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EFFECT OF INOCULATION ON ALUMINUM ALLOY WELDS

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ABSTRACT

AA 6000 alloys suffer from Solidification cracking of fusion zone and loss of strength in the fusion zone and heat-affected zone. Being non-heat treatable compositions, AA4043 and AA5356 fillers result in fusion zone with poor strength (only about 40%) compared to their base metal in aged condition (T4 or T6 condition). Due to the above reasons, the section thickness of weld structures is increased. If the strength of the fusion zone can be increased by some means, the cost and weight savings would be significant. In the recent years, lot of interest is shown in the use of Ti, B and Zr in wrought and cast alloys and not many studies are available in welding. This work aims at such an improvement by using Ti + B with varying compositions in AA 4043 filler. Ti, B elements were added directly to the weld pools either as filler rods cut from master alloy castings or by pre-placing weighed amounts of pieces of master alloys along with 4043 fillers in a groove cut in the base material. Good numbers of weld metal compositions were generated in this manner, and their properties were assessed by macro-hardness measurements in the weld metal. Significant grain refinement and increase in hardness were observed by the addition of Ti+B. The influence of grain size reduction on tensile properties was studied. Properties are related to micro structural changes.

1. INTRODUCTION

Aluminum alloys have been widely used in welded structures and are most promising material for aerospace applications. They have been studied extensively because of their benefits such as formability, weldability and low cost, comparing to other alloys. AA6000 series alloys are used for applications such as rocket shells, cryogenic tanks, engine casings and other medium strength structures. These alloys are preferred mainly due to their specific strength and good corrosion resistance. AA6061-alloy, one of the Al-Mg-Si series alloy, is suitable for welding, but they can lose some of their strength, both in the welding seam and in the zone, which is influenced by heat, as a result of the heat generated during the welding process.

One-way of improving weldability is through modification of weld metal microstructures. The refinement of the fusion zone grain structure helps in reducing solidification cracking. Various techniques for grain refining fusion zones have been reported in the literature, electromagnetic stirring, surface cooling, current pulsing and inoculation. These have been applied for several materials such as steels and aluminum alloys.

Following early work by Kov and le[6] were able to refine GTA welds in an Al-Mg alloy by magnetic arc oscillation and also significantly reduced weld bead cracking as a result. Pearce and Kerr[1] reported that the formation of equiaxed grains owing to electromagnetic stirring increased with increasing titanium percentage. The importance of heterogeneous nucleation in the columnar- equiaxed transition caused by imposed magnetic fields was reported by KOV and Le6. Janikiram[5] and co- workers stated the beneficial effect of the inoculation, magnetic arc oscillation and also combined inoculation and magnetic arc oscillation on welds in an Al-Zn-Mg alloy.

Thus, even though many investigations have been concerned with the grain refinement of aluminum alloy welds, less information is available on Al-Si-Mg alloy welds, especially on 6061 alloy. In the present work, the refinement of the fusion zone grain structure in 6061 alloys was studied using inoculation. The effect of grain refinement and the tensile properties of the weld metals were studied.

2. EXPERIMENTAL WORK

The base materials taken up in this study was AA6061-T-6 of 4mm thickness plates. Single V-grooves with 60^0 included angle were made and of root height 1mm. Before welding, the specimens and fillers were cleaned with wire-brush thoroughly and immediately with acetone. Three filler wires used, AA4043, AA4043 with 2% Al-5Ti-1B (0.1%Ti), AA4043 with 2% Al-1Ti+3B (0.06%B), for the study. The welding was done with manual AC-TIG. The compositions of the base material and reference filler are shown in table 1.The welding parameters used were as follows: current, 150A,voltage, 12V. In all the cases welding was performed perpendicular to the rolling direction. A sufficient number of samples were welded for subsequent metallogrphy, and tensile testing.

