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Effect of tool rotational speed on Friction Stir Welding of AA6061 and AA7075

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Abstract: Friction stir welding has proved to be a priceless wonder since it has enabled the welding of conventionally unweldable 2XXX and 7XXX series Al alloys. The welding of corrosion resistant AA6061 and high strength unweldable AA7075 Al alloys of 6mm thickness was carried out using High Carbon Steel (HCS) -D2 grade tool bearing a cylindrical pin profile. The process parameters - tool rotational speed, welding speed and welding load were optimized to 1200 rpm, 44 mm/min and 12.25kN respectively using orthogonal arrays. Adequate weld strength and microhardness values were observed. Temperature profiling of the weld zone and the TMAZ (Thermo-mechanically Affected Zone) was performed which reported low temperature prevalence during welding. Finite Element Analysis based heat flow modeling was carried out using ANSYS which showed 80% unaffected base metal.
Keywords: Tool rotational speed, Friction Stir Welding, AA6061, AA7075.

Introduction and Experimental:

Friction Stir Welding (FSW) has proved its ability to weld conventionally unweldable metals and alloys. Welding Aluminium and some of its potential alloys like AA6061 with special properties of corrosion resistance and age hardening ability has been carried out successfully and commendable strength has been obtained [1]. 2XXX and 7XXX series alloys are unweldable by conventional methods due to their hot cracking tendency. AA7075 is used because of its high strength close to 550 MPa in the T6 tempered condition. FSW of similar AA7075 has also been carried out by Rajakumar et al [2]. AA6061 alloys are highly corrosion resistant and AA7075 alloys have very high strength and thus this combination can be used in for a variety of applications. The present manuscript concentrates thus on making defect free weld of AA6061 and AA7075alloys with various tool rotational speeds, measuring their strength and microhardness, optimizing the process parameters, measuring temperatures during welding and performing heat flow analysis of the various zones.AA6061 and AA7075 were procured as 6mm thick plates. Initial EDS (Energy Dispersive Spectroscopy) was carried out to confirm the compositional adherence. The plates were then cut to 150mmX70mm using Electric Discharge Machining (EDM). D2 grade High Carbon Steel was procured with 32mm diameter in the annealed condition and was machined to a straight cylinder with pin profile (Fig 1) having a pin diameter of 6mm and a tool shoulder diameter of 18mm [3]. The tool was then subjected to hardening by heat treatment. The initial hardness was 35 HR_c. The tool was first heated to 950^0C and then austenized for 2 hours. This was then followed by air cooling since it was of air hardening type. The hardness rose to 64 HR_c. To relieve the locked in residual stresses, low temperature tempering was carried out at 210^0C for 2 hours. This finally gave a hardness of 59 HR_c. The ranges for the process parameters were adopted from individual similar friction stir welding of AA6061 and AA7075 [1,2]. L9 orthogonal array was constructed using the adopted parameters and the FSW was carried out (Adopted ranges: Tool rotational speed=1000-1200rpm, welding speed/traverse speed=40-48 mm/min and Welding load= 12.25-16.25 kN). Proper depth of penetration could only be obtained with welding load and welding speed of 12.25kN and 44mm/min respectively as was confirmed by radiography. A single factor experiment was conducted to optimize the tool rotational speed. Microhardness values investigated at 100kgf and radiography results gave optimum values for 1200 rpm. Tensile test was conducted using ASTM E8 standard samples. To study dissolution characteristics, SEM (Scanning Electron Microscopy) images were taken. K-type thermocouples were utilised to measure the temperatures of all the zones. Using Chao et al[4] equation the heat generated during the FSW process was calculated. ANSYS 10.0 was used to carry out heat flow analysis.

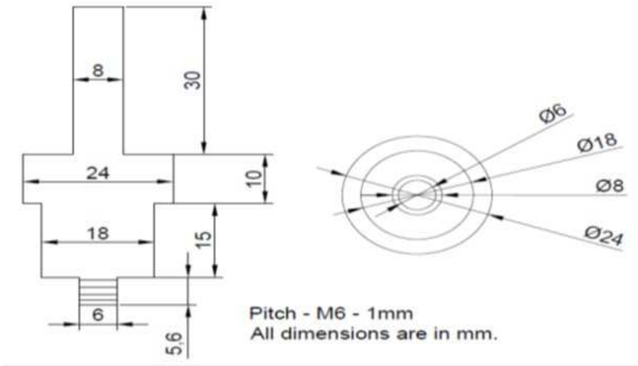


Fig 1 : Tool Profile

Results and discussion:

