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EFFECTS OF JOINT GEOMETRIES ON WELDING OF MILD STEEL BY SHIELDED METAL ARC WELDING (SMAW)

Brajesh Kumar Singh[1], A.K. Jha[2], Pravin K. Singh[3]

[1] M.Tech Scholar, Mechanical Engineering Department, UIT Barkatullah University Bhopal, M.P, India
[2] Chief Scientist , CSIR-Advanced Materials and Processes Research Institute Bhopal, M.P, India
[3] Assistant Professor, Mechanical Engineering Department, UIT Barkatullah University Bhopal, M.P, India

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Abstract: In the present study experimentation on welding were carried out. Effect of the variations in joint designs on the properties of the weldment was studied. Mild steel plates, IS 2062: E250, were taken as sample for the study. The experimental weld metals were aimed at high strength applications and were prepared using the shielded metal arc welding (SMAW) technique. Main objective was to compare the effects of variations in geometry of butt-joint welding on the mechanical properties of mild steel plate. The welding was carried out on different butt-joint designs, such as, square butt-joint, single V-joint, double V-joint and single J-joint, keeping all other process parameters like current, voltage, welding speed etc. as constant. The mechanical test and the microstructural investigation were carried out to analyse the change in mechanical and microstructural behaviour of the weld metal. The results of tests peformed revealed that the Double-V joint was the superior of all other joints, having better mechanical properties than other joints. Single-V was also up to the mark but the more width of HAZ was recorded in this case as compared to others. This increased the chances of weld defects and thus limiting its application areas. Single-J joint on the other hand was also a good option, but the presence of martensite in its microstructures increases its hardness value considerably, inducing the property of brittleness in it and hence limiting its applications too. In case of square joint, it was found that this joint is not suitable for plates having high thickness, as taken in the present study. The study led to the comparative analysis of the results obtained and it enhanced the working knowledge of the welding processes.

Key Words: *SMAW, Butt joints, Mild steel, Mechanical properties, Microstructures*

1. INTRODUCTION

Welding is the permanent joining process of similar or dissimilar metals with or without the application of heat and pressure. Unlike other manufacturing process employed to produce a single component, welding processes are used to assemble different members to yield the desired complex configuration[1]. It is an efficient and economical method for joining of metals. It has made significant impact on the large number of industry by raising their operational efficiency, productivity and service life of the plant and relevant equipment. SMAW occupies the most important position in the group of fusion welding processes, and due to its flexibility and cost effectiveness, it is an indispensable technology for the construction of steel-framed buildings, ship building, motor vehicle manufacture, power plants and other industries[2]. Since the SMAW method is so versatile; it is the most suitable method to work with even in the most awkward situations

1.1 Butt Joints:

A Butt joint is used to join two members aligned in the same plane. This joint is frequently used in plates, sheet metal, and pipe work where high strength is required. They are reliable and can withstand stress better than any other type of weld joint[3].

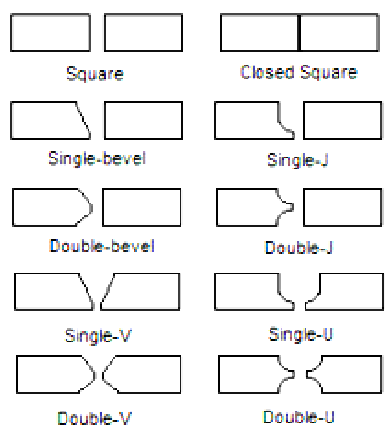

Fig. 1: Butt joint geometry[4]

1.2 Metallurgy In Welding:

Metal is heated over a range of temperature up to fusion and followed by cooling to ambient temperature. Because of differential heating, the material far away from the weld bead will be simply warmed out, but as the weld area is approached, progressively higher temperatures are obtained, resulting in a corresponding complex microstructure [5]. The heating and cooling also results in setting up internal stresses and plastic strain in the weld. So at high temperatures physical, chemical and metallurgical properties are liable to change.

2. EXPERIMENTAL PROCEDURE

2.1 Parent Metal

The Mild Steel specimen of standard (IS2062: E250) was taken as the base material for welding. IS2062 is an Indian Standard covers the requirement of steel. It is easily available and commonly used materials for welding and fabrication in industry. The chemical compositions of the base material [7], based on material data sheets, are shown in tables 1.

