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Overview of the Effect of Post Welded Heat Treatment on Friction Stir Welding Of Aluminum Alloys

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Abstract:-The objective of this investigation is to learn how and why certain alloys (primarily Aluminum alloys) can be strengthened by Precipitation Hardening heat treatment processes and their effects on the friction stir weldments of Aluminium alloys. The strength and hardness of some metal alloys may be enhanced by the formation of extremely small uniformly dispersed particles of a second phase within the original phase matrix; this must be accomplished by appropriate heat treatment. The process is called Precipitation Hardening or Age Hardening which involves three distinct steps: Solution Treatment to minimize segregation in the alloy, Quenching to create a supersaturated solid solution and Aging to facilitate the formation of coherent precipitates which strengthen the alloy by interfering with dislocation movement.

I. INTRODUCTION

Generally, Al alloys have many specific properties and can be applied to many structural parts that need both light weight and high mechanical properties. In these days, Al alloys have been used in the transportation industry such as high speed rail way [1], shipping and external fuel tanks of rockets .Structural parts and frames composed of Al alloys must be welded using the sound welding technique commonly employed in this industry. If Al alloys were welded using conventional fusion welding, many welding defects, such as voids, hot cracking and distortion, related to the melting and solidification were formed in the weld zone. Moreover, problems of fusion welded Al alloys were the precipitates resolution, the loss of work hardening effect and hard to melt for welding [4–7]. Therefore, the solid state bonding technique is highly recommended to solve these many problems. Friction stir welding, invented by TWI in 1991, is a promising technique because it resulted in superior joint quality of the varieties of Al alloys .The resulting weld is composed of three primary zones: the heat-affected zone (HAZ), the thermo mechanically- affected zone (TMAZ), and the weld nugget. FSW produces a dynamically recrystallized grain structure in the nugget, which has reached near-solution zing temperatures, before being “quenched” by the surrounding material back to room temperature at the completion of the weld. Because of this, the local microstructure is no longer stable and will begin to naturally age at room temperature. For heat treatable Al alloys, FSW processing generates a softened region within the weld zone because of the dissolution of strengthening precipitates [2]. For non-heat treatable Al alloys, softening is not observed, when alloys are not sensitive to strain hardening [3]. However, non-heat treatable and sensitive to strain hardening aluminum alloys exhibit softening in weld zone owing to decrease in dislocation density [4]. Most of the earlier studies on friction stir welding of similar type of Al alloys are confined in evaluating stirring zone microstructure, micro-hardness and bond strength [5].

II. PRINCIPLES OF PRECIPITATION HARDENING

Heat treatment processes for increasing the strength and hardness of either wrought or cast aluminum alloys utilize the mechanism of precipitation hardening. All heat treatable aluminum alloys are strengthened by precipitation hardening. Precipitation hardening involves raising the temperature of the alloy into the single phase region so that all of the precipitates dissolve. . In order for an alloy system to be able to be precipitation-strengthened, there must be a terminal solid solution that has a decreasing solid solubility as the temperature decreases. One essential attribute of a precipitation hardening alloy system is a temperature and time dependent equilibrium solid-solubility characterized by decreasing solubility with decreasing temperature and then followed by solid-state precipitation of second phase atoms on cooling in the solidus region. These conditions are usually met by most aluminum equilibrium systems of heat treatable types, such as the Al-Si and Al-Cu alloys etc [6]. The alloy is then rapidly quenched to form a supersaturated solid solution and to trap excess vacancies and dislocation loops which can later act as nucleation sites for precipitation. The precipitates can form slowly at room temperature (Natural ageing) [7] and more quickly at slightly elevated temperatures, typically 100C to 200C (artificial ageing) .The degree of hardening obtained depends on the size, number and relative strength of the precipitates. These factors are determined by the composition of the alloy and by the tempering temperature and tempering line. During welding, liquid films form at grain boundaries adjacent to the fusion boundary. These liquid films lead to the formation of microscopic intergranular cracks after welding which may provide paths for subsequent brittle intergranular fracture. The pre-existing precipitation state can be modified in the following different ways: i) Dissolution of precipitates. ii) Growth of coarsening of pre-existing precipitates. iii) Transformation of metastable phases to

