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Effect of Groove Design on the Mechanical Properties of Shielded Metal Arc Welded Joints

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Abstract

Objective: To investigate the effects of groove angle on tensile and impact strength of the joints. **Methods:** To achieve above objective various groove designs having included angle of 50°, 60° and 70° were prepared using a shaper. The weld grooves were completely filled using shielded metal arc welding process. All the weld joints were subjected to visual inspection, dye penetration test and radiographic test. Then tensile and impact specimens were removed from these joints. The tensile and impact specimens were machined in accordance with ASTM E8M-09 and ASTM E23-12C specifications. The tensile and impact strength was evaluated using universal testing machine. **Findings:** The tensile strength of the specimen having groove angle as 50° is 513.68 MPa which is more than that of the specimen having 60° and 70° groove angle. The tensile strength of base material used is 540 MPa. It is clear that the tensile of the joint is less than base material used. The joint efficiency obtained is 95.12% which is the highest compared with other joint i.e. 60° and 70°. It is further observed maximum impact strength achieved is 53.45 Joule at 50° groove angle. The tensile and impact strength provided by the joint having groove angle as 70° is 471.29 MPa and 39.15 J respectively which is minimum amongst all the joints produced.It can be concluded that 50° groove angle is the best groove design. Moreover less number of welding electrodes is required to fill this joint compared with 60° or 70° groove angle. Hence it is more economical also. **Application:** This research is useful for industries which are engaged in fabrication work for designing of correct and economical welding grooves.

Keywords: Groove Design, Impact Strength, Radiography, Shielded Metal Arc Welding, Tensile Strength

1. Introduction

Welding is widely accepted all over the world for its leak proof joining. After the invention of electric arc, shielded metal arc welding process was applied for joining of various materials. Shielded Metal Arc Welding (SMAW) is a process of joining metals by heating them with the help of an electric arc generated between work piece and coated electrode[1]. Electrode is coated with flux having minerals to provide shielding to the molten pool from bad effects of atmosphere[2]. The flux coated electrode having many functions such as it provides shielding; add alloying elements to the weld metal and direct arc heat.

When electrode moves along the metal the metallic part of electrode interact with the metal and molten bead formation took place[3]. The molten slag is floating on weld pool and prevent it from surrounding environment until it gets solidify after cooling the flux converted into solid slag. The solidified slag is removed with the help of chipping hammer after welding. In this research electrode

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positive i.e. reverse polarity was maintained[4]. The power in a welding circuit is measured in voltage and current. Current is a more practical measure of the power in a weld circuit and is measured in amperes (Amps).

The voltage is governed by the arc length between the electrode and the work piece and is influenced by electrode diameter[5]. For butt joint a weld groove is required which is generally prepared by machining. The weld groove should be designed in such a way that weld joint produced should have required load carrying capacity at the same time have minimum volume. In this research various groove angles were produced and their effect on tensile and impact strength of the joint was investigated.

2. Materials and Methods

2.1 Methodology

The methodology adopted in this research work is given below:

2.1.1 Selection of Material

Mild steel plates having size of 300x125x10 mm^3 and grade IS2062 (E410) were selected as a base material because this material is widely used for engineering applications in the industries. Mild steel has excellent weldability hence widely used for structural and fabrication work. The chemical and mechanical properties of base material used have been presented in Table 1 and 2 respectively.

2.1.2 Selection and Preparation of Weld Groove

Selection and preparation of a weld groove is an important step in the fabrication of a weldment. Selection of a correct joint design of welded member leads to perform within load service, corrosive atmosphere and safely. The weld joint should have required load carrying capacity and good surface finish. It should be designed in such a way that will produce minimum distortion and residual stresses in the weldment as well as it should be economical also[6]. Based on the thickness of base plate 50°, 60° and 70° groove angles were selected.

Both the ends of work piece were beveled to achieve required included angle of the joints. The shaper used for producing weld groove is shown in Figure 1(a). The plates after beveling the edges have been presented in Figure 1(b).