Table 1: Chemical compositions of IS2062: E250

Sr No.	ELEMENTS	Wt %
1	CARBON	0.23
2	MANGANESE	1.50 max.
3	SILICON	0.40
4	SULPHUR	0.045
5	PHOSPHORUS	0.045
6	IRON	REMAINDER

The parent metal possesses a tensile strength: 410 MPa, yield strength: 200 MPa and elongation: 23%.

2.2 Filler Metal

The filler metal of specification AWS-6013 was used in this study. It is a low carbon steel electrode with high titanium and can be used on AC or DC and is suitable for all positions. Its arc is smooth and quite stable and the striking and the re-striking properties are good. It is an all-purpose welding rod with good penetration and fast deposition rates. The chemical compositions of AWS-6013 are shown in table-2.

Table 2: Chemical composition of AWS-6013

ELEMENTS	Wt %
CARBON	0.06
PHOSPHORUS	0.012
MANGNESE	0.32
SILICON	0.23
SULPHUR	0.013
IRON	REMAINDER

2.3 Welding Procedure

Plates of dimensions (250 × 125 × 15) mm were cut from a large sheet of the mild steel and finished by machining. In order to perform welding operation the finished plates were again cut transversally into equal halves of (125×125×15) mm for groove preparation as required in the present study. Before welding, the plates' surfaces were cleaned, thoroughly using both chemical and mechanical processes. This was done to remove any types of contaminations, which may results from oil, grease, corrosive products etc. to obtain a good quality weld [8]. The power source used for welding was a Rectifier type air-cooled welding machine of model Adore Arc 601. During welding m/c was set at a range of, Current: (100-110) A and Voltage: (80-100) V. The welding rod used was of mild steel having length: 350mm and diameter: 3.15mm for filling the groove and 2.5mm for weld take.

Table 3: Detailed welding descriptions

Joint shape	G	B in mm	A	N	D (cm)	S	V mm^3
Square butt	2	3	30	2	10.4	9.03	90
Single-V	3	6	45	12	10.4	13.95	270
Double-V	3	4.5	45	10	10.4	11.17	203
Single-J	3	4	45	10	10.4	13.5	180

Here,
'G' is root gap in mm, 'B' is weld width in mm, 'A' is approx. Gap to thickness (t=15mm) area in mm^2, 'N' is no. of passes required for welding, 'D' is weld distance in cm, 'S' is the average welding speed in cm/min., and 'V' is approx. weld metal Volume for given weld width (B).

2.4 Sample Preparation

The samples for tensile, impact and hardness tests were prepared of the strips, cut from the welded plate followed by machining them according to the ASTM standards. The samples for hardness test were firstly used for the metallographic examination by polishing them to produce mirror like and ridge free surface. The polished samples were etched with 2% nital agent and finally dried by using air blower. After the metallographic tests, same samples were used for hardness testing.

3. MECHANICAL TESTING

3.1 Tensile Test

The welded samples were tested for tensile strength using an universal testing machine (Model-8801) make-INSTRON, UK. The load was applied at a rate of 0.50000 mm/sec, uniaxially along the axis of the specimens until fracture. This was used in determining the strength and stiffness of the materials.

3.2 Charpy Impact Test

Charpy V-notch testing was used to measure the impact energy which is sometimes also termed the notch toughness of the welded samples. For Charpy testing, High Energy Impact Tester (Model-600 MPX) make-INSTRON was used having maximum capacity of 600 J.

3.3 Hardness Test

The hardness value is a measure of the weld metal's resistance to localized plastic deformation or the resistance of a material to any scratch or indentation. Hardness testing was conducted according to Brinell hardness test method using load step of HBW 5/250. Hardness of samples were tested starting in the weld bead followed by proceeding in the both leftward and rightward, of the weld bead across the section in 2 mm steps.

3.4 Metallographic Examination

Analysis of the microstructures of welded samples was done using Optical microscopy and Scanning Electron Microscope. The structural changes in parent zone, weld metal zone and HAZ region were analyzed at different magnifications.

3.5 Simulation Of Tensile Test

The simulation of tensile specimen were done to show the stress distribution in tensile testing. The model were prepared on ANSYS workbench [10]. The dimensions of model samples were same as of experimental tensile specimen.

