Chapter 7

Conclusions and Scope for the Future Work

7.1 Summary

FSW process received substantial attention in last decade due to the increasing use of process in various industrial applications. Welding of the heat treatable aluminium alloy is difficult because heat provided by welding process is responsible for the decay of mechanical properties due to phase transformations and softening induced in the alloy. The research in this area has been mainly concentrated to air FSW but very few attempts were made in the area of immersed FSW. By controlling the temperature in immersed FSW, mechanical properties of welded component can be improved. In view of the above advantage possessed by immersed FSW, the present work investigates the effect of FSW parameters on the mechanical properties and microstructural changes occur while FSW of AA2014-T6 in air as well as in immersed condition. In this research work efforts have been made to study the influence of the process parameters on the critical factors such as weld zone temperature, tensile strength and micro hardness. The microstructure evolution has been studied as a part of this work. The results obtained would help in understanding the immersed FSW process better.

7.2 Major Contributions of this Work

In the present study, the influence of FSW parameters on tensile strength during immersed FSW of AA2014-T6 has been investigated. Second order mathematical model has been developed to predict tensile strength by correlating the input parameters namely tool shoulder diameter, rotational speed and welding speed. Significant parameters have been identified for the tensile strength in this study. ANOVA is used to establish adequacy of the developed model. The developed model has been validated using Chi square test and confirmation experiments. It has been observed that shoulder diameter, welding speed and rotational speed significantly influence the tensile strength.
It is observed that an increase in welding speed, initially increases the tensile strength of the welded joint to a maximum value and tensile strength decreases afterward. This could be mainly due to higher heat input in the welded joint at lower welding speed which leads to more flash formation and improper metal consolidation. Also, high welding speed leads to less heat input at the joint and reduces the material movement which produces the internal defects. Tensile strength of joint increases with an increase in rotational speed which reaches its maximum value and then start decreasing. It is due to an increase in the heat input in the welded joint which leads to good material movement and consolidation in the friction stir welded region. Lower tensile strength of joint at lower rotational speed is due to the presence of pin holes and crack in weld region. The tensile strength model developed in this work has been used to ascertain optimal immersed FSW condition for maximization of tensile strength under constraints. GA used for this purpose provides the facility for user to set the desired constraints. The optimum conditions obtained are shoulder diameter as 17 mm, rotational speed as 1211 rpm and welding speed as 104 mm/min, corresponding to maximum tensile strength of 336 MPa. This attempt may be useful in assisting the manufacturer in selection of process parameters in immersed FSW of AA2014-T6.

Taguchi method combined with the grey relational analysis to optimize the immersed FSW weld parameters with consideration of multi performance characteristics namely tensile strength, power consumption and hardness at NZ has been used in this study. It is found from the response table for grey relational grade that shoulder diameter, rotational speed and welding speed at 17mm, 1400 rpm and 80 mm/min respectively result in the largest value of grey relational grade. Therefore, these are the recommended levels of controllable welding parameters when better tensile strength, hardness at NZ and lower power consumption are simultaneously obtained. The ANOVA of grey relational grade for multi performance characteristics revealed that shoulder diameter has highest contribution of 53% among three weld parameters. The effectiveness of use of this approach for immersed FSW of AA 2014-T6 is successfully established by the confirmation experiments.

Thermal numerical modeling of FSW using AA2014-T6 plate for air and immersed conditions has been carried out at rotational speed of 1000 rpm and welding speed of 100 mm/min. Various backing plates namely asbestos, mild steel and copper are considered for this study to check the effect of the same on the temperature profile developed during welding. Commercially available software ANSYS is used to develop thermal numerical model using temperature dependent material properties of AA2014-T6. The coefficient of
friction between a tool and plates has been considered constant throughout the analysis for simplification for both air and immersed condition. The maximum temperature obtained at weld line by simulation is 350.37 °C for air FSW using mild steel backing plate. The experimentally measured temperature is 339.50 °C for similar weld conditions. Thermal numerical simulations are also carried out using other backing plates’ namely asbestos and copper for both air and immersed FSW. It has been observed that the peak temperatures obtained by simulation differs slightly from the temperatures obtained experimentally. This may be due to the variation in coefficient of friction between shoulder and plate with temperature which has been considered constant for the simplification of the simulation. Thus, the simulation results obtained both for air and immersed FSW are in good agreement with those obtained experimentally. It is also observed that the immersed FSW exhibited a narrower high-temperature distribution area compared to air FSW. The simulation results show that FE simulation could be conveniently used to predict effect of the various FSW parameters on the temperature profile. The temperature profiles thus obtained for air and immersed FSW of AA2014-T6 are used to understand their effect on microstructure developed by simulation without doing expensive experiments.

