Fluidity and Weld Bead Characteristics of Al-Si-Cu Alloy Prepared by Mig Welding

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ABSTRACT: *This paper highlights the effects of fluidity and joint design on the weld bead characteristics of Al-alloy. The fluidity was largely affected by the both type of the alloy and joint design. The mechanical properties were greatly influenced by the type of the alloy and moderately by the joint design. The microstructures of narrow joint designs exhibit the breakup and/or redistribution of the primary Si particulates.*

Keywords: *Fluidity, weld bead, Al-Si-Cu alloy, MIG welding.*

1. INTRODUCTION

The intensive demand for Al and its alloys arises chiefly from their attractive physical, mechanical and chemical properties. Al and its alloys have certain welding characteristics, which need some special attention during welding when compared to other metals and alloys. The first and the foremost consideration is the effect of the thin film of oxide which is always present on the surface of Al. This thin film contains moisture which may react during fusion welding, with the liquid metal in the weld pool, to form oxide and to liberate hydrogen which can cause porosity [1, 2]. The oxide layer needs to be removed from the aluminium immediately before welding. A stainless steel wire brush is sufficient to remove the oxide and leave a clean surface. The edges of the aluminuim should be cleaned with a file.

Aluminium, being a very good conductor of heat, dissipates heat at a very fast rate from the joint being welded to the adjacent base metal. Fast heat removal rate affects the fluidity characteristics particularly in the narrow joints [3, 4]. Al has got high coefficient of linear expansion [5]. Unless some precautions are taken the welding heat causes distortion and bulking.

In case of Al-alloys, at the solidus, both strength and ductility are low, so that when welded under restraint the metal is likely to crack. Cracks may develop either in the weld metal due to its low strength around the solidus of the freezing pool or in the overhead zone of the parent metal due to fusion of low melting point constituents. The joint filling capability and metallurgical behavior are therefore, essential as they not only help in the selection of appropriate welding procedure, but also minimize weld rejections.

An investigation has been carried out to study the effect of alloy composition and joint design on the fluidity, mechanical and microstructural characteristics of weld beads made by the MIG welding.

2. EXPERIMENTAL PROCEDURE

The composition of Al-alloys used in the present investigation is given in the Table 1. A strip fluidity testing mould of cast iron, whose design and dimensions are shown in Figure 1, was used for determining the fluidity of Al-alloys. The strip fluidity test measures the ability of alloy to fill a joint of different cross sections and thus provide wider specifications of actual welding conditions. The butt-welded joints of Al-alloys were prepared using MIG welding process. An electric arc was struck between Al-alloy continuously fed electrode (+) pulled from a spool by a wire-feeding mechanism and the job (-). A shielding gas of 100% argon was used to protect the weld pool. Figure 2 and Table 2 gives the details of the design of joints. 1.6 mm dia electrode with a composition given in Table 3 was employed. The machine settings are given in Table 4. The welding gun was brought to within about 25 mm of the work, with the electrode protruding about 13mm beyond the cup. The trigger was then pulled to close the power supply contacts and energies the wire and open the shielding and water solenoids. The arc was struck by scratching the electrode against the work.

Table 1
The Compositions of the Alloys

Alloy	*%Cu*	*%Si*	*%Fe*	*%Mg*	*%Zn*	*%Mn*	*%Al*
1	3.5	6.0	—	0.002	0.013	0.003	Rest
2	3.5	6.0	0.25	0.002	0.013	0.003	Rest

