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Title: Some studies on Under Water Friction Stir Welding

ABSTRACT

Friction Stir Welding (FSW) is a solid-state welding process which is capable of joining difficult to weld marine grade AAs and finds its extensive application in aerospace, automobile, shipbuilding and offshore construction. FSW offers several advantages over fusion welding but the thermal cycles involved in FSW cause softening in joints generally in heat treatable aluminum alloys (AAs) due to the dissolution or coarsening of the strengthening precipitates leading to decrease in mechanical properties. Underwater Friction Stir Welding (UFSW) can be a process of choice to overcome these limitations.

In the present study, UFSW of marine grade AA 6082-T6 plates of 3 mm thickness was performed using a H13 tool having tri-flute probe. The tool shoulder diameter (A), rotational speed (B) and traverse speed (C) were selected as the main process parameters and the effect of all these process parameters on the mechanical properties and microstructure along with the load and temperature was investigated. The experiments were performed as per Taguchi's L18 orthogonal array. Experimental data were statistically analyzed using Minitab software. Analysis of Mean (ANOM) was performed to determine the optimum UFSW process parameters combination and Analysis of Variance (ANOVA) was performed to assess the significance of each UFSW parameters and their interaction on the response. Normality plots were also generated for performing the diagnostic check of the validity of assumption related to ANOVA.

The UFSW of AA 6082-T6 was successfully performed and defect-free joints were observed in UFSW at all the process parameter combination. Three distinct zones namely SZ, TMAZ and HAZ both on the AS and RS were identified from the macrostructure. The precipitated phases in BM and different zones of the UFSW joint were identified as Al-Mn-Fe-Si intermetallic phases. The black color precipitates were identified as Mg-Si particles in the BM. The black precipitates were found to be strengthening phase β in the SZ, β’ and β in TMAZ and β’in HAZ. The maximum tensile strength of 241 MPa was obtained equivalent to 79% of the base material (BM). Most of UFSW joints fractured from the HAZ of the AS or HAZ of the RS. Higher microhardness values in the SZ were observed in the majority of the joints as compared to TMAZ/HAZ showing a typical W type hardness profile. A noticeable variation in temperature and traverse force was observed at different parametric combinations. The most significant factor affecting the temperature deviation and traverse force was rotational speed (B) and traverse speed (C) respectively. The most significant factor affecting the impact strength was traverse speed (C) followed by shoulder diameter (A).

The effect of cooling media on mechanical and microstructure were also analyzed and maximum tensile strength of the joints was obtained during UFSW followed by FSW and water with crushed ice (CFSW). The UFSW and CFSW joints resulted in lower peak temperature and less thermal gradient than FSW joint. The microstructural analysis revealed finer grains in UFSW and CFSW joint as compared to FSW joint due to lower peak temperature obtained due to water cooling. Moreover the grains were finer in the RS side in comparison to AS. Al-Mn-Fe-Si intermetallic phases were seen in all the joints along with the BM. The main strengthening precipitates found in HAZ of UFSW and a CFSW joint was β’ which changed to β precipitates during FSW. The FSW joint fractured from the AS-HAZ corresponding to the MHR. Fracture location shifted towards the RS-HAZ during UFSW and to SZ during CFSW showing strength improvement in the MHR. Maximum tensile strength and micro hardness was obtained in the UFSW joint due to refined grain structure, high density dislocations and presence of β’ phases.

Keywords: Aluminum, Friction Stir Welding, Taguchi Method, Underwater Friction Stir Welding