After welding, the weld metal samples were cut of suitable dimensions and prepared for metallographic examination. In preparation, specimens were first finely polished down to a 3 mm finish and then etched with killer's reagent (5ml HNO_3, 3ml HCl, 2ml HF in 190 ml water). Areas of interest were observed under a light microscope using polarized light and photographed at different magnifications on top surface of weld metals.

The grain refinement was accomplished by taking grain size measurements in weld metals. Grain size measurements weld metals were made from the top view using the line intercept method across the full width of the fusion zone. Mean grain size values were used to represent the overall effect of grain refinement.

Hardness tests were carried out on Vickers hardness testing machine.
The mechanical properties of 6061-aluminum alloy base material and weld metals with different fillers (AA4043, AA4043+0.1%Ti, AA4043+0.06%B) have been studied. Longitudinal weld tensile specimens were prepared from the weldments as per the ASTM standard E 8M and testing is carried out using INSTRON machine. The fractography of the fractured tensile specimens was performed by using SEM.

3. RESULTS

3.1 Grain refinement evaluation

Figs. 1 (a) - (c) show the microstructures on top surface of the uninoculated and inoculated welds in region near the weld metal center. The effect of inoculants in weld metal through inoculation may be clearly noted by microstructures. Addition of master alloy 0.06%B, results more refinement than other master alloy, 0.1Ti, added to Al-5%Si The mean grain size with addition of 0.06%B, 0.1% was obtained 30μm, 53.5μm and 205 without addition as shown in fig.2.

The microstructures of weld metal made with the different inoculants added to filler material are shown in fig: 3a-c, which represents a transverse section close to weld center. Addition of master alloy 0.06 %B, results more refinement than other master alloy, 0.1Ti, added to Al-5%Si. The mean grain size with addition of 0.06%B, 0.1% was obtained 35μm, 60μm and 220 without addition. as shown in fig.4. From these micrographs, the inoculation treatments convert the untreated columnar structure in to truly equiaxed structures, i.e. equiaxed in all three dimensions.

The addition of 0.06%B, 0.1%Ti to reference filler resulted grain refinement in weld metal. The addition of 0.06%B to reference filler material has led to a greater degree of refinement than 0.1%Ti in weld metals. This is due to addition of higher amount of boron addition to titanium yields better performance: this is usually ascribed to the role of TiB_2 as well as to the effect of boron in lowering the solubility of Ti in liquid aluminum. This latter behavior shifts the peritectic point towards the aluminum end of the phase diagram, thus enabling the titanium aluminide crystals to be thermodynamically stable even at very low levels of Ti addition.

3.2 Hardness

Hardness of weld metals was taken along the bead and perpendicular to the bead. Average of 5 values were considered, finally Hardness values were shown in table: 2. The addition of 0.06%B have resulted higher hardness values than other elements added to reference filler.

3.3 Tensile properties

Tensile test data obtained from all weld longitudinal tests are given table: 2, as indicated earlier, these longitudinal all weld specimens taken from the fusion zone. For comparison, the base material tensile properties in the peak-aged condition are also included. In the as welded condition, addition of elements to reference filler, the reduction in grain size is seen to have increased yield and ultimate strength, although not by a large amount. However, there was substantial improvement in tensile elongation due to grain refinement. The improvement in tensile properties shows the same trend as the degree of grain refinement, i.e. addition 0.06% B confirming a greater benefit than other elements added to reference filler.

The effect of addition of inoculants on fractured weld metal tensile samples was evaluated using SEM as shown in fig: 5, which represents, the addition of 0.06%B, a remarkable fine dimple structure is observed on the fracture surface of weld metals compared without inoculation.

4. CONCLUSIONS

1. Significant grain refinement achieved in aluminum alloy weld metals with both the inoculants seed, viz, 0.1%Ti+0.02%B (0.01Ti) and 0.02%Ti+0.06%B (0.06%B).
2. The use of 0.02%Ti+0.06%B results in a slightly greater reduction in grain size than the other.
3. The tensile properties are improved by inoculation, the increase in ductility being particularly significant.

