CHAPTER 8

CONCLUSIONS

FSW is a formidable development in material joining process. It is considered as a better option for joining aluminium alloys. In this scenario, two extreme cases can be considered; precipitation hardened alloys and solid solution hardened alloys. Both these are weldable by conventional fusion welding processes. However, precipitation hardened alloy welds were found to be more defective under fusion welding. Hence FSW is a promising technology for these types of aluminium alloys. In this work FSW of precipitation hardened alloys were dealt with by considering AA 2219 O and AA 6082 T6 alloys as representative examples. The effect of various parameters on the strength and microstructure were analysed. The parameters were so chosen that they can be easily adjusted in the dedicated machines presently available. Simple tool geometries with tapered, cylindrical and threaded pin profiles were selected so as to minimize the initial cost. The welding is performed at higher linear speeds to enhance the productivity. Hence the experimental analysis focused on the commercialization and popularisation of the technology.

Effect of axial force on the FSW was explored taking AA 6082 – T6 as the base metal. Experiments were conducted by varying the axial force when other parameters were kept constant. Process parameters considered were tool rotational speed and tool translational or linear speed with a threaded pin profile.

Even for these parameters selected form a ‘process window’ for good weld conditions as recommended by previous studies, axial force was found to influence the weld properties significantly.
UTS vary with axial force and this variation was attributed to the defect formation. This effect is justifiable as the axial force influences the material flow during welding. The macrographs showed onion ring formation and with surface defects in case of some welds. However 4 kN axial force produced welds with adequate material flow depicted by good onion ring structure and with no defects. This fact was substantiated by the mode and location of the tensile fracture. Welds with low tensile strength due to defects were having a brittle fracture with no neck formation and the fracture occurred at the NZ. In the case of welds formed with 4 kN and 5 kN axial force, the axial force was found to have strong influence in material flow for a given shoulder diameter.

Microhardness of the welds was significantly higher than the base metal. The microstructural characterization revealed that NZ underwent dynamic recrystallization and showed presence of fine fragmented particles of $\text{Mg}_2\text{Si}$. This was the possible reason for the enhancement in hardness for all weld specimens. However, the axial force appeared to have no effect on the re-precipitation of the strengthening particles which indicated that the heat flow is least influenced by the variation in axial force. All these factors along with the microstructure of the shoulder zone, pointed out that the axial force was ineffectual to bring about any substantial change in the weld microstructure.

Effect of process parameters on the FSW of AA 2219 - O were analyzed by varying tool rotational speed, tool linear speed, axial force and tool pin profile. The welding was performed at speeds in a range (100 - 150 mm/min.) higher than the generally reported studies. Three types of simple tool pin profiles were used in the experimental campaign namely; tapered, cylindrical and threaded pin profiles.
The selected range of parameters set a hot weld conditions as indicated by the weld appearance and the axial force values were high so that the shoulder couldn’t confine the weld material along the weld line as indicated by the flashes associated with most of the welds. But it is noteworthy that the base material AA 2219 - O is a soft alloy in annealed condition.

Taguchi analysis of the experimental results showed that tool pin profile is the most influential process parameter. Threaded pin profile and tapered pin profile provided the best results for the UTS. The microhardness for threaded pin profile and tapered pin profile registered higher values than that of the base metal. Microstructural analysis indicated that threaded pin profile resulted in grain reorientation and re precipitation of Al₂Cu as fine and undissolved particles. For the precipitation hardened alloys, the distribution of strengthening particles determine the strength, rather than the grain size. EDS analysis showed that precipitation of Al₂Cu particles was more for the threaded pin profile. This is the reason for the better strength for the welds produced using threaded pin profile. Higher values of microhardness values welds also substantiated the presence of more precipitates in case of these welds. As the rotational speed and linear speed determine the heat flow and the pin profile influences the material stirring, the impact of pin profile on the degree of precipitation of strengthening particles can be considered as a general characteristic for the precipitation hardened alloys.

FSW of AA 6082 – T6 was performed at the highest linear speed ever reported (600 mm/min, 700 mm/min.) for the considered thickness (6 mm) with a common tool with threaded pin profile to check the feasibility of the process. Apart from the tool rotational speed and linear speed, effect of tool tilt was inquired. A tilt for the tool was recommended for producing good weld was reported in the previous studies. Strength
of the welds were analysed in terms of UTS. Since, welding defects were expected at higher speeds, macrostructure of the weld cross sections were studied. Microstructure evaluation was carried out using microhardness tests and optical micrography.

It was observed that FSW at higher welding speeds was feasible for the given parameters; however the tilted tool produced defective welds. Taguchi analysis of the experimental results proved that the tool tilt was the most influential parameter deciding the weld strength. The weld pressure at higher welding speed was possibly low and the tool tilt caused further depletion in welding pressure. In these cases, the pressure was reduced below a limiting value which was required to avoid volumetric defects. The macrostructure vindicated this fact as it showed that weld material flow for the welds with a tool tilt was not synchronised and periodic. Microhardness of the welds was found to be lower for welds produced with a tool tilt. Hence it can be concluded that tool tilt is detrimental at higher welding speeds or causing a reverse effect at higher welding speeds.

An analytical model was suggested for the FSW of aluminium alloys based on the slip factor with simple tool having cylindrical pin. An expression for slip factor is suggested which represented slip as a partition of frictional work and work of plastic deformation. The slip factor is expressed in terms of the tool torque. It is noticeable that tool torque increases at higher welding speeds. The model enabled computation of maximum temperature in the FSW process. The proposed model has taken partial slipping and partial sticking tool contact conditions in to consideration. That could be the reason that the model displayed errors in the computation of maximum temperature for lower welding speeds. At lower welding speeds slipping contact conditions dominated during welding process. However, at higher welding speeds the model displayed better results for maximum temperature with minimum error when it
is compared with experimental results. The maximum temperature value will be useful in deciding the process parameters if the variation in flow stress of the alloys with temperature is known.

The present experimental work sought the effect of process parameters on FSW of aluminium alloys at higher welding speeds along with the microstructural analysis. Further study is needed to suggest a process window helps to suggest various process parameters with simple tool geometry at higher speeds. This will support the commercialisation of the FSW technology.