ABSTRACT

In modern engineering industry, aluminium matrix composites (AMCs) have now replaced traditional monolithic alloys, as AMCs have excellent mechanical, thermal and tribological properties. Due to continuous development in production methods of AMCs reinforced with particulate form of ceramic reinforcements, AMCs are increasingly employed in aerospace, automotive industries, etc. As aluminium nitride (AlN) has high specific strength, high thermal conductivity, high electrical resistivity, low dielectric constant, low coefficient of thermal expansion and good compatibility with aluminium alloy, Al/AlN composite is extensively used in electronic packaging industries.

Though AMCs are processed by many methods, stir casting process is commonly employed to fabricate AMCs as it is economical, flexible and near net shape with uniform distribution of reinforcement phase can be achieved. Welding of AMCs is indispensable in many engineering applications. Hence, to achieve widespread industrial applications of AMCs, it is necessary to develop a suitable welding procedure. But fusion welding of AMCs encounters many problems including segregation of particles, decomposition of particles, etc., resulting in reduced joint strength. Solid state welding process is an appropriate process for joining AMCs to avoid those problems. Among various solid state welding processes friction stir welding (FSW) is a low energy, hot shear, and solid state welding process that is most suitable for joining AMCs.

In the present research work, an attempt was made to fabricate AA6061 matrix composite reinforced with aluminium nitride particles (AlNₚ) by
modified stir casting process and those AMCs were joined using FSW process. A
detailed study on the metallurgical characterization, mechanical characterization
and dry sliding wear behaviour of as-cast composites and friction stir welded
composite joints were made.

AA6061 cast alloy and AA6061 matrix composite reinforced with 5,
10, 15 and 20 wt.% of AlN$_p$ were fabricated using a modified stir casting
electrical furnace with bottom pouring attachment. Metallurgical and mechanical
properties of the composite were analysed. X-ray diffraction patterns ensured the
dispersion of AlN$_p$ reinforcement in AA6061 matrix. Optical and SEM
micrographs revealed the homogeneous distribution of reinforcement particles in
the matrix. Strength and hardness of the composites increased with increase in
amount of AlN$_p$ reinforcement in the matrix. Yield strength (YS) and ultimate
tensile strength (UTS) of the AA6061/20 wt.% AlN$_p$ composite were 158 MPa
and 241 MPa respectively which were 92.68% and 46.95% higher than that of
AA6061 alloy. Macrohardness and microhardness of the AA6061/20 wt.% AlN$_p$
composite were found to be 79 BHN and 91VHN respectively which were
107.89% and 106.82% higher than that of AA6061 alloy. But, percent elongation
(PE) of the composite decreased with increase in wt.% of reinforcement. PE of
the AA6061 alloy was found to be 8.91% and reduced to 4.07% in AA6061/20
wt.% AlN$_p$ composite.

Dry sliding wear behavior of AA6061/0-20 wt.% AlN$_p$ composite was
investigated at room temperature by using a pin-on-disc wear testing apparatus.
A regression model was developed to predict the wear rate (WR) of the
composites by incorporating the significant parameters such as sliding velocity,
sliding distance, normal load and wt.% of AlN$_p$ reinforcement in the matrix. A
A four factor, five level central composite rotatable design matrix was used to minimize the number of experimental runs. A regression model was developed using statistical software SYSTAT 12. Conformity tests were conducted to validate the developed regression model and it was found that the accuracy of prediction of WR of composites was within ± 6% of their experimental values. The regression model indicated that the WR of AA6061/AlN<sub>p</sub> cast composite decreased with increase in the wt.% of AlN<sub>p</sub> and increased with increase of the sliding velocity, sliding distance and normal load acting on the composite specimen. The possible sliding wear mechanisms were examined with the help of SEM micrographs of worn surface. It was found that at higher sliding velocity delamination was the dominant wear mechanism along with ploughing and abrasive mechanisms. At higher sliding distance and normal load the principal wear mechanism was delamination. When the wt.% of AlN<sub>p</sub> reinforcement in the matrix was maximum, wear mechanism of composite was found to be abrasive.

AA6061/AlN<sub>p</sub> composites were welded by FSW process using a design matrix which was a four factor, five level central composite rotatable design and their UTS, PE and WR were estimated. Significant factors considered for this investigation were tool rotational speed, welding speed, axial force and percentage of AlN<sub>p</sub> reinforcement in the matrix. Heat generated in the joint during FSW was calculated. Regression models were developed to predict the UTS, PE and WR of the friction stir (FS) welded AA6061/AlN<sub>p</sub> composite joints using statistical software SYSTAT 12 and those models were validated by conducting conformity tests. From the conformity tests it was found that the accuracy of prediction of UTS, PE and WR of FS welded AA6061/0-20 wt.% AlN<sub>p</sub> composite joints was above 93% at 95% confidence level. The regression models indicated that when the amount of AlN<sub>p</sub> reinforcement in matrix was
increased UTS of the joint increased whereas PE and WR decreased. The developed regression models were optimized using generalized reduced gradient method for seven different conditions such as maximization of UTS, minimization of WR, maximization of UTS at higher welding speed and so on. It was found that the maximum UTS of the FS welded joint fabricated at maximum UTS optimized condition was 227 MPa.

Metallurgical characterization such as microstructural analysis and microhardness survey of FS welded AA6060/AlN\textsubscript{p} composites joined at different heat input conditions were carried out to study the properties of various metallurgical zones. Microstructure of heat affected zone (HAZ) of composites were almost similar to its corresponding base composites. In thermomechanically affected zone (TMAZ), ceramic reinforcement particles were stretched along the shear stress direction. AlN\textsubscript{p} were homogeneously distributed in the weld zone (WZ). Number of AlN\textsubscript{p} was increased while size of AlN\textsubscript{p} was reduced in the WZ as compared to that in base composite.

Microhardness survey was carried out across the various metallurgical zones of the FS welded AA6061/AlN\textsubscript{p} composites. Maximum hardness was obtained at the WZ irrespective of the wt.% of the reinforcement. The maximum microhardness of WZ of FS welded AMCs joined at maximum UTS optimized condition was found to be 133.8 HV. Fractography and worn surface morphology of the FS welded composites were analyzed. Fractography confirmed the brittle failure of the composite containing higher wt.% of reinforcement. Wear mechanism of aluminium alloy joint was plastic and changed to abrasive wear mechanism when more reinforcement particles were incorporated in the matrix.