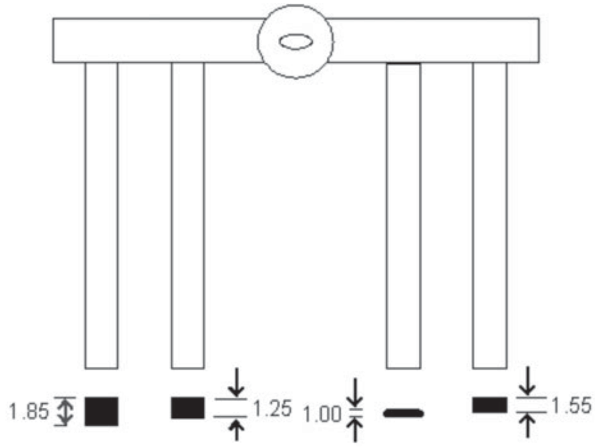

Figure 1: Strip Fluidity Test Mould

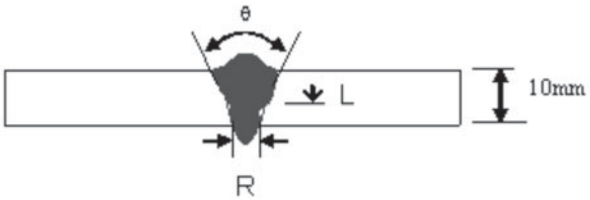

Figure 2: Weld bead

Table 2
Design of Joints

Joint	*R, mm*	*L, mm*	θ, *Degrees*
Joint-1	0.5	4.0	60
Joint-2	0.5	2.0	45
Joint-3	1.0	4.0	60
Joint-4	1.0	2.0	45
Joint-5	2.0	4.0	60
Joint-6	2.0	2.0	45

Table 3
The Chemical Composition of Electrode

%Cu	*%Si*	*%Mg*	*%Fe*	*%Ti*	*%Mn*	*%Zn*	*%Al*
0.30	4.50	0.05	0.80	0.20	0.05	0.10	rest

Table 4
Machine Settings

Current (DCRP), Amp	*Voltage*	*Argon flow rate, lpm*	*Welding speed, cm/min*
250	28	25	50

After the arc struck, the end of the gas cup was held approximately 19 mm from the work. A 10^0 forehand angle of the electrode relative to the work was maintained during welding. The samples of weld beads are shown in Figure 3.

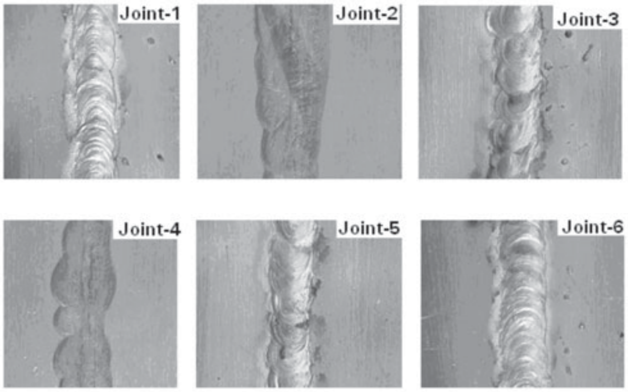

Figure 3: Samples of Weld Beads

Tensile specimens of 5 mm dia and 39 mm length (Figure 4) were prepared from the weld beads. The mechanical properties (viz., tensile strength, hardness, and %elongation) and microstructures of weld beads were studied using standard procedures.

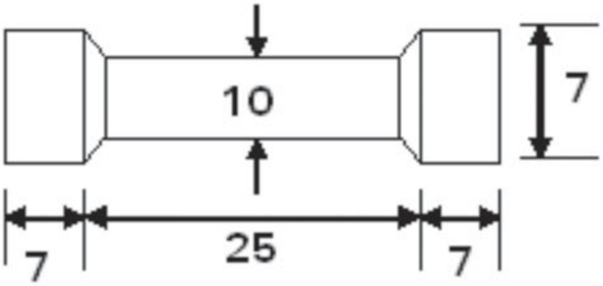

Figure 4: Tensile Specimen

3. RESULTS AND DISCUSSION

Each experiment was repeated thrice to avoid inconsistency or errors in the results. The average of the readings are plotted and analyzed against the controlling parameters (viz., joint design and channel size).

3.1. Fluidity Characteristics

Flow capabilities of liquid metals in various channels of strip fluidity testing mould are shown in Figure 5. An interesting observation is seen between the flowing characteristics of alloy-1 and –2. Alloy-1 is restricted to the short distances of liquid flow in various channels. The argument is justified by the following reaction:

$$\text{Mg (molten)} + H_2O \text{ (vapor)} = \text{MgO (dross)} + 2H \text{ (dissolved in melt)}$$

Two harmful effects accompany this reaction: oxide inclusions may be entrapped in the channels, and hydrogen gas defects causing vaporized turbulence. Therefore, retracted flow is the result.

