CHAPTER 5

CONCLUSIONS

According to the objectives laid down by the author, the experimental work was carried out and necessary tests were conducted within the limited resources. The results found will provide guideline for conducting research and also will help industry to adapt it. The extracts of the experiments are drawn and narrated below briefly. It's an eye opening type of research work, will give fundamental understanding about how, where to start and execute the work systematically touching the covert variables and design invisibles.

5.1 THE CONCLUSIONS DRAWN FOR CFSW

- It is essential to use proper fixture to clamp the substrate rigidly so that its position is restrained. Equal attention and importance should be given to clamping system.
- From the tensile test result the conclusion was carried out that the weld sample prepared at 765 rpm tool rotation speed and 120 mm/min welding speed with hexagonal pin profile that possess the highest ultimate tensile strength of value 144 MPa with elongation of 21.88% and fracture occurred at the base metal region indicating pure ductile behavior. In case of weld prepared by square pin profile with 765 rpm and 1070 rpm at 78 mm/min welding speed possess the ultimate tensile strength of value 125MPa and 128MPa and elongation of 25.56% and 20.84% respectively. The fracture occurred at the base metal region at the advancing side of weld, indicating pure ductile behavior.
- The weld sample prepared by the hexagonal pin profile that possess the lack of penetration and the samples made by the square pin profile that possess the tunnel defect in small region at end portion of weld.
- The weld prepared by square pin profile possess good mechanical properties compare to hexagonal pin profile

- From the Brinell hardness profile the observation was carried out that there was an average 57% decreases in the hardness of weld region compare to base metal.
- From the face bend test result it is concluded that there was no cracking observed after testing and result meets the requirements of the ASME section IX.
- From the electrical conductivity measurement it was confirm that there was negligible decrease in electrical conductivity after welding which also indicating that the grain refinement was took place in the weld region.
- With increase in the tool rotation speed, in the weld center region, the plastic deformation of the material increases, which lead to the deformation of the grain structure.
- The stirring action of the tool leads to the breaking and cutting of the coherent precipitates of the Mg_2Si by gliding of dislocation. The stirring action also helps in the distribution of the Mg_2Si precipitates.
- With increase in the tool rotation speed and traverse speed, the heat input increases, because the friction generated between the tool material and work piece material. The heat input affects the size of the nugget formation. With increases in the heat input, the size of nugget also increases which would lead to discontinuity in the microstructure. The nugget comprise of the onion ring structure with fine equiaxed grains with heavy density precipitates and coarse grains with low density precipitates of the Mg_2Si precipitates The microstructure comprise more coarse grains of Al with low density precipitates of Mg_2Si with increase in the welding speed and tool rotation speed.
- The thermal dissolution of precipitates and re-precipitation increases with increase in the welding speed and tool rotation speed.
- The TMAZ, it is the zone characterized with the gradient of the plastic strain and the temperature. In this zone there is no stirring action take place, the material deform with increase in the temperature. The level of deformation is less compare to weld Center region. It consist of fine grains of Al with the presence of ripen precipitates of the Mg_2Si there is also formation of precipitates free zone.
- In the HAZ there is only temperature gradient exists. So it consist of the coarse grain structure with presence of Mg_2Si precipitates. There was also some

precipitates free zone in the HAZ. With increase in the tool rotation speed and welding speed the grain refinement was observed in HAZ either at advancing side or at retreating side. At tool rotation speed of 1070 rpm the grain refinement was observed in HAZ of both side that is an advancing side as well as at retreating side.

5.2 CONCLUSIONS FROM CORROSION STUDIES

- FSW welding results into formation of distinguished zones namely nugget, TMAZ, HAZ.
- HAZ (heat affected zones) and TMAZ (thermo mechanically affected zones) are of more of the interest as they incorporate the most thermal and mechanical stress which make them most likely to be attacked by environment.
- In case of HAZ the passivity film may be or may not be repairable, it depends on the heat input & extent of heat distribution.
- Among all the samples welded with rotational speed of 1070 rpm shows pitting resistance in HAZ.
- From overall observation, it can also be concluded that at all rotational speed and at low welding speed, pitting resistance is observed.
- In general high rotational & low welding speed results into less distorted HAZ & TMAZ and hence better pitting resistance.