Table 1. Chemical properties of base material

Element	%
carbon	0.20
manganese	1.60
sulphur	0.045
phosphorous	0.045
silicon	0.45

Table 2. Mechanical properties of base material

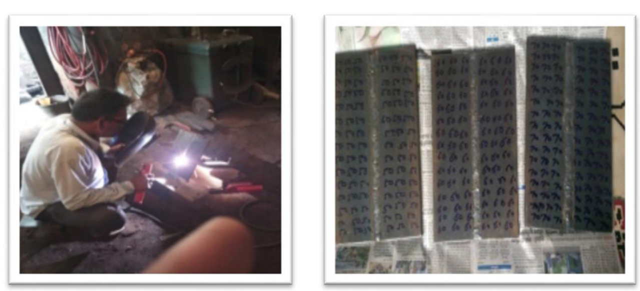
Tensile strength	Yield strength	Elongation (Min.)
540Mpa	410Mpa	20%

2.1.3 Welding Procedure

The weld joints were welded using shielded metal arc welding process. The DC rectifier manufactured by ESAB India having current rating 450 ampere at 60% duty cycle was used as a power source in this experimentation. The specifications of power source have been indicated in Table 3. The welding power source used has been shown in Figure 2(a). The welded joints have been shown in Figure 2(b). The welding electrode used was E6013 having size of 3.15 mm. This electrode was selected as it has matching properties with the base metal and can be used in any position. The mechanical and chemical properties of electrode used have been shown in Table 4 and Table 5 respectively. Welding parameters used have been indi-

(a) (b)

Figure 1. Groove preparation setup.



(a) (b)

Figure 2. Welding setup used and welded test plates.

cated in Table 6. The groove was filled using three passes i.e. root pass (pass 1), hot pass (pass 2) and capping pass (pass 3) as shown in Figure 3.

2.1.4 Visual Inspection of Weld Joints

The visual inspection of test plates was carried out. No visual defect in the weld was observed. No under-cuts, surface blow holes, surface porosity were observed. Evenly distributed ripples and good surface finish was obtained. Overall appearance of welds was good.

2.1.5 Liquid Dye Penetration Test

After visual inspection of weldments, dye penetrate test was performed. Dwell time used here was 30 minutes.

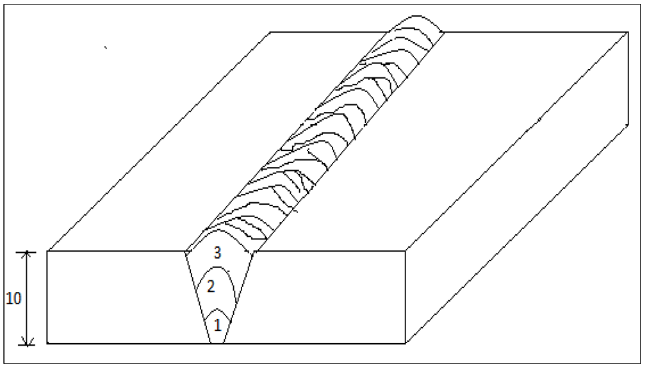


Figure 3. Shows root pass, hot pass and capping pass.

Table 3. Specifications of power Source

Make	ESSAB India
Maximum current capacity	450 Amperes
Duty cycle	60%
Cooling	Air cooled
Output current	DC

Table 4. Mechanical properties of electrodes used

AWS Specification	E6013
Tensile strength	470Mpa
Yield strength	410Mpa
Elongation	28%

Table 5. Chemical compositions of electrodes used

Carbon	0.08
Manganese	0.45
Silicon	0.18
Phosphorous	0.012
Sulphur	0.009

Table 6. Welding parameters used for different passes

Pass No.	Size of electrode used	Current used (Amp)
Root Pass_1	3.15 mm	90
Hot Pass_2	3.15 mm	100
Capping Pass_3	3.15 mm	110

After removing the dye reentrant, a developer was applied with the help of a brush. No surface crack or porosity was detected during this test.

