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Influences of pulsed current tungsten inert gas welding parameters on the tensile properties of AA 6061 aluminium alloy

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Abstract

Medium strength aluminium alloy (Al–Mg–Si alloy) has gathered wide acceptance in the fabrication of light weight structures requiring a high strength-to-weight ratio, such as transportable bridge girders, military vehicles, road tankers and railway transport systems. In any structural application of this alloy consideration its weldability is of utmost importance as welding is largely used for joining of structural components. The preferred welding process of aluminium alloy is frequently tungsten inert gas (TIG) welding due to its comparatively easier applicability and better economy. In the case of single pass TIG welding of thinner section of this alloy, the pulsed current has been found beneficial due to its advantages over the conventional continuous current process. The use of pulsed current parameters has been found to improve the mechanical properties of the welds compared to those of continuous current welds of this alloy due to grain refinement occurring in the fusion zone. Many considerations come into the picture and one need to carefully balance various pulse current parameters to arrive at an optimum combination. Hence, in this investigation an attempt has been made to study the influence of pulsed current TIG welding parameters on tensile properties of AA 6061 aluminium alloy weldments.

Keywords: Pulsed current; Tungsten inert gas welding; Medium strength aluminium alloy; Tensile strength; Design of experiments; Analysis of variance

1. Introduction

Weld fusion zones typically exhibit coarse columnar grains because of the prevailing thermal conditions during weld metal solidification. This often results in inferior weld mechanical properties and poor resistance to hot cracking. It is thus highly desirable to control solidification structure in welds and such control is often very difficult because of higher temperatures and higher thermal gradients in welds in relation to castings and the epitaxial nature of the growth process. Nevertheless, several methods for refining weld fusion zones have been tried with some success in the past: inoculation with heterogeneous nucleants [1], microcooler additions, surface nucleation induced by gas impingement and introduction of physical disturbance techniques such as torch vibration [2].

The use of inoculants for refining the weld fusion zones was, as a matter of fact, not as successful as in castings because of the extremely high temperatures involved in welding and also due to the undesirable effects of inoculating elements on weld mechanical properties at the levels required for producing grain refinement. Other techniques like surface nucleation and microcooler additions were also turned down because of the complicated welding set-ups and procedures associated with their use. In this process, two relatively new techniques namely, magnetic arc oscillation and current pulsing, have gained wide popularity because of their striking promise and the relative ease with which these techniques can be applied to actual industrial situations with only minor modifications of the existing welding equipment [3].

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Pulsed current tungsten inert gas (PCTIG) welding, developed in 1950s, is a variation of tungsten inert gas (TIG) welding which involves cycling of the welding current from a high level to a low level at a selected regular frequency. The high level of the peak current is generally selected to give adequate penetration and bead contour, while the low level of the background current is set at a level sufficient to maintain a stable arc. This permits arc energy to be used efficiently to fuse a spot of controlled dimensions in a short time producing the weld as a series of overlapping nuggets and limits the wastage of heat by conduction into the adjacent parent material as in normal constant current welding. In contrast to constant current welding, the fact that heat energy required to melt the base material is supplied only during peak current pulses for brief intervals of time allows the heat to dissipate into the base material leading to a narrower heat affected zone (HAZ). The technique has secured a niche for itself in specific applications such as in welding of root passes of tubes, and in welding thin sheets, where precise control over penetration and heat input are required to avoid burn through.

Extensive research has been performed in this process and reported advantages include improved bead contour, greater tolerance to heat sink variations, lower heat input requirements, reduced residual stresses and distortion [4]. Metallurgical advantages of pulsed current welding frequently reported in literature include refinement of fusion zone grain size and substructure, reduced width of HAZ, control of segregation, etc. [5]. All these factors will help in improving mechanical properties. Current pulsing has been used by several investigators to obtain grain refinement in weld fusion zones and improvement in weld mechanical properties [6,7]. However, reported research work related to the effect of pulsed current parameters on mechanical and metallurgical properties are very scanty. Moreover, no systematic study has been reported so far to analyse the influence of pulsed current parameters on mechanical and metallurgical properties.

Hence, in this investigation an attempt has been made to develop mathematical models to predict the effects of PCTIG welding parameters on tensile properties of medium strength AA 6061 aluminium alloy using statistical tools such as design of experiments, analysis of variance and regression analysis.

2. Scheme of investigation

In order to achieve the desired aim, the present investigation has been planned in the following sequence:

(i) Identifying the important PCTIG welding parameters which are having influence on fusion zone grain refinement and tensile properties.
(ii) Finding the upper and lower limits of the identified parameters.
(iii) Developing the experimental design matrix.
(iv) Conducting the experiments as per the design matrix.
(v) Recording the responses.
(vi) Developing mathematical models.
(vii) Identifying the significant factors.
(viii) Checking the adequacy of the developed models.

2.1. Identifying the important parameters

From the literatures [5–8] and the previous work [9] done in our laboratory, the predominant factors which are having greater influence on fusion zone grain refinement of PCTIG welding process have been identified. They are: (i) peak current; (ii) background current; (iii) pulse frequency; (iv) pulse on time.

2.2. Finding the working limits of the parameters

A large number of trial runs have been carried out using 5 mm thick rolled plates of AA 6061 aluminium alloy to find out the feasible working limits of PCTIG welding parameters. AA 4043 (Al–5%Si) aluminium alloy of 3 mm diameter has been used as the filler metal. Different combinations of pulsed current parameters have been used to carryout the trial runs. The bead contour, bead appearance and weld quality have been inspected to identify the working limits of the welding parameters. From the above analysis following observations have been made:

(i) If peak current is less than 160 A, then incomplete penetration and lack of fusion have been observed. At the same time, if peak current is greater than 180 A, then undercut and spatter have been observed on the weld bead surface.
(ii) If background current is lower than 80 A, then the arc length is found to be very short and addition of filler metal becomes inconvenient. On the other hand, if the background current is greater than 90 A, then arc becomes unstable and arc wandering is observed due to increased arc length.
(iii) If pulse frequency is less than 2 Hz, then the bead appearance and bead contours are appear to be similar to that of constant current weld beads. Further, if pulse frequency is greater than 6 Hz, then more arc glare and arc spatter have been experienced.
(iv) If pulse on time is lower than 40%, then weld nugget formation is not so smooth due to incomplete melting of filler metal. On the contrary, if the pulse on time is greater than 60%, then overmelting of filler metal and overheating of tungsten electrode have been noticed.

2.3. Developing the experimental design matrix

By considering all the above conditions, the feasible limits of the parameters have been chosen in such a way that the AA 6061 aluminium alloy should be welded without any weld defects. Due to narrow ranges of factors, it has been decided to use two level, full factorial design matrix to optimise the experimental conditions. Table 1 presents the