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TABLES

Table: 1. Chemical Composition of base material and filler wire

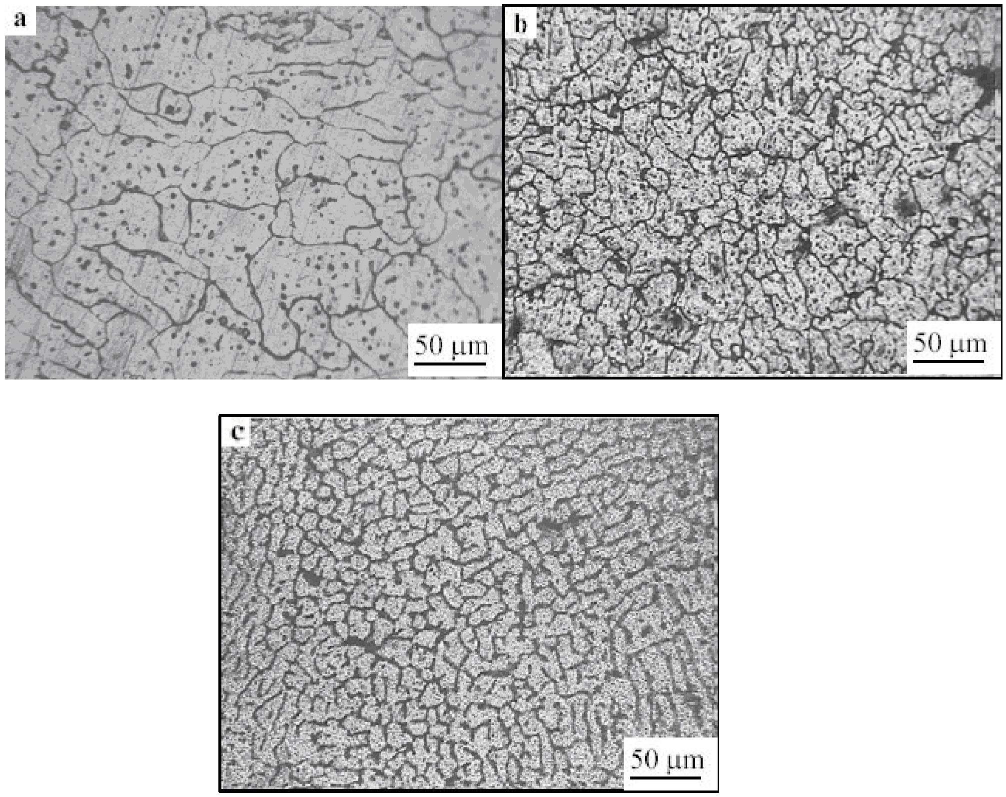
Material	Mg%	Si%	Fe%	Mn%	Cu%	Al%
AA6061Base material	0.689	0.531	0.23	0.331	0.305	Remaining
AA4043 filler	0.04	5.0	0.2	0.03	0.07	Remaining

Table 2: Mechanical properties of weld metals with different fillers [a, b]

Filler material	Yield strength (0.2%) MPa	UTS MPa	%of elongation	Hardness (VHN)
AA4043	100	123	4	36
AA4043+0.1%Ti	106	132	6.5	42
AA4043+0.06%B	115	155	9.1	55

a. Each set of tensile data is average of measurement on three specimens.
b. Base metal:0. 2% proof stress 275Mpa; ultimate tensile strength 345Mpa, 12%elongation

FIGURES



Figs. 1 Microstructures of top surface of untreated and inoculated weld metals at region near weld center (a) Untreated (b) Inoculated with 0.1%Ti (c) Inoculated with 0.06%B