2.1.6 Radiographic Test

All the three sets of plates were subjected to radiographic test. The radiographic test i.e. x-ray test was performed at Testing Research Engineering Technological Services (TREATS) situated at Jamshedpur. All the test plates cleared the x-rays test. The radiographs of the test plates have been shown in Figure 4 to 6.

2.1.7 Removing Specimen for Tensile Test

Two samples for tensile test were parted out from each set of plate. First of all, 20 mm of material are parted out from

Figure 4. X-ray plate 5.

Figure 5. X-ray plate 6.

Figure 6. X-ray plate 7.

both edges (perpendicular to weld joint) of plates and discarded to vanish the effect of possible defective weld at the starting and end points of the weld joints. After that two tensile test samples from each plate were sliced using a band saw shown in Figure 7(a). The removed test specimen for tensile test has been shown in Figure 7(b).

2.1.8 Preparation of Tensile Specimen

The sliced tensile specimens were machined as per ASTM E8M-09 specifications. All the surfaces of samples were grinded, polished and prepared as per the requirements mentioned in the reference standard ASTM E8M-09. Figure 8 below shows the tensile test samples.

(a) (b)

Figure 7. Tensile and Charpy test samples parting setup.

Figure 8. Tensile test samples.

2.1.9 Tensile Testing of the Samples

The tensile tests were carried out at Tata Cummins Limited (Jamshedpur). After marking the gauge length as 50 mm (as per reference standard), all the samples got ready for the tensile tests. Tensile test was conducted on CNC machine model Shimadzu/AG-G-250KN which is having capacity 250 kN for tensile load. Figure 10 shows the CNC control and machine setup for the tensile tests. The results of tensile test have been presented in Table 7-9.

2.1.10 Removing Specimen for Charpy Test

Two samples for Charpy test were parted off from each plate perpendicular to weld joint. The removed test specimens for Charpy test have been shown in Figure 9(b).

Table 7. Tensile strength obtained

Samples ID↓	Ultimate tensile stress (MPa)	Average Ultimate tensile stress (MPa)
5A(50°)	509.461	513.6805
5B(50°)	517.9	
6A(60°)	493.555	487.2875
6B(60°)	481.02	
7A(70°)	475.25	471.29
7B(70°)	467.33	

Table 8. Yield strength obtained

Samples ID↓	Yield stress (MPa)	Average Yield stress (MPa)
5A(50°)	420.174	422.5215
5B(50°)	424.869	
6A(60°)	394.728	404.3215
6B(60°)	413.915	
7A(70°)	398.491	387.54
7B(70°)	376.589	

Table 9. Percentage elongation obtained

Samples ID↓	% elongation	Average % elongation
5A(50°)	17.000	17.4
5B(50°)	17.800	
6A(60°)	12.200	12.2
6B(60°)	12.200	
7A(70°)	10.100	10.2
7B(70°)	10.300	

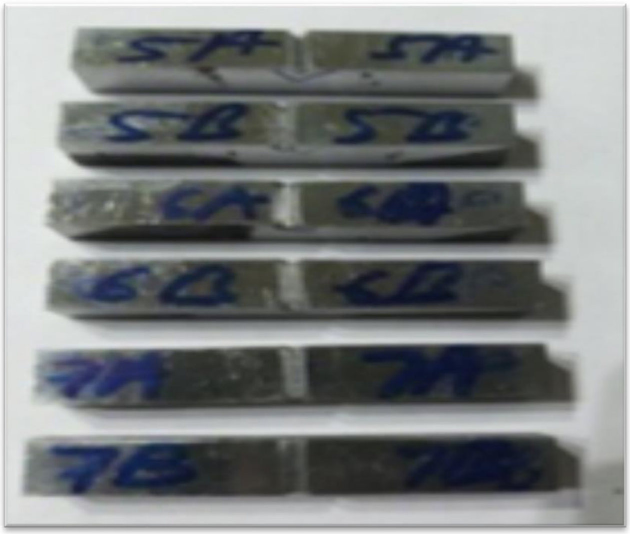


Figure 9. Charpy test samples.