4. RESULTS AND DISCUSSION

4.1 Tensile Test

The graphs obtained during tensile tests of each joint were merged in Plot (Fig.2) to visualise their variations.

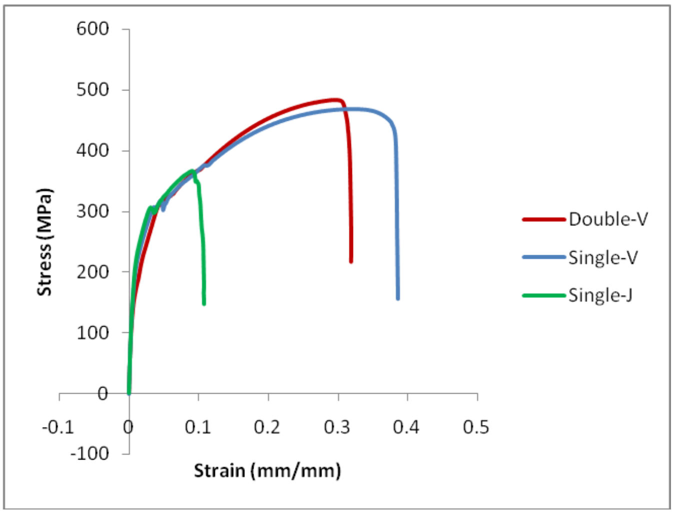

Fig. 2: Stress-Strain curve of weld joints

According to the tensile test results shown in the Fig. 2 Double-V joint has maximum ultimate tensile strength of 482.73MPa followed by Single-V and Single-J joints having values of 469.01MPa and 365.90MPa respectively.

4.2 Impact Testing

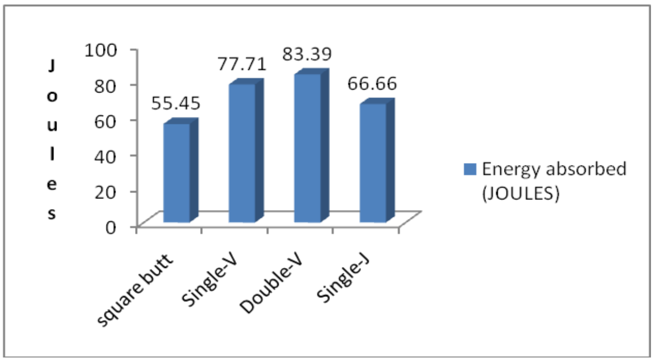

Fig. 3: Toughness comparisons of weld joints

The energy absorbed in breaking the test samples were measured in Joules. The results obtained is shown in Fig. 3, it is evident that the impact strength of the Double-V joint was maximum with a value of 83.39 J, while the downtrend in the impact strength was followed by Single-V, Single-J and Square butt joint respectively. This is a measure of toughness of the materials.

4.3 Hardness Test

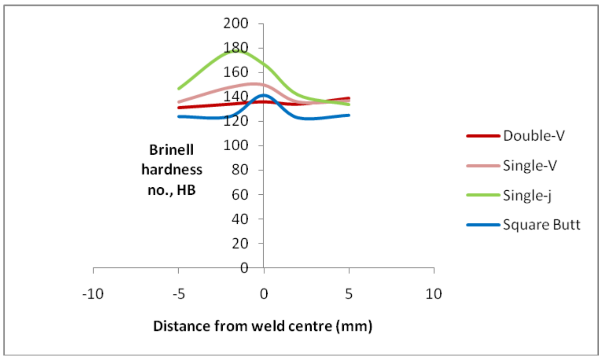

Fig.4: Hardness profile comparisons of weld joint

Figure 4 reveals that the hardness profile of single-j joint is superior to all other weld joints. The decreasing trend in the hardness profile is followed by single-v, double-v, and square butt weld joints respectively. But in all joints the maximum hardness values were measured in the area of fusion zone and heat affected zone (HAZ). The variation in hardness across the weld can be attributed to several factors, mainly to residual stresses just after welding. However, other factors like grain size, phase composition and metallic inclusion can also contribute to this hardening.

4.4 Metallographic Test Results

To analyse the microstructural changes after welding, the microstructures of fusion zone, HAZ, and base metal (BM) were observed using Light optical microscope (LOM) and Scanning electron microscope (SEM) with magnification of 200×.

