indicators of joint tensile strength whereas generation of metal spatter with noisy sound results into less deposition efficiency or poor arc stability.

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