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more stable forms.iv) Nucleation of new particles. Abdulwahab [7] divided HAZ into two sub zones a) the dissolution zone where dissolution is complete. b) Over ageing zone, where growth and coarsening of preexisting particles occur. Precipitation modeling is generally described by three different mechanisms taking place in the evolution history of a precipitate family. a) Nucleation. b) Growth. c) Coarsening. The first case nucleation increasing the particle number, is the predominant mechanism , followed by the growth of the resulting particles(second case) .Finally , coarsening of the precipitates, favoring large particles at the expense of the smaller ones, becomes predominant (Third Case) , leading to decrease of the particle number density. Precipitation hardening aluminum alloys are difficult to join by fusion welding techniques. They often lead to significant strength deterioration in the joints due to the dentritic structure formed in the fusion zone [8]. The dissolution of the precipitate, which leads to unpinning and creates, softening as well as grain coarsening, is another reason for the loss of mechanical properties. These alloys can be successfully joined by FSW technique in which no fusion zone is formed. There are some previous studies concerning the FSW of precipitation hardening aluminum alloys. Priya et al.[9] attempted the post weld heat treatment of friction stir welded AA 2219 and AA6061 –T6 aluminum alloy in two ways a) Direct ageing at 165ºC for 18 hours b) Solutions treatment at 520 °C for 1 hour followed by ageing at 165°C for 18 hours. Post weld ageing at 165°C for 18 hr resulted in notable improvement in the weld nugget hardness .However outside the nugget hardness recovery did not take place. During FSW, The weld nugget alone would have reached the solutionising temperature .The improvement in hardness in the nugget following direct ageing is attributed to the reprecipitation of strengthening phases which are dissolved during FSW. Post weld solution treatment at 50°C and ageing resulted in significant improvement in hardness throughout the weldments. The solutionising treatment resulted in dissolution of precipitates throughout the weldments In any weld aments, the heat affected zone (HAZ) exhibits the lowest hardness and strength and the fracture usually occurs in the HAZ. Post Weld Heat Treatment (PWHT) is an option to recover the loss of strength in the HAZ caused by over ageing due to the weld thermal cycle. Recent studies on the effect of PWHT on FSW of AL alloy 2219-T6 showed significant improvement in the mechanical properties of the weldments [9].Feng et al [10] reported that PWHT following FSW of 2219(in O temper) has significant effect on the fracture locations of the joints The tensile strength of the joints is increased with increasing solutionising temperature. Krishnan et al [11] have shown that PWHT (solutionising and ageing) following FSW of 6061(in O temper) resulted in increase in hardness across the whole weldment. Nelson and coworkers [26] studied the micro structural evolution (the grain structure, dislocation density and precipitation phenomena) at various regions of friction stir welded Al alloy 7050-T651 in detail. They reported that the dynamically recrystallized zone (DXZ) consisted of recrystallized, fine equiaxed grains, 1-4 µm in diameter, and contained a high dislocation density with varying degrees of recovery from grain to grain. Research by Nelson et al. has shown that 7075 will continue to naturally age at room temperature beyond 1000 hours in the as-welded condition, as typically observed in 7XXX series alloys in the W condition. Therefore, a degree of artificial aging is at least recommended to stabilize welds in 7075, and 7XXX series alloys in general. PWAA can also be used to modify the distribution of precipitates in the final joint to influence strength and corrosion properties, and has been demonstrated to be beneficial for a number of alloy and temper combinations. Sato et al. [13] emphasized that the precipitates within the weld region (0-8.5 mm from the weld center) were completely dissolved into a 6063 aluminum matrix. They also reported that the hardness profile was strongly affected by precipitate distribution rather than grain size in the weld. Similarly, a complete dissolution of the precipitates in FSW of 6013 Al-T6 and T4 at a tool rotation speed of 1400 rpm and welding speeds of 400- 450 mm/min was also reported. Sato and Kokawa [14] conducted two different post weld treatments on the FSW samples of 6063 Al-T5 alloy with the thickness of 4 mm. The first was only an aging process at 175ºC for 12 h, while the second was both a solutionising (at 530ºC for 1 h) and an aging (at 175ºC for 1 h) process. They concluded that the elongation, the yield, and the ultimate tensile strengths (UTS) were the lowest for the FSW samples, and the highest for both the solutionized and the aged conditions of FSW samples. In the case of the post weld aging process, the tensile properties were a bit more than that of the base metal. Alaaddin Tokta et al[15] study, the effects of the welding parameters and the post weld aging procedure on the micro structural and the mechanical properties of friction stir-welded aluminum alloy 6063-T4 The post weld aging process (at 185ºC for 7 h) was applied to a group of the welded plates. In this study, the effects of the welding parameters and the post weld aging treatment on the micro structural and mechanical properties of 6063-T4 Al alloy were studied. It was observed that the ultimate tensile strengths (UTS) increased slightly (on average by approx. 8%) and the percent elongations decreased (on average by approx. 33%) by the post weld aging treatment. The maximum bending forces (Fmax) of all the welds were less than that of the base metal.