2.1.11 Preparation of Charpy Specimen

After slicing, Charpy specimens were machined using shaper and surface grinder. The Charpy samples were prepared as per ASTM E23-12C. All the surfaces of samples were grinded, polished and prepared as per the requirements mentioned in the ASTM reference standard ASTM E23-12C. Figure 10 shows the machined Charpy test specimens.

2.1.12 Charpy Testing of the Samples

The Charpy samples were tested for their impact energy absorption on machine FIT-300-ASTM-EN D installed at Jamshedpur Metal Treat Limited (Jamshedpur unit). Figure 11 (a) shows the machine setup used for the Charpy tests and Figure 11 (b) shows broken Charpy samples. The results of Charpy test have been presented in Table 10.

2.1.13 Results and Discussions

All the test plates were subjected to visual inspection, dye penetration test and radiographic test before cutting for tensile and impact specimens. Tensile and impact strength of the weld joints were evaluated. The results obtained are being discussed below.

Figure 10. Tensile testing setup: CNC machine model Shimadzu/AG-G-250KN.

(a) (b)

Figure 11. (a) Impact test setup used, and (b) Samples after breaking.

Table 10. Effect of groove angle on impact strength

Charpy test results		
Samples ID↓	Breaking energy (Joule)	Average Breaking energy (Joule)
5A(50°)	52.510	53.455
5B(50°)	54.400	
6A(60°)	46.500	46.85
6B(60°)	47.200	
7A(70°)	40.200	39.15
7B(70°)	38.100	

2.2 Visual Inspection

No surface defects such as surface cracks, surface porosity, blow holes, under cuts, overlap was detected. Regular beads with evenly distributed ripples were obtained. Top surface of the welds was smooth and surface finish was good. No distortion in transverse direction of weld was observed as the test plates were held in a fixture designed for this purpose.

2.3 Dye Penetration

No surface cracks or under cuts were revealed by dye penetration test. No porosity or surface blow holes or any surface defect was detected by dye penetration test in any of the plate. All the test plates cleared dye penetration test. The dwell time used was 30 minutes.

2.4 Radiographic Test (X-rays test)

The radiographs of the weld plates having groove angle 50° and 70° reveal some porosity at some isolated locations. The test specimens meant for tensile and impact test were sliced from weld area having no porosity. Under cut in the plate having 60° was also detected. Minor slag inclusion was indicated by the radiograph of test plate having weld groove 50° at central location which is due to improper cleaning after deposition of root pass.

2.5 Effect of Groove Angle on Tensile Strength, Yield Strength and Elongation

2.5.1 Tensile Strength with 50° Groove Angle

Table 7 and Figure 12, it is observed that the average tensile strength of the specimen (5A&5B) having groove angle as 50° is 513.68 MPa which is more than the specimen having 60° and 70° groove angle. The tensile strength of base material used is 540 MPa. It is clear that the tensile of the joint is less than base material used. The joint efficiency obtained is 95.12% which is the highest compared with other joint i.e. 60° and 70°. The reason for highest efficiency may be due to less internal stresses induced in the weld metal as the volume of groove is less compared with the groove volume having included angle as 60° and 70°[7-8]. Larger the included angles of weld groove have larger volume and larger volume of filler metal is required to fill it. Larger is amount of molten causes more expansion and contraction resulting more induced internal stresses. Another reason for higher tensile strength at 50° groove angle may due to formation of inter metallic compound with concentration heat in small groove angle[9].