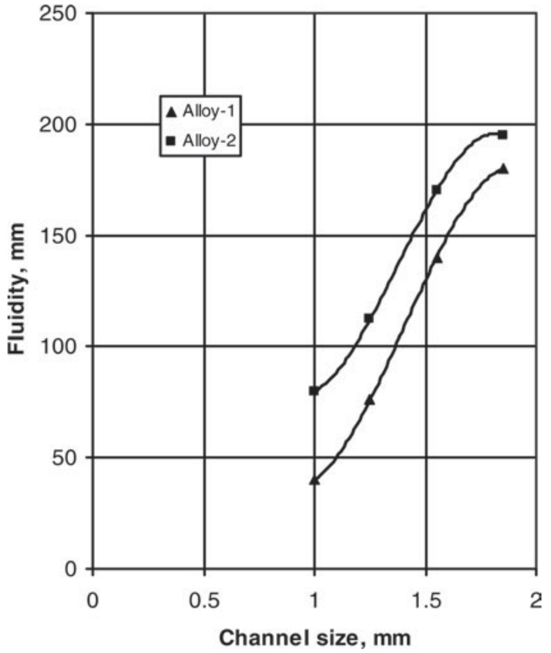

Figure 5: Effect of Channel Size on the Fluidity

The flow characteristics of alloy-2 are better than that of alloy-1. The reason could be addition of Fe, which reinforces the streams of liquid metal and subsequently decreases the turbulence in the flow. The other reason could also be the enhancing of sustainable and prolonged liquidity characteristic of metal. These lead to the long run of metal even in narrow channels. The resultant effect is increasing trend of fluidity with opening capillary mode in the channels (i.e., the fluidity is directly proportional to the channel size). This is ensued during the progressive solidification of liquid metal while flowing through the channel. Of course friction is applied with fluid and geometry interactive consequence.

The fluidity (Y) for the alloys is expressed in terms of channel size (x) is as follows:

For alloy -1, $Y = -355.44\, x^3 + 1469.4x^2 - 1823.2x + 789.14$

For alloy-2, $Y = -305.17\, x^3 + 1285.7x^2 - 1585.4.2x + 644.84$

3.2. Mechanical Properties

Tensile strength, hardness of heat affected zone (HAZ), and %elongation) are illustrated in Figure 6, 7 and 8. The tensile strength of weld bead with input variables of alloy-2 and joint-5 is greater than that of any other weld bead (Figure 6). This is supported by the fluidity characteristics in relevant to the joint design in addition to the resistance to tearing during solidification process and the resistance to plasticity fracture by Fe constituent. The alloy-1 is demoralized with low strength due to pinhole porosity resulted from the evolution of hydrogen gas.

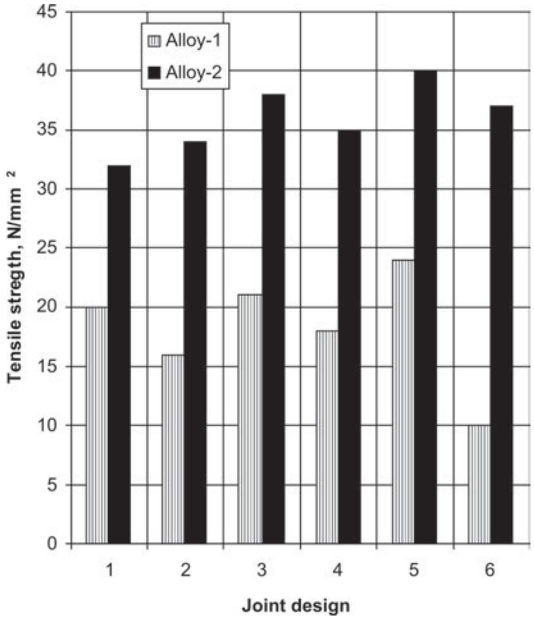

Figure 6: Effect of Joint Design on the Tensile Strength of Weld Bead

The heat affected zone (HAZ) hardness is found to be high in joint-1 and-2 (Figure 7). There is clear contribution of Fe constituent towards the hardness value. The role of Mg in the form of metallic compound Mg_2Si is to promote hardening effect of the alloy. The mechanical properties of hardness and strength can be expected to increase as copper content increases while the ductility decreases. But there is not much influence of the joint design over the surface hardness.