III. POST WELD HEAT TREATMENTS ON CORROSION RESISTANCE

A. Post-Weld Artificial Ageing: Prior researchers have shown that the resistance of 7XXX series alloys, particularly Al 7075, to exfoliation, intergranular

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corrosion, and stress corrosion cracking is greatly reduced by friction stir welding when left in the as-welded condition [5-9]. One potential method of restoring the corrosion resistance to 7XXX series alloys is through post-weld artificial aging after joining by FSW. The results of a variety of post weld heat treatments have been reported in literature; however, they deal almost exclusively with peak aged (T6) and underaged tempers (W,O,T3, and T4) [21]. The general approaches thus far have been to: 1) leave the material in the as-welded condition, 2) apply a low temperature stabilizing heat treatment (e.g. 24 hours at 100-121°C), 3) apply a solution heat treatment to the material after welding and then age to the desired temper, 4) apply additional post-weld aging to material originally in a T6 or earlier temper to arrive at the final desired temper, or 5) to apply a localized post-weld heat treatment.

B. Stabilization Treatments. Again, friction stir welded 7XXX material, specifically 7075, in the as-welded condition, is unstable and has reduced exfoliation and stress corrosion cracking resistance, and thus is not suitable for critical applications. Therefore, it is recommended that at a minimum the second solution be utilized in which some type of stabilization treatment, similar to a standard T6 artificial aging step, be applied to 7075. Pao et al. [12] reported restoring the SCC resistance to 7050-T7451 with a PWAA of 24 hours at 121°C, when tested by FCP in a 3.5% NaCl solution. Sanakaran et al. [20] investigated the corrosion resistance of the same alloy and Post Weld Artificial Ageing (PWAA) treatment in an ASTM G-85 procession chamber. They also found that the corrosion resistance of the weldment was comparable to the parent material. Dunlavy et al. [24] went on to investigate the corrosion fatigue resistance of the same alloy/PWAA combination. In this case, they found that the fatigue strength of the weldment was reduced by 50% compared to the parent material. One of the more successful heat treatments implemented in 7XXX series reported in the literature is a 100 hours at 100°C treatment for 7050-T7451 and 7075-T73. [24, 25, 26] This treatment however, is primarily effective for the overaged T7 tempers. It is however, most often the approach that yields the best mechanical properties, hence if some form of corrosion mitigation plan is preferable, i.e. surface coatings, etc., then leaving the material in the as-welded condition might be a consideration.