2.5.2 Tensile Strength with 60° Groove Angle

Table 7 and Figure 12, it is observed that the average tensile strength of the specimen (6A&6B) having groove angle as 60° is 487.287MPa which is less than the specimen having 50° and more than 70° groove angle. The tensile strength of base material used is 540 MPa. It clear that the tensile of the joint is less than base material used. The joint efficiency obtained is 90.24% which is the less compared with 50° specimen and more than specimen with groove angle 70°. The reason may be due to more internal stresses induced in the weld metal as compared with groove having 50°as included angle. Moreover, the groove is completely filled with three passes and more heat is required for increasing melting rate of the electrode[10]. More heat input causes slow cooling rate leading coarse grains. Formation of coarse grains may result in decreased tensile strength. Table 7 and Figure 12, it is observed that the average tensile strength of the specimen (7A&7B) having groove angle as 70° is 471.29 MPa which is lesser than specimen having 50°and 60° groove angles. As mentioned previously that the tensile strength of base material used is 540 MPa.

It is clear that the tensile of the joint is less than base material used. The reasons for decrease in tensile strength have already been explained in above paragraph.

2.6 Effect of Groove Angle on Yield Strength

Table 8 it is observed that yield strength of the joints having groove angles of 50°, 60° and 70° is 422.52, 404.32 and 387.54 MPa respectively. The yield strength obtained at different groove angles have been presented in Figure 13 in the form of a bar chart for easy understanding and interpretation. It is very clear from the figure that yields strength linearly decreasing with increase in groove angle. The reasons for decrease in yield strength may be increase in developed internal stresses during welding. As groove angle increases, the volume of groove also increases. With increase in groove volume filler material required also increases. Increased

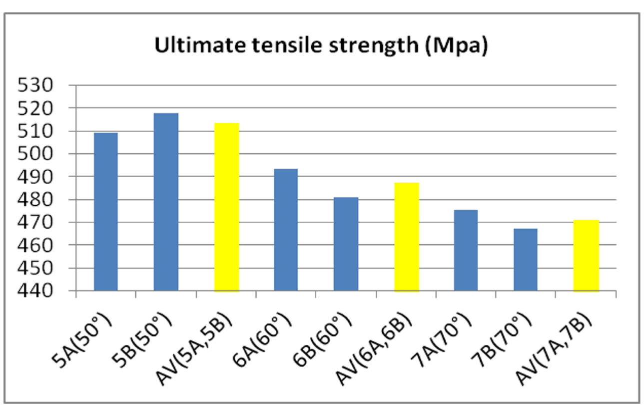


Figure 12. Tensile strength at different groove angles.

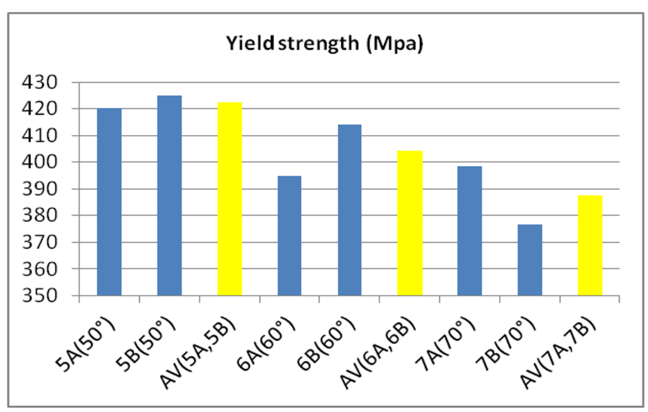


Figure 13. Effect of groove angle on yield strength.

volume of molten metal in the groove produced more internal stresses in the joint as a result yield strength decrease. Another reason may be increased heat input. Melting rate of electrode is required to be increased for filling larger groove[11]. Increased heat input leads to slow cooling rate as a result coarse grain. Coarse grains are responsible for decrease in yield strength.

2.7 Effect of Groove Angle on Percent Elongation

Table 9 indicates the percentage of elongation achieved at groove of 50°, 60° and 70° groove angles. The same data has been presented in Figure 14 in the form of a bar chart for easy understanding. The maximum elongation achieved is 17.7 at 50° groove angle. As the groove is increased to 60°and 70°, percentage elongation decreased to 12.2% and 10.2% respectively. It is very clear from the table and bar chart that elongation linearly decreases with increase in groove angle.

