Developing Empirical Relationship to Predict Maximum Tensile Strength on AA 7075 CMT Welded Al Alloy

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Abstract. Aluminum alloys are predominantly utilized by transportation industries globally to reduce the vehicle mass which in turn reduces fuel consumptions and greenhouse emissions. In case of joining these alloys into a successful product, a suitable welding technique is required. Therefore, in this research work, the Al alloys were joined using an Advanced Cold Metal Transfer (ACMT) welding machine to understand the integrity of the joints. Also to predict the maximum strength of the ACMT joints, a relationship has been developed utilizing Design of Expert (DOE).

1. Introduction

The aluminum alloys provide considerable amount of intrinsic and extrinsic properties which made this material the prime choice for manufacturers. In general, majority of the products are produced from components where welding plays a key role for manufacturers [1-2]. Many joining technologies are available in the market but it is not reliable in rapid conditions due to the dynamic changes caused by the operation. The fusion welding technologies more often produces many defects in the joints due to the high amount of heat generated during the process which resulted in poor mechanical properties that drives interest of many researchers to develop a reliable fusion welding technology to address the scenario. Finally, in 2004, FRONIUS came up with a process known as Cold Metal Transfer (CMT) welding process which is an advancement of gas metal arc welding process by controlling wire feed motion which turns to be a major breakthrough by providing enhancement in physical properties of the weldment compared to conventional fusion joining techniques [3]. The metal transfer behavior and arc characteristics of CMT process during joining was investigated by Zhang [4] wherein the significance of transfer modes during joining was highlighted.
Amin [5] developed a model for the cold metal transfer welding process which proclaims that this technology can be used for joining of dissimilar alloys and will produce better properties compared to the other fusion welding techniques. The dissimilar joining of Al to Mg [6] and Al to steel [7] were carried out by using CMT welding technique and sound joints were attained with better strength in the weldment. The influence of process parameters on AA6061 aluminum alloy was carried out by Pavan kumar [8] to determine the vulnerability in the weldment area caused by parameter attributes. The impact of heat input on the weldment area and the porosities obtained in Al-Cu alloys were investigated by Cong Baoqiang [9] to determine the suitable working conditions for joining the materials.

From the overview technical report under CMT welding process, it can be moralized that major research works are focused on joining the various materials and researchers are focusing on property enhancement but are not concentrating to develop a suitable working constraints for a particular material. Therefore, in this research work, the AA 7075 aluminum alloy was joined using an Advanced Cold Metal Transfer (ACMT) welding process and an empirical relationship was developed using Response Surface Methodology incorporating ANOVA design matrix to identify the maximum strength attained in the CMT joints.

2. Experimental work

A high strength light weight AA 7075 grade Al alloys comprising of zinc and magnesium as the principle alloying element was chosen as the parent metal in this investigation. The Al-Zn-Cu alloys were preferably the widely used aluminum alloys in the material processing industry due to its excellent mechanical and corrosion resistant properties. The material was joined using an advanced TPS 400i cold metal transfer welding machine which provides low thermal input to the molten pool by controlling the wire deposition rate. Also, in CMT welding process, the current drops to non-zero during the metal transfer which results in no spatter formation. The suitable working constraints for the CMT joints are presented in Table 1 and the corresponding response (output) was displayed in Table 2 respectively. The CMT welding machine and the CMT welded joints were shown in Fig. 1 (a-b) respectively.

The mechanical testing such as microhardness and tensile testing was carried out using advanced E-UTM and Vicker’s hardness machine. The tensile tested specimens are displayed in Fig. 1 (c). In order to govern the tensile strength of the fabricated joints, the microstructure and macrostructure of the advanced cold metal transfer welded joints were examined to correlate it with the optimized joint. The microstructure of the ACMT weldments are examined using light optical metallurgical microscope with various magnification (Make: MEJI, Japan; Model: MIL-7100). Shown in figure1 (d).

