CHAPTER 7

CONCLUSIONS

7.1 Introduction

The following conclusions have been arrived at after the present study involving the fabrication of the AA6061/AlN\textsubscript{p} composite, dry sliding wear test and friction stir welding of AA6061/AlN\textsubscript{p} composite. The scope for future investigation is also presented at the end of this chapter.

7.2 Thesis contributions

The cast AA6061 alloy and AA6061/AlN\textsubscript{p} composites containing different weight percentage of reinforcement (viz., 5, 10, 15 and 20) were successfully fabricated by using modified stir casting furnace with bottom pouring attachment. It was evident from the optical microstructures and SEM micrographs that AlN\textsubscript{p} were clumped together to spherical shape and distributed uniformly in the matrix and good bonding was obtained between the AlN\textsubscript{p} reinforcement and the aluminium alloy matrix. XRD patterns ensured the presence of AlN\textsubscript{p} in the composites. UTS of the AA6061/AlN\textsubscript{p} composite increased linearly with increase in weight percentage of AlN\textsubscript{p} reinforcement. Both macrohardness and microhardness of the composite increased with increase in weight percentage of AlN\textsubscript{p} reinforcement at the same time, percent elongation of the composite was decreased. Proper process parameters such as stirring speed, incorporation time of AlN\textsubscript{p} in the melt, addition of magnesium as wetting agent, controlled inert argon atmosphere to the melt and bottom pouring attachment in the stir casting furnace attributed to the uniform distribution of
AlN\textsubscript{p} and good bonding of AlN\textsubscript{p} reinforcement with AA6061 alloy matrix results in enhanced mechanical properties. YS and UTS of the AA6061/20 wt.% AlN\textsubscript{p} composite were 158 MPa and 241 MPa respectively which were 92.68% and 46.95% greater than that of AA6061 alloy. Macrohardness and microhardness of the AA6061/20 wt.% AlN\textsubscript{p} composite were 79 BHN and 91HV respectively which were 107.89% and 106.82% greater than that of AA6061 matrix alloy. PE of the AA6061 alloy was found to be 8.91% and reduced to 4.07% in AA6061/20 wt.% AlN\textsubscript{p} composite.

The dry sliding wear behavior of AA6061/AlN\textsubscript{p} composite was evaluated using the pin-on-disc apparatus. Four factor, five level central composite rotatable design matrix was used to conduct the experiments. To predict the wear rate of AA6061/0-20 wt.% AlN\textsubscript{p} composite, regression model was developed by incorporating significant parameters such as sliding velocity, sliding distance, normal load and percentage of AlN\textsubscript{p} reinforcement in the matrix. Conformity tests were conducted to validate the developed regression model. It was found that the accuracy of the prediction of wear rate of AA6061/AlN\textsubscript{p} composite was within ± 6% of their experimental values. Wear rate of the composite linearly increased with increase in sliding velocity, sliding distance and normal load. Wear rate of the composite decreased with increase in amount of AlN\textsubscript{p} reinforcement. The wear rate of AA6061 alloy and AA6061 matrix composite reinforced with 10 and 20 wt.% of AlN\textsubscript{p} were 722 x 10\textsuperscript{-5} mm\textsuperscript{3}/m, 411 x 10\textsuperscript{-5} mm\textsuperscript{3}/m and 232 x 10\textsuperscript{-5} mm\textsuperscript{3}/m respectively.

Worn surface of AA6061/AlN\textsubscript{p} composite was examined by using SEM micrographs to identify the possible wear mechanism during dry sliding. The worn surface of composite tested at higher sliding velocity, sliding distance and normal load was exposed with deeper grooves, crater, delamination and cracks. At higher sliding velocity delamination was the primary wear mechanism along with ploughing and abrasive mechanisms. At higher sliding distance and normal load the dominant wear mechanism was delamination. Worn surface of
the composite reinforced with maximum wt.% of AlN_p reinforcement was found to be abrasive wear mode.

AA6061/0-20 wt.% AlN_p composite was successfully joined by friction stir welding process. Experiments were conducted as per four factor, five level central composite rotatable design matrix and their UTS, PE and WR were estimated. Regression models were developed to predict the UTS, PE and WR of FS welded AA6061/AlN_p composite joints by incorporating significant parameters such as tool rotational speed, welding speed, axial force and percentage of AlN_p reinforcement in the matrix. Conformity tests were conducted to validate the developed regression models. It was found that the accuracy of prediction of UTS, PE and WR of FS welded AA6061/0-20 wt.% AlN_p composite joints was above 93% at 95% confidence level. The parameters considered in this study such as tool rotational speed, welding speed, axial force and percentage of AlN_p reinforcement independently influenced the UTS, PE and WR of the weld joints over the entire range of parameters studied in this work.