This study also investigates the influence of welding speed, rotational speed and backing plate materials on microstructure and mechanical properties of FSW joints obtained using AA2014-T6 in air and immersed conditions. Boundary separating NZ and TMAZ is more clearly visible in immersed FSW joint than air FSW joint. The temperature profiles obtained for both air and immersed FSW of AA2014-T6 reveal that peak temperature obtained while immersed FSW is lower than that of air FSW. Temperature distribution area having higher temperature is also narrower in immersed FSW. This is the reason for lower dissolution of strengthening precipitates in the immersed FSW joints compared to air FSW joints at same welding parameters. Therefore, microhardness measurement at various locations in NZ of immersed FSW welded joint has higher value than micro hardness obtained for air FSW at same locations in NZ. Dissolution of strengthening precipitates are increased and decreased with an increase in rotational speed and welding speed respectively. This trend of dissolution of strengthening precipitates is common for both air and immersed FSW. It is found that the plate having lower diffusivity has higher weld region temperature. Higher dissolution of strengthening precipitates of weld joint is observed with asbestos backing plate. The ductility of the joint obtained using asbestos as backing plate is the highest among the joints obtained using various backing plates. Higher tensile strength and micro
hardness are attained for the joints produced using mild steel backing plate in immersed FSW compared with other backing plates for same weld parameters. Maximum tensile strength obtained in an immersed FSW joint is around 17% higher than maximum strength obtained by air FSW joint due to lesser dissolution of strengthening precipitates in immersed condition. Obtained results could be utilized to increase the strength of the welded joint used in various industrial applications.

The research work has dealt with the problems that have hitherto not been given much attention. The results will go a long way to increase the mechanical properties of FSW of aluminum alloys and most of the information on such process is augmented through these findings.

7.3 Scope for the Future Work

Present study shows that there is a scope for further work. Accordingly, work in the following areas would be useful:

1. In present work, FSW is carried out for the butt joint configuration and same can be further extended to other weld joint configurations in air and immersed condition to make process more acceptable to various industry associate with fabrication work.
2. Experiments can be attempted with thicker materials with different tool geometries and tool angles which have not been considered for the present work.
3. FSW of dissimilar material combinations like aluminium to steel, aluminium to copper etc. which are industrially useful could be tried in air and immersed conditions. Experiments can be carried out by changing the various welding parameters like rotational speed, welding speed, tilt angle, materials on AS and RS, axial load and tool geometry to obtain optimum mechanical properties in the welded joints.
4. Thermal numerical model developed for air and immersed FSW in present work is without considering the material flow. The comprehensive thermo-mechanical model could be attempted in future which would be more realistic. Thus, developed 3D thermo-mechanical model can be further utilized for parametric analysis.
5. FSW is carried in the solid state without melting of the base material therefore, it is subjected to development of complex kind of residual stresses. In the literature it has
been found that lot of work have been carried out to predict residual stresses developed during fusion welding. Very few attempts were made in the past to predict residual stresses developed while FSW. There is wide open scope to predict residual stresses produced while FSW of aluminium alloys particularly heat treatable aluminium alloys. It is a challenge for the researcher to attempt grey area of residual stresses development by both numerically and experimentally.

6. It is evident from the results of this research work that FSW of aluminium alloy in immersed condition improves microstructure and weld joint strength considerably. It may be useful if such study could attempted for other aluminium alloys.