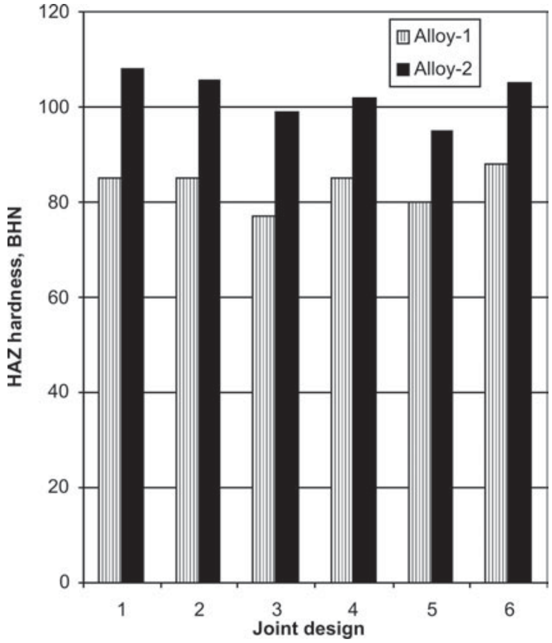

Figure 7: Effect of Joint Design on the HAZ Hardness of Weld Bead

The ductility characteristic measured in terms of %elongation is viewed in Figure 8. Alloy-2 once again dictates its supremacy in the ductility. It is all due to the role of Fe. The alloy-1 gives low ductility due to the hardening effect of Mg_2Si.

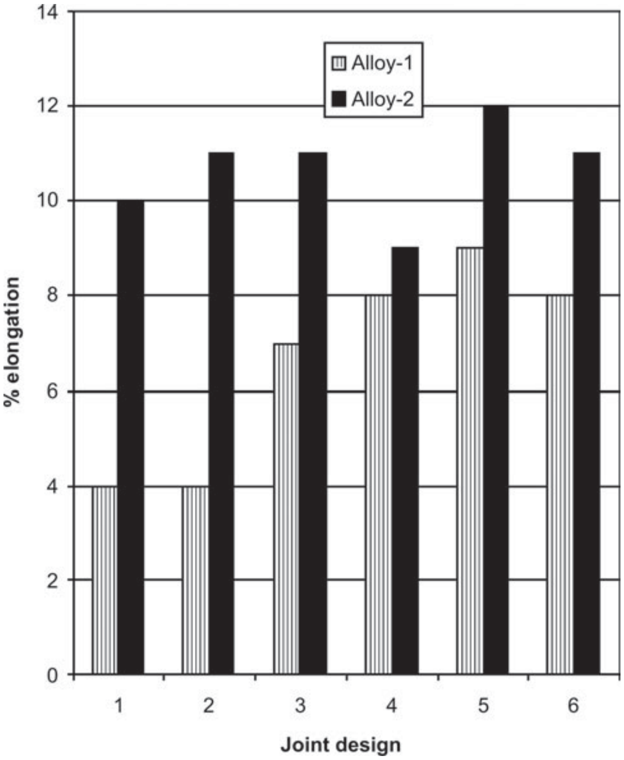

Figure 8: Effect of Joint Design on the Ductility of Weld Bead

3.3. Microstructural Characteristics

The microstructures of base metals are shown in Figure 9. Microstructure contains primary aluminum dendrites, eutectic silicon crystals, iron-based intermetallics and copper-based intermetallics are shown on Figure 9. The microstructures of weld bead obtained from joint-5 and alloy-2 is shown in Fig. 10. Two locations namely base metal and HAZ of the weld bead were chosen for the study. The structure is fine in the heat-affected zone (HAZ) whereas it is coarse in the base metal. The fine grain results in the increase of hardness in the heat affected zone as compared to base metal.