5.3 CONCLUSION DRAWN FOR BFSW

Out of different tools developed for BFSW, convex shoulder bobbin tool gave good quality welds and defect free joints. The tool so developed is capable to weld different plate thickness within limit. The sheets or plates manufactured are always has some variations in the thickness which is very critical issue during welding. Variations in the manufacture of sheets can be taken care of by this design of fixed gap bobbin tool, which itself is an innovative design.

The need for developing a fixture for BFSW should not be taken lightly. It is an important aspect to be considered for quality weld by friction stirring. It will help in easy clamping of the substrate and will save setting time.

Secondly the fixture developed for BFSW research work is also a new thinking as no such designed fixture is presented in the literature. The fixture is also having economical and flexible design which can accommodate plates of different thicknesses.

It concludes that the tool design plays an important role in deciding the quality of weld. The samples welded by the convex bobbin tool were clear in X-Ray radiography and no defect was found in the weld nugget.

The macrostructure of weld cross section show an hour glass profile.

5.4 CONCLUSION DRAWN FROM IR THERMOGRAPHY

Infrared Thermography is a new dimension explored in this research work. Very few researchers have tried to use this excellent device but still there is a scope to explore it in a complete sense.

In case of BFSW the temperature on retreating side is always higher than that of advancing side. While in CFSW the case is reverse. The highest temperature in BFSW of AA 6082 alloy is found to be less than 400 ^{o}C while in case of CFSW it crosses the limit of 400 ^{o}C.

The tool design plays a vital role in deciding the temperature distribution as well as the grain structure. The process parameters also has an equal impact on quality of weld. Very fine grains are found in welds made by convex shoulder, square pin, and fixed gap bobbin tool. There is absolutely no difference between weld joint and base metal, an excellent microstructure ever found.

5.5. LIMITATIONS

Limitations of the studies can be divided into four areas: the approach, the material and the platform used. In term of approach, an explorative study was used compared to the design of experiment method. Because in the statistical method factors are required to be under control, which is not the case at the beginning of the study. The impact of substrate clamping, rigidity and tool features were not well-known in the literature. The study was done in a piecemeal manner by the researchers and few data were missing which required detailed study for developing understanding of the process.

Secondly the material available in the local market was taken for experiment and then different grades were procured from outstate. The material was found to have different thickness at different areas, so uniformity of the thickness was questions which was never taken into consideration in the past. Hence the fixture and tool design needs to accommodate this variation.

The third factor i.e. welding platform is also equally important. A dedicated industrial FSW machine was not available, and the studies were started from conventional manual milling machine. The work was started from procurement of milling machine, which consumed a lot of time. The welding by bobbin tool was carried out on CNC milling machine.

It was intended to explore IR Thermography and for that IR camera was procured, but it was received too late to work extensively on it. It has a wide scope to work upon this new dimension.

5.6 FUTURE WORK

The present research work has provided a fundamental understanding of FSW process and feasibility of incorporating this technology with existing and developed resources to weld aluminium alloys in the abutting configuration and characterized mechanically & metallurgically, which covered tensile testing and microstructural development, as well as corrosion behaviour in aluminium alloys 6xxx welds. Future work is still required to quantify the FSW process with variable weld process parameters that would concentrate on the following aspects:

- Design of experiment approach to identify sensitivity to various factors. There is a need to develop a better understanding of how the process variables relate together in BFSW and thereby predict weld quality. Additionally, process window can be proposed to the users as a quick reference for establishing parameters for a successful weld.
- Dimensional accuracy and consistency need to be better understood to know impact of temperature variations on tolerance and accuracy.
- Development of portable friction stir welding machine to achieve in-situ welding.
- Development to operate at higher feed rates or higher welding speed without affecting weld quality.
- Comparative study for temperature variations using thermocouple and IR Thermography together. A database need to be developed so that in future directly IR thermography can be used as a tool for thermal analysis without temperature measurement by touch method through thermocouples.