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Effects of thermo-mechanical treatments on mechanical properties of AA2219 gas tungsten arc welds

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ABSTRACT

Fusion zone of AA2219 alloy gas tungsten arc welds was subjected to compressive deformation by rolling the crown of the weld in the welding direction. Twelve percent compressive deformation improved the as-weld hardness from 75 to 100 VHN. The yield strength increased from 125 to 220 MPa. The welds made by pulsed current technique exhibited better strength and ductility compared to their continuous current weld counterparts, both in the as-welded condition and the deformed condition. The improvement in strength was found to be due to dislocation loops formed near the grain boundaries in the fusion zone. Direct aging of fusion zone at 190 °C, increased the yield strength significantly from 125 to about 200 MPa. Aging of the deformed fusion zone did not improve tensile strength further.

1. Introduction

Deformation as in planishing process involves compressing the weld joint between steel rollers. After welding of the part is completed, planishing will flatten the fusion zone to the same level with the base metal. The compressive deformation of welds, particularly the fusion zone, has found application in the form of roll planishing of welds to relieve the tensile residual stresses and improve some of the mechanical properties of welded joints. A U.S. Patent issued in 1975 (Anon., 1975), explained the process of planishing wherein the first set of wheel electrodes create a weld joint and the second set depending on the shape, area, and pressure of the wheels, either reduced the weld thickness, tempered the weld joint, or both.

This technique has many applications in aerospace industry; it offers multiple solutions to the problems encountered when conventional cold forming processes are applied to integrally stiffened structures (Newman et al., 1992). It was found to reduce residual tensile stresses. Gladstein (1959) reported the decrease in residual stresses in steel weld metals. Another U.S. patent issued in 1999 (Anon., 1999) claimed that weld residual stresses were relieved by planishing in case of an external propellant tank of the space shuttle made of 2195 aluminum–lithium alloy. Similar results were reported by Kurikino et al. (1960) where compressive deformation of the fusion zone was found to change the stress patterns.

Such plastic deformation prior to artificial aging in Al–Cu–Li alloys has been found to enhance the strength, ductility and aging kinetics over non-deformed material through the

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Table 1 – Chemical composition of alloys

Alloys	Cu	Mn	Zr	Ti	Fe	Si	Rest
2219-T87	6.7	0.30	0.07	0.06	0.14	0.10	Al
2319 filler	6.5	0.23	0.17	0.15	0.11	0.08	Al

introduction of dislocations, which act as preferential matrix nucleation sites for the primary strengthening phase θ' (Kim and Park, 1993; Ringer et al., 1995; Hopkins et al., 1996). It was reported by Gladstein (1959) that crushing or cold working of the fusion zone by planishing improves the yield and tensile strengths of the welded joint by reducing porosity.

The work carried out by Russel (1965) on inert gas arc butt welds of stainless steel 304 showed noticeable improvement in strength and significant improvement in ductility by roll planishing the weld in the welding direction. Investigations by Boldyrev et al. (1983) on austenitic–martensitic stainless steels highlighted the usefulness of rolling the fusion zone in terms of the response of the material to hardening during subsequent aging. After rolling and aging the strength of the joint was found to be 50% higher. They have also concluded that the rolling pressure controls the mechanical properties, the greater the rolling pressure the better the strength.

Methods such as cold rolling, shot blasting, roll planishing and machining were reported (Trufyakov and Mikeev, 1964) to improve the mechanical properties including fatigue limits. Trufyakov and Mikeev (1964) have concluded that local mechanical compression is an extremely effective method of increasing the endurance limit of some types of welded joints. It was reported by Gopinathan (1974) that 40% reduction in weld bead thickness by rolling and subsequent aging resulted in equalizing the hardness of fusion zone, HAZ and the base metal in stainless steel and Cr–Mo steel welds. Application of an elastic stress during the aging process of age hardenable aluminum alloys was also reported to improve the mechanical properties by altering the distribution of strengthening precipitates This effect was also observed in Al–Cu alloys by Zhu and Starke (2001).

Copper containing alloys such as AA2219 are used for their excellent weldability and cryogenic applicability. Increased precipitation can be produced in AA2219 alloy by strain hardening after solution heat treatment and artificial aging. The increased density of precipitation caused by strain hardening is reflected in the high strength (475 MPa) of the alloy in T87 temper. However, AA2219 welds suffer from relatively poor fusion zone and HAZ hardness and strength compared to their base metal counterpart in T87 condition. However, the loss of HAZ hardness in the case of AA2219 in T6 condition is found to be much more than that noticed in AA2219-T87. The hardness in the HAZ of AA2219-T87 tungsten inert gas welds was found to be 94 VHN (Koteswara Rao, 2005), whereas the fusion zone hardness was found to be about 75 VHN.

The joint efficiency of AA2219 achieved is only about 40%, mainly because the fusion zone gets softened significantly during the melting and re-solidification. The loss of strength is due to the dissolution of strengthening precipitates and the material in the fusion zone is as good as solution treated material. Another reason for the lower strength of the fusion zone is the segregation of copper to grain and dendrite boundaries. The copper–aluminum eutectic (α-Al + $CuAl_2$), which contains about 32% Cu, forms at the grain boundaries, resulting in depletion of Cu in the matrix. Due to the low fusion zone strength, AA2219 welded sections are designed to be twice or thrice thicker, compared to the rest of the sections in a structure. Fabrication starts with a thicker plate and it is machined at sections which are away from the welding area. Chemical milling or CNC pocket milling is employed to cut away the portions and reduce the total weight of the tank or a shell. The whole fabrication becomes costly and cumbersome. If the strength of the fusion zone can be increased to any extent, by any means, the cost and weight savings would be significant. In view of the expected benefits of compressive deformation, the current work was taken up to study the effects of compressive deformation on the mechanical properties of the fusion zone of aluminium–copper alloy (AA2219-T87) gas tungsten arc welds.

2. Experimental

Material used in this study was an aluminum alloy AA2219-T87 plate of thickness 8.4 mm and AA2319 filler wire of 1.6 mm diameter was used to make gas tungsten arc welds where high purity argon was used as shielding gas. Chemical composition of materials is given in Table 1. Gas tungsten arc (GTA) alternating current (AC) welding process was used. Welding was done with continuous current (CC) and pulsed current (PC) modes. Welding parameters employed are given in Table 2. The parameters were selected based on their effectiveness to change the solidification structure from columnar to equiaxed grains in the fusion zone. Welding speed was kept constant at 120 mm/min in all cases to maintain the heat input approximately the same. In case of PC welding, time at peak current was equal to time at base current.

X-ray spectral analysis was conducted for quantitative chemical analysis of all the elements. Aging studies were conducted on both CC and PC welds. The experiments were designed in such a way that the effect of deformation, aging and deformation followed by aging could be evaluated. Four different aging temperatures 100, 130, 160 and 190 °C were considered. Aging time was up to 100 h. The full factorial matrix of all the deformation, aging and deformation + aging parameters investigated is given in Table 3.

Table 2 – Welding parameters used to make GTA welds using 2319 filler

S. No	Process (AC-GTAW)	Peak current (A)	Base current (A)	Pulsing frequency (Hz)
1	CC	260	–	–
2	PC	320	160 (50%)	6