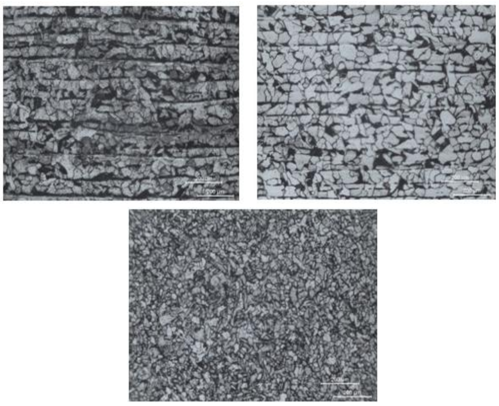

Fig.5 Microstructure of double-v joint weld

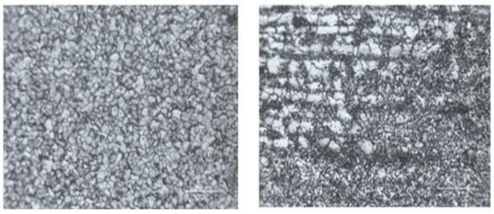

Fig.6: Microstructure of single-v joint weld

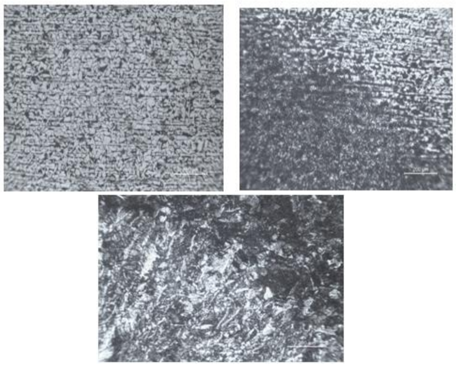

Fig.7: Microstructure of square butt weld

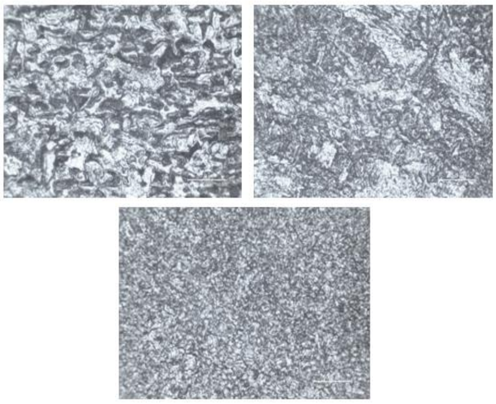

Fig.8 Microstructure of single-j joint weld

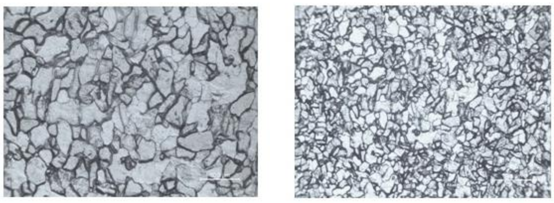

Fig.9 Microstructure of as-received metal

Micrographs (Fig.5) clearly reveal that the metal is the rolled product and consists of pearlite colonies (dark contrast) at grain boundaries edges and corners and ferrite grains (light contrast), a characteristics of mild steel[6]. Figures 6, 7, 8 & 9 show the microstructures of regions across the weld i.e. fusion zone, HAZ, and base metal. The variations in the structures and grain sizes were mainly due to directional heat flow from the fusion line (Fig.7). The coarse grained region of the HAZ is adjacent to the fusion zone and contains grains larger than those in the base metal, while in the weld metal zone the grains are finer[9] Fig.8. The irregularities observed in the pattern of microstructure for different weld joints was solely due to the level of diffusion take place during welding, which is the results of variation in groove designs. Figure 10 shows the micrograph of double-v joint weldment. Interface is also evident in fig.10.