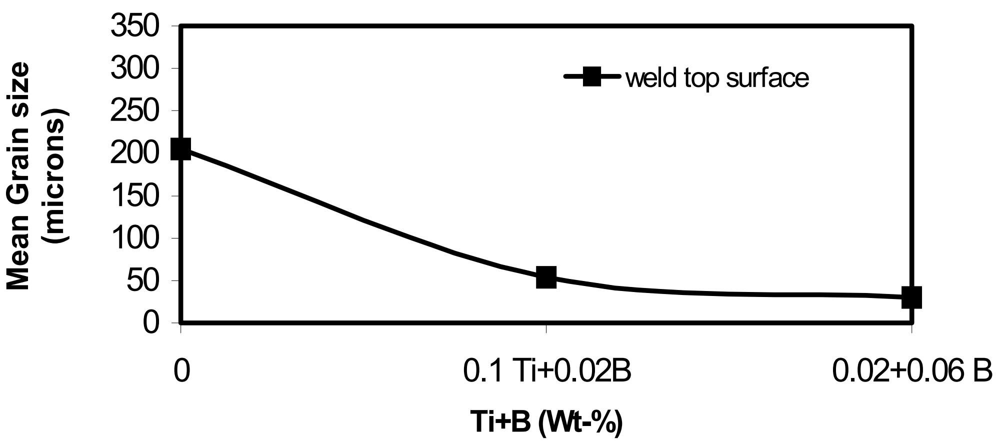


Fig. 2 Effect of inoculation on top surface of AA6061 alloy weld metals

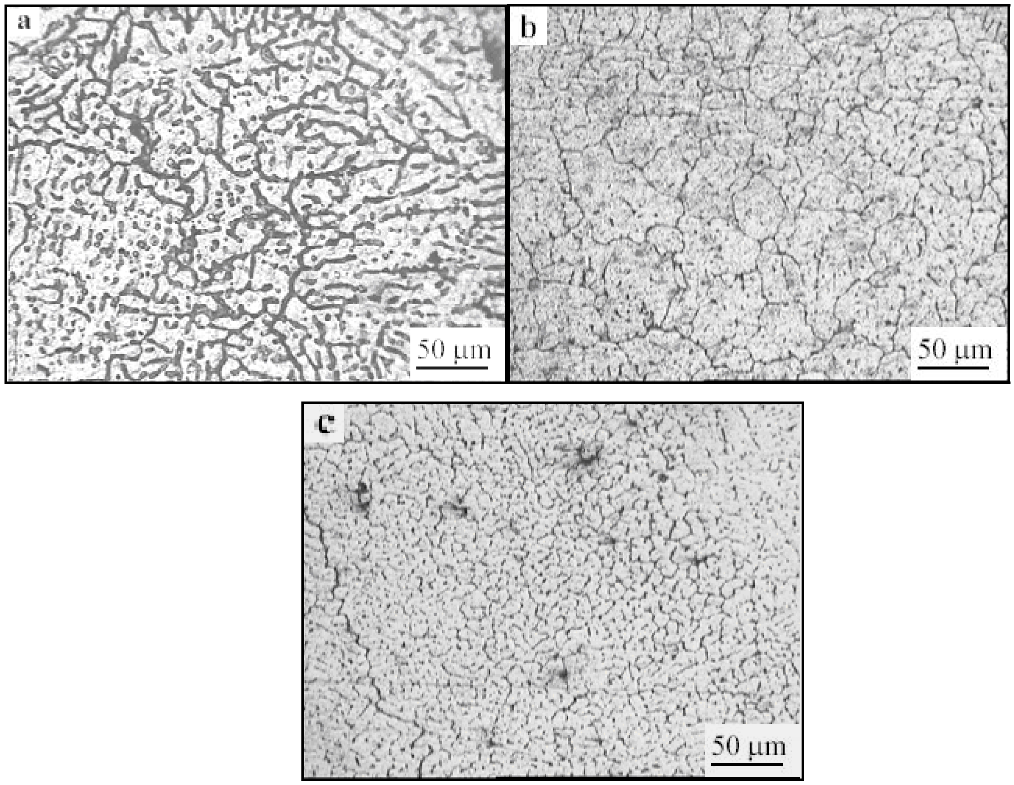


Fig.3 Microstructures of cross section of untreated and inoculated weld metals at region near weld center. (a) Untreated (b) Inoculated with 0.1%Ti (c) Inoculated with 0.06%B