Table 1. Suitable working constraints for CMT welding parameters

| Process Parameter | Representation | Unit       | Level     |
|-------------------|----------------|------------|-----------|
|                   |                |            | -1.68     |
|                   |                |            | (-1)      |
|                   |                |            | (0)       |
|                   |                |            | (+1)      |
|                   |                |            | +1.68     |
| Current           | D              | A          | 81.59     |
|                   |                |            | 85        |
|                   |                |            | 90        |
|                   |                |            | 95        |
|                   |                |            | 98.40     |
| Voltage           | S              | V          | 11.65     |
|                   |                |            | 12        |
|                   |                |            | 12.5      |
|                   |                |            | 13        |
|                   |                |            | 13.34     |
| Welding Speed     | T              | mm/min     | 266.59    |
|                   |                |            | 270       |
|                   |                |            | 275       |
|                   |                |            | 280       |
|                   |                |            | 283.40    |
Table 2. The design matrix and the output response

| Std. Order | Run Order | Coded Value | Tensile Strength (MPa) |
|------------|-----------|-------------|------------------------|
|            |           | D (A)       | S (V)                  | T (mm/min) |          |
| 1          | 15        | -1          | -1                     | -1         | 321      |
| 2          | 20        | 1           | -1                     | -1         | 335      |
| 3          | 14        | -1          | 1                      | -1         | 330      |
| 4          | 13        | 1           | 1                      | -1         | 335      |
| 5          | 16        | -1          | -1                     | 1          | 346      |
| 6          | 19        | 1           | -1                     | 1          | 342      |
| 7          | 12        | -1          | 1                      | 1          | 353      |
| 8          | 2         | 1           | 1                      | 1          | 340      |
| 9          | 5         | -1.68       | 0                      | 0          | 324      |
| 10         | 8         | 1.68        | 0                      | 0          | 327      |
| 11         | 17        | 0           | -1.68                  | 0          | 335      |
| 12         | 3         | 0           | 1.68                   | 0          | 341      |
| 13         | 10        | 0           | 0                      | -1.68      | 348      |
| 14         | 6         | 0           | 0                      | 1.68       | 376      |
| 15         | 4         | 0           | 0                      | 0          | 396      |
| 16         | 1         | 0           | 0                      | 0          | 401      |
| 17         | 9         | 0           | 0                      | 0          | 400      |
| 18         | 11        | 0           | 0                      | 0          | 399      |
| 19         | 18        | 0           | 0                      | 0          | 402      |
| 20         | 7         | 0           | 0                      | 0          | 402      |

3. Results and Discussion

In the current work, the RSM was utilized to develop the empirical relationship to decide the quality characteristics for the ACMT joints. The responses of strength of the CMT joints are dependent of the process parameters that includes current (D) A, voltage (S) V, welding speed (T) mm/min as expressed in equation (1)

\[ TS = f(D, S, T) \]  

The second-order polynomial equation was utilized to represent the tensile strength of the joints by formulating an empirical relationships and the developed equations are represented in equation (2).

\[ TS = [399.019 +0.51* D + 1.76* S +7.84*T -2.25*D*S – 4.5*D*T -0.5*S*T-26.11*D^2 -21.69 * S^2 -13.21 *T^2] \text{ Mpa} \]
The ANOVA method is followed to predict the appropriateness of the established mathematical relationship. The level of confidence was found to be 94%. From the ANOVA design matrix, it was found that the developed model is found to be adequate and also calculated ‘F’ and ‘R’ values doesn’t exceed beyond the tabulated ‘F’ and ‘R’ values. Also the residuals are falling over the straight line which can be significantly concluded that the errors are distributed normally [10].

An optical microscopic view for the CMT joints at different zones in optimized condition were shown in figure 2 (a-d). The micrographs reveals that the weld zone displays fine-equiaxed grains and also the heat affected zone is similar to 80% compared to the base metal structure. Fine grains were observed in this process due to continuous contraction (heating) and retraction (cooling) of the filler wire in the weld pool because of the wire feed mechanism. Also no defects were encountered in the joints which is because in this welding technique, the short circuit transfer takes place during the deposition of filler without the assistance of electromagnetic force and the same was observed by Zhang [4]. On the other hand, the spatter and heat input can be minimized significantly which is the main reason for achievement of enhanced properties in this process compared to other fusion welding techniques and on the contrary, it can be concluded that the strength achieved in this process is in close relation with that of the solid state friction stir welding technology [13].
4. Conclusion

The detailed report of this research work is summarized as follows:

- The advanced cold metal transfer joining was successfully carried out for the AA7075 aluminum alloys
- The mathematical models are established to calculate the maximum strength for the CMT welded joints
- Very fine-equiaxed grains were observed in the fusion zone; no defects were observed throughout the weldment area
- The maximum strength was predicted to be 402 Mpa which is achieved under the welding condition of current of 90 A, voltage of 12.5 V and welding speed of 275 mm/min in the CMT welding process
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