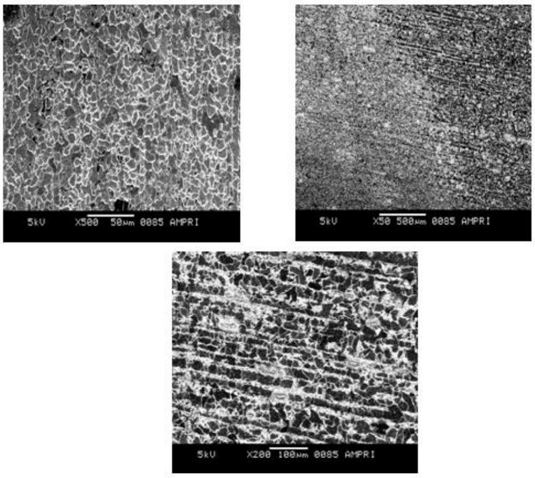

Fig.10 SEM micrographs of double-v joint weld

4.5 Stress Distribution Diagram

It was a 3-D finite element model, composed of solid elements.

Table 4: Details of material property

Sr. No	Material Property	Parent Metal	Filler Metal
1	Density	7.85 g/cc^3	7.87 g/cc^3
2	Young's Modulus	200 MPa	205 MPa
3	Poisson's Ratio	0.29	0.29
4	Tensile Strength	410 MPa	470 MPa

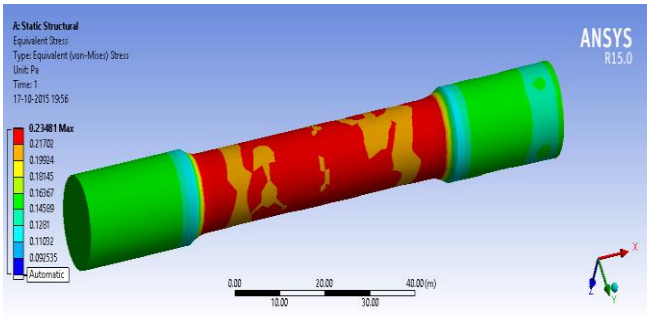

Fig.11 Stress distribution diagram of square butt joint weld

The weldament and the HAZ in gauge length of finite element model were highly stressed region [11]. These were shown by red colours in fig.11.

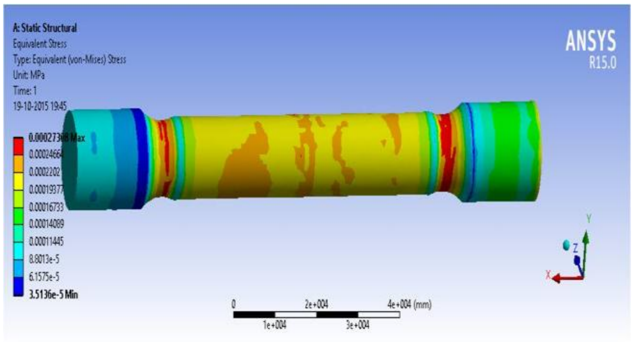

Fig.12 Stress distribution diagram of Double-V joint weld

In case of simulation of double-V joint tensile test, it was found that the result was much away from that of experimental one. The portion of fillets instead of the gauge length, were highly stressed (see fig.12). This is because of the flaws in finite element modelling, which results as the groove was not axisymmetric. While in case of square butt joint model, the groove was axisymmetric.

5. CONCLUSIONS

Following conclusions may be drawn from this study:

- The tensile strength and toughness of Double-V joint is superior to other joint geometries. While its hardness value is comparatively low. This is because of the presence of ferrite and pearlite in the microstructures of the weld zone.
- The hardness value is maximum in case of Single-J joint and its toughness and tensile strength are comparatively low. This is because of the traces of martensite and bainite found in the WZ of this joint, which results from the rapid cooling of the weld metal. This rapid cooling was not done intentionally in this case, it happened of its own due to its unique groove design.
- The limitation to this study was that the square butt joint was inferior in every aspects but the detailed analysis suggested that this inferiority is mainly because of the poor root gap available for proper penetration. And this is due to the excess thickness of the plates chosen for the present work.
- Highest volume of weld metal was deposited in the Single-V joint followed by Double-V, Single-J and the least volume in the square butt joint. This difference in weld metal volume is because of the variation in groove design of the joints. High volume of the weld metal increases the weld width and so HAZ width, and thus increases the chance of weld defects.

- In the context of the present study, Double-V weld joint was superior and the best choice to go for.
- The simulation results was solely dependent on the accuracy of finite element modelling. In the present study the model for each weld design was difficult to generate due to their unsymmetric nature of grooves.
- The simulation results of square butt joint was in agreement with the experimental results.

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