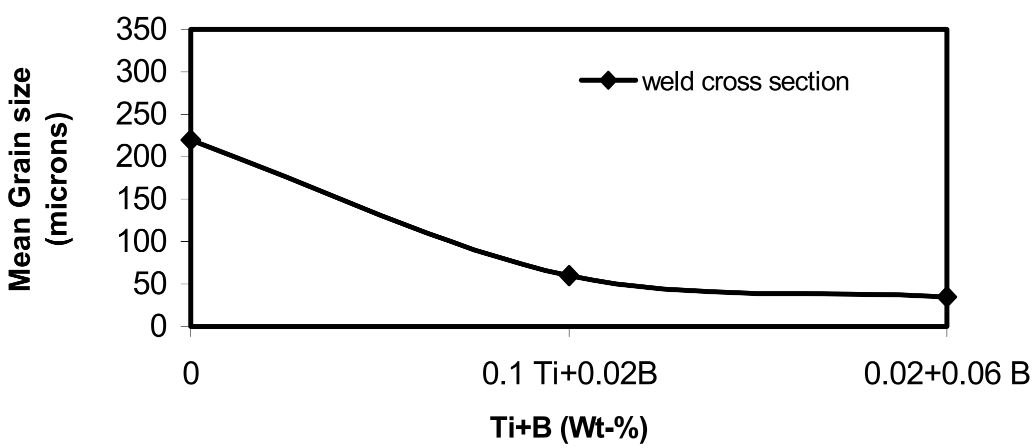
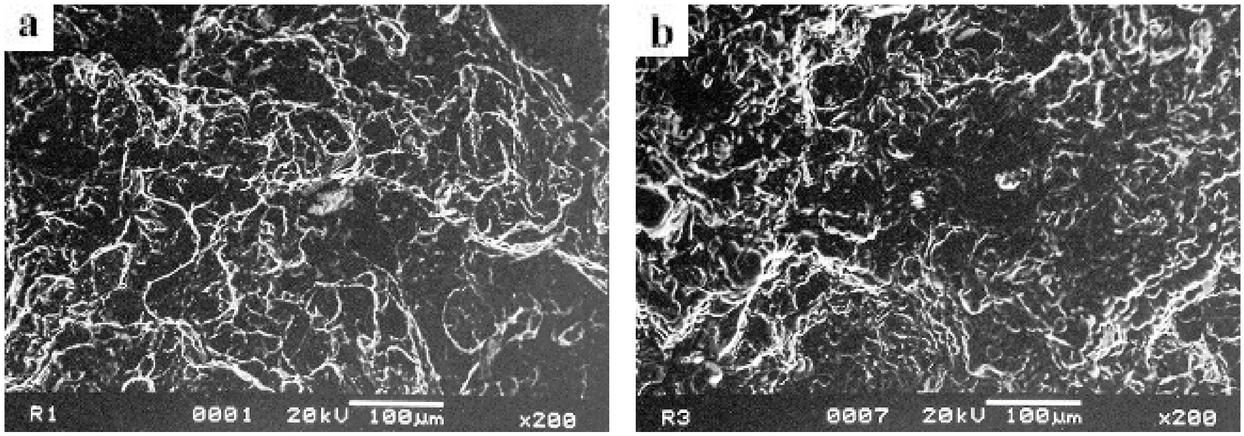


Fig. 4 Effect of inoculation on cross section of AA6061 alloy weld metals



(a). Without inoculation (b). inoculated with 0.06%B

Fig: 5 Scanning electron micrographs of fractography results on AA6061 alloy weld metals