UTS of the FS welded joint increased linearly with increase in percentage of AlN_p reinforcement from 0% up to a level of 20%. Defect free weld joints were obtained for narrow range of process parameters. UTS of FS welded AA6061 alloy, AA6061 alloy matrix reinforced with 10 and 20 wt.% AlN_p composite joints were 152.94 MPa, 181.12 MPa and 225.14 MPa respectively under the same FSW process parameters value. PE of the FS welded joint reduced with increased weight percentage of reinforcement in the composite. WR of the FS welded composite joints decreased with incorporation of higher weight percentages of reinforcement. Heat generated at the weld joint during FSW did not influence the WR of FS welded joints. WR of FS welded AA6061 alloy, AA6061 matrix reinforced with 10 and 20 wt.% AlN_p composite joints were 504 x 10^{-5} mm^3/m, 366 x 10^{-5} mm^3/m and 225 x 10^{-5} mm^3/m respectively. Wear rate of FS welded composite joints was less than that of its corresponding base composites under the same wear testing conditions.
FSW process parameters were optimized to maximize the UTS under seven different conditions including maximization of UTS, maximization of UTS at higher welding speed, minimization of WR by using the generalized reduced gradient method. Conformity tests were conducted to validate the optimized conditions. UTS of the joint fabricated at the optimized FSW parameters (OP1-tool rotational speed of 1217 rpm, welding speed of 51.68 mm/min, axial force of 5.09 kN and AlN_p of 20 wt.%) was 227 MPa and found to be maximum.

Macrostructure of friction stir welded AA6060/AlN_p composite joints exhibited different metallurgical zones such as weld zone (WZ), thermomechanically affected zone (TMAZ) and heat affected zone (HAZ). Optical photomicrographs of various metallurgical zones obtained were analyzed. Microstructure of HAZ of composite was almost similar to its corresponding base composite. In TMAZ, ceramic reinforcement particles and aluminium matrix grains were stretched along the shear stress directions. From the optical microstructure, it was found that recrystallized aluminium matrix grains were found at the WZ. The optical and SEM micrographs captured at WZ of composite joints revealed homogeneous distribution of AlN_p in the WZ. It was also noticed that number of AlN_p was increased while size of AlN_p was reduced in the WZ as compared to that of corresponding base composite.

Microhardness survey was carried out across the various metallurgical zones on the selected FS welded composite joints based on the percentage of reinforcement and magnitude of the heat generated in the joint during FSW. In all the specimens, maximum microhardness was obtained at the WZ irrespective of the weight percentage of the reinforcement and heat input. Microhardness of the WZ of FS welded AA6061 alloy joint was 48.4 HV, and that of FS welded AA6061 matrix composites containing 5, 10, 15 and 20 wt.% AlN_p were 72.9, 91.7, 108.4 and 132.6 HV respectively (made with almost same heat input condition). Microhardness of the WZ of AA6061/20 wt.% AlN_p composite joint
made using maximum UTS optimized condition was 133.8 HV and found to be maximum.

Fractography and worn surface morphology of the FS welded AA6061 alloy and AA6061/AlN_p composite joints were analyzed with the help of SEM micrographs. From the fractography analysis the mode of failure of the FS welded AA6061 alloy was found to be ductile and failure of the composite was more brittle at higher percentage of reinforcement. Wear mechanism of aluminium alloy joint was plastic and that of composite containing higher percentage of AlN_p reinforcement was changed from plastic to abrasive.

**7.3 SCOPE FOR FUTURE STUDY**

1. Fabrication AA6061/AlN_p composite with more than 20 wt.% of AlN_p may be attempted using modified stir casting process and their mechanical properties may be studied.

2. AMCs incorporated with different sizes of AlN_p could be fabricated and their mechanical and metallurgical properties can be compared.

3. Post weld heat treatment (age hardening) of friction stir welded joint could be done and its mechanical properties can be analysed.

4. Laser-friction stir hybrid welding on AA6061/AlN_p composite could be carried out and those joint properties can be compared with composite joint made by FSW.

5. Tool wear rate during FSW and its effects could be analyzed.

6. Secondary process such as cutting, machining, etc of AA6061/AlN_p composite could be carried out.

7. Finite element simulations of FSW could be carried out to study the effects of FSW process parameters and different tool profiles on weld quality.