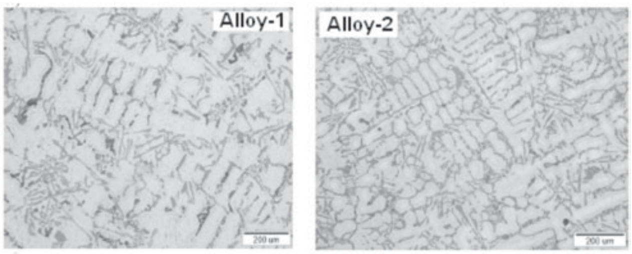

Figure 9: Microstructures of Base Metals

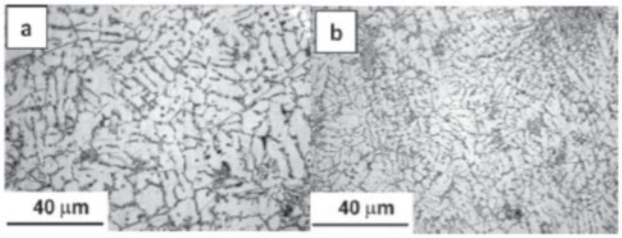

Figure 10: Microstructures of Base Alloys: (a) Base Metal and (b) HAZ

Figure 11 shows micrographs of the Si particulates at the centre of the beads of the joints welded with different joint designs. As compared to the base metal shown in Figure 9, the microstructures of narrow joint designs exhibit the breakup and/or redistribution of the primary Si particulates. The joint-2 (narrow) exhibits greater breakup of primary Si particles than the joint-5 (wider). In the base metals, the acicular Si particles are distributed at the boundaries of the primary α -Al phase and at the formed eutectic structure.

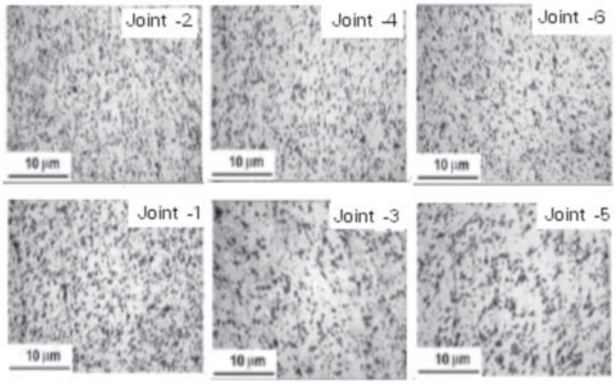

Figure 11: Micrographs of Different Joints at the Centre of Beads

It is observed from Figure 12 that there is an un-penetrated weld metal (or cavity) in the joint-2 (narrow) where the complete penetration (or fill) of weld metal is seen in the joint-5 (wider). Regions showing dark black samples (numbered 1, 2, 3, and 4 with arrows) of un-penetrated weld metal are indicated in the narrow joints by arrows. The joints -1, -3 and -6 exhibit equiaxed grains with sizes larger than those of the joints -2, -4 and -6.

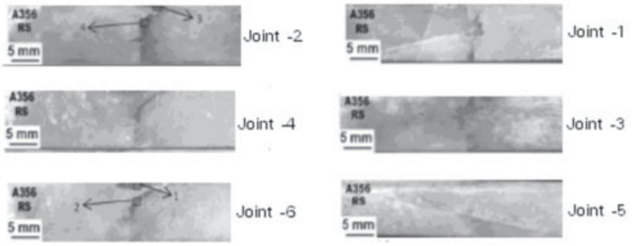

Figure 12: Possession of Weld Metal in the Joints

4. CONCLUSIONS

The fluidity of the liquid metal depends on the joint design and type of the alloy. The fluidity is increased by the addition of Fe and decreased by the inclusion of Mg. There is turbulence due to the evolution of hydrogen gas. The turbulence and the additional viscosity owing to the solidification process reduce the fluidity. The mechanical properties are largely influenced by the type of alloy and moderately by the joint design. The microstructure of weld beads is finer in the heat-affected zone and coarser in the base metal. The microstructures of narrow joint designs exhibit the breakup and/or redistribution of the primary Si particulates.

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