Radiography results confirmed that 44 mm/min (welding speed) and 12.25kN (welding load) gave complete depth of penetration and defect free welds. Fig. 2 shows the variation of microhardness values with the tool rotational speed. The results are reported for every zone at Hv1 (100 kgf). The 1200 rpm rotational speed yields better hardness of 96.7 Hv1 in the weld zone than the other 1000 rpm and 1100 rpm samples. This brought about the optimized process parameters as 1200 rpm, 44 mm/min and 12.25kN. The variation of the microhardness was also less than 5 Hv1 in the Heat Affected Zone (HAZ) and the Thermo-Mechanically Affected Zone (TMAZ) than that of the base metal. The tensile tests were taken using ASTM E8 standard for both parent alloy and the welded metal. AA6061 showed an ultimate tensile strength of 276 MPa and AA7075 showed 567 MPa respectively. The ultimate tensile strength of the weld was found to be 106 MPa. FSW of dissimilar welds with 6XXX and 7XXX alloys had always yielded such low strengths. Fig 3 SEM images taken show that at 1200 rpm the microstructure is fine throughout and that also confirmed the optimum tool rotational speed is 1200 rpm. The maximum solubility of Mg, Si and Zn in Al are 17.4%, 15.4% and 90% respectively. Zn has high affinity towards Al and its solubility is high but the weld was with AA6061 on the advancing side leading to the dissolution of Si and Mg first. The solubility of zinc in Al-Si or Al-Mg alloy is within 6% at about 300°C and therefore most of the Al-Zn solution stays as such producing good strength but some dissolution results in formation of unfavourable Al-High Zn-Low Si-Low Mg structure which reduces the overall strength of the base metal and AA7075-T6 is also not workable so no strain hardening takes place. This type of dissolution behaviour was determined as the cause for weld strength being lower than that of the base metal. To investigate the extent to which the base metal remained unaffected and to determine the temperature that developed during the welding process K-type thermocouples were attached to the temperature conditioning unit. Fig 4 gives a better idea about the temperature rise and fall during welding. The maximum temperature encountered in the TMAZ was about 220^0C. The other positions namely the HAZ on both sides only encountered a maximum temperatureof156^0C which showed evidently that these zones were not affected by high temperatures and grain coarsening doesnot occur to a large extent. This was why the microhardness did not dip below 100 Hv1 in these zones. Chao et al [Equation no (1) & (2)] proposed an equation to determine the heat input as a function of the friction co-efficient, process and tool parameters [4]. The total heat input Q is given by-

$$Q = \frac{\pi\mu\omega F(r_0^2 + r_0 r_i + r_i^2)}{45(r_0 + r_i)} \text{ ---------- (1)} \quad ; \quad q(r) = \frac{3Qr}{2\pi(r_o^3 - r_i^3)} \text{ ------------------ (2)}$$

ω = Tool rotational speed (rpm), μ = Frictional co-efficient, F = Weld load, r_i = Pin radius, r_0 = Tool shoulder radius, q(r)= Heating rate.

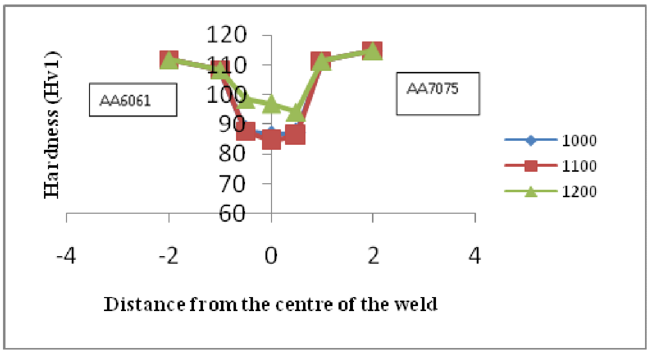
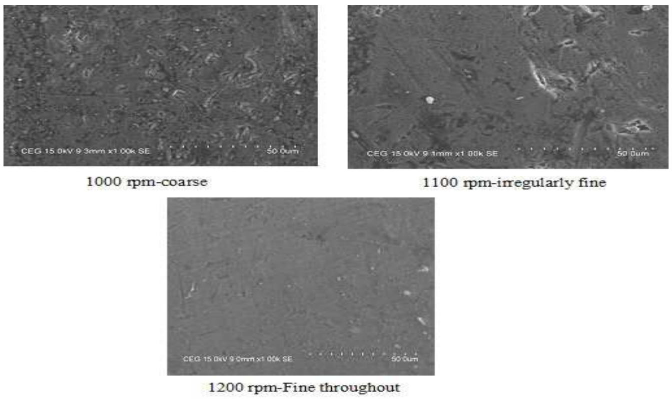


Fig 2 : Microhardness at different tool rotational speeds



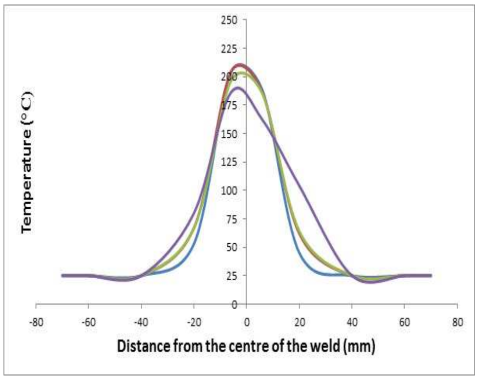


Fig 3: 1000X SEM micrographs for different tool rotational speeds

Fig 4: Temperature profile including all zones.

The heat input calculated using the equation 1was 496.417 kJ and the heating rate was 2.532 kJ/mm. Now the heat flow modelling was made by using SOLID 70 element in ANSYS 10.0 quoting temperature dependent structural and thermal properties like Young's modulus, thermal conductivity, ultimate tensile strength etc. SURF 152 element was used in order to apply convection to the surface and a contact element was also provided for the joining the two plates. The heat input was applied and the surrounding air temperature was made as 25^0C.It was observed that most of the base metal was unaffected. To be precise, calculations of the unaffected base metal were made and the value was found to be 16743 mm^2. This constituted 79.72% of the unaffected base metal.

Conclusions:

Dissimilar welding of AA6061 and AA7075 was successfully carried out and the parameters were optimised to 1200 rpm, 44 mm/min and 12.25kN indicating that of tool rotation speed, welding speed and welding load respectively. Strength was investigated through tensile tests, the UTS was found to be 106 MPa. The Vicker's Microhardness tests yielded a maximum hardness of 96.7 Hv1 at the weld region. The maximum temperature was detected to be 220°C at the TMAZ using K-type thermocouples. The high temperature zone inmodelling was due to the longer contact time in nugget zone and in other non-contact regions the heat dissipation was higher. The maximum heat flux was found to be 496.417 kJ at the tool contact zone. The temperature effects did not exceed 20% of the workpiece surface area.

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