The reason behind this is the heat input has to be increased to fill increased volume of weld groove. For this purpose, melting rate of electrode is required to be increased[12]. With increase in heat input per unit length of weld, cooling rate decreases as a result coarse grains in weld metal are formed. The coarse grains in weld metal are responsible for decreasing percentage elongation.

2.8 The Effect of Groove Angle on Impact Strength

The impact strength of weld joints obtained at different groove angles have been recorded in Table 10. The same information has been present in Figure 15 in bar chart for better understanding. It has been observed maximum impact strength achieved is 53.45 Joule at 50° groove angle. It is further observed that impact strength decreases with increase in groove angle. The minimum impact strength obtained is 39.15 Joules at 70° groove angle. The reason behind decrease in impact strength with increase in groove angle is that groove volume increases. To fill increased groove volume melting rate of the electrode is required to be increased. To increase melting rate of the electrode heat input is increased. Due to increased heat input cooling rate of weld metal decreases. Slow cooling rate results in coarse grains which are responsible for decrease in impact strength of the joint.

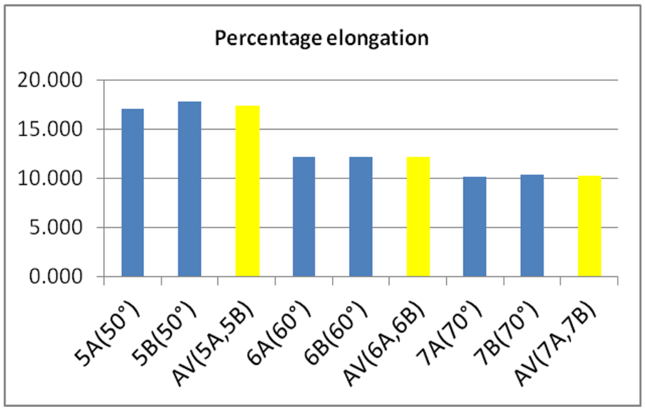


Figure 14. Effect of groove angle on percentage elongation.

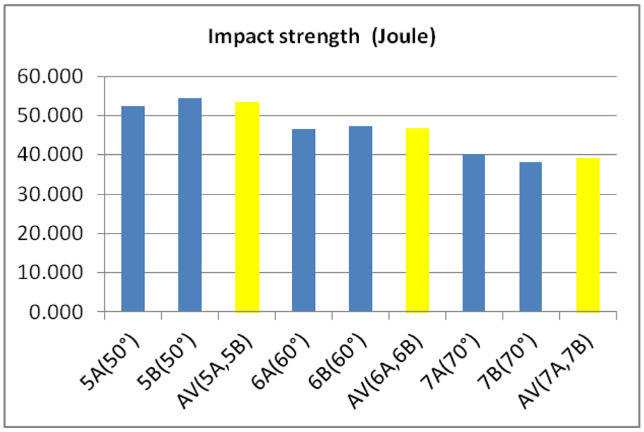


Figure 15. Effect of groove angle on impact strength.

3. Conclusions

1. The tensile strength decreases linearly with increase in groove angle.
2. The maximum tensile obtained is 513.68 MPa at 50° groove angle.
3. The minimum tensile achieved is 471.29 MPa at 70° groove angle.
4. Maximum percentage elongation i.e. 17.4% is obtained at 50° groove angle.
5. Minimum percentage elongation i.e. 10.2 % is obtained at 70° groove angle which is the lowest.
6. Impact strength decreases with increase in groove angle.
7. The maximum impact strength of 53.455 Joules was achieved at 50° groove angle.
8. The minimum impact strength of 39.15 Joules was achieved at 70° groove angle.
9. The best groove angle obtained is 50°.

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