C. Solution Heat Treatments for large structures: There are occasions, for example with very long vessels, when the entire vessel will not fit into a fixed furnace [27]. This has been catered for in most Standards, and it is permissible to post weld heat treat section of the vessel first, then turn the vessel around and heat treat the remaining section. As with local heating, there are restrictions in this case as well over the degree of overlap and the longitudinal temperature gradient. The option of applying a solution heat treatment to the material after welding is not a viable option for large built-up aircraft structures. The expense of solution heat-treating a large structure is prohibitive, but more importantly it would be difficult or impossible to maintain the dimensional stability of the built-up structure. In addition, the propensity for abnormal grain growth, reported by many researchers in the nugget and TMAZ, discourages the use of solution heat treatment following FSW as a primary mode of improving its resistance to corrosion.

IV. WELDING IN UNDERAGED OR PEAK AGED TEMPERS

ANOTHER approach is to weld the material in an under-aged or peak-aged temper, and then apply PWAA to reach the final desired over aged temper in the parent material. This approach attempts to minimize the over aging effect in the HAZ, and to initiate beneficial types of precipitation in the weld nugget to achieve a more uniform precipitate distribution, similar to unaffected parent material in the desired final temper. Several approaches have been tried, mainly re-aging to T6, aging to T73, or aging using retrogression re-aging techniques. Li et al. [2] demonstrated that the resistance to stress corrosion cracking could be restored to 7249-W511, 7249-T651, and 7249-T76511 when aged by various means to a final T7 temper. They also correlated the improvement in SCC resistance to increase in the electrical conductivity of the alloy because of the treatments. A similar finding has also been reported for 7075[6]. This is perhaps the most beneficial treatment reported by other authors to date for the joining of 7XXX series alloys. Welding in an under-aged temper and aging to the desired temper ensures that the parent material is in a known material condition with desirable properties, and yields a weld zone with good stress corrosion cracking resistance and a stabilized structure. However, although it has also been reported that post weld aging can restore the stress corrosion cracking resistance, it has been found to be at the expense of exfoliation resistance in some instances [5]. Retrogression and re-aging treatments have also been tried, but not extensively, and with limited time and temperature schemes [5, 17]. There is some potential benefit for retrogression and re-aging treatments and other multi-stage PWAA treatments, however, so research in these areas continues.

V. LOCALIZED HEAT TREATMENTS

Another novel approach to post-weld artificial aging of friction stir welded joints, suggested by Merati et al. [28], is localized heat treatment of friction stir welds. Since FSW is a process which induces localized thermal gradients and micro structural changes to a material, their approach was to correct it with a localized low temperature artificial aging heat treatment. They were specifically investigating 7475-T7351, which is an overaged temper of an alloy very similar to 7075, and were able to stabilize the weld nugget and restore the materials corrosion resistance. They were able to restore high electrical conductivity to the weld, and were able to restore the stress corrosion cracking resistance as well. Their treatment consisted of a stabilizing treatment at 121°C for 24 hours, plus 195°C for 24 minutes, followed with a final treatment again at 121°C for 24 hours. Other researchers have also been able to restore the electrical conductivity to the FSW region in 7XXX series alloys through PWAA, including Li et al. [11]. They were able to affect significant change in the electrical conductivity of the weld by post weld aging 7249-T6 to the T73 temper. The weld zone showed the highest increase in electrical conductivity, with values higher than the parent material in the nugget and TMAZ, with the highest values achieved in the TMAZ.

VI. CONCLUSION

Friction welding is a more classic process than FSW in terms of use of friction phenomenon. Therefore, many journals have been published on mechanical properties microstructures, modeling, and welding temperature estimation and so on in wide variety of materials from steels to ceramics. However, lack of published works on effect of post weld heat treatment (PWHT) will be a serious problem in near future. This is because the feature of microstructure of friction welding is also grain refinement that is caused by similar mechanism to FSW, that is, dynamic recrystallization. However, the grain growth behavior of friction weld joint has not been studied yet. So it is necessary to investigate thermal stability of microstructures made by friction welding.

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