Chapter 10

CONCLUSIONS AND FUTURE SCOPE OF WORK

10.1 CONCLUSIONS

The following are the conclusions drawn from the current research:

IMPROVEMENT OF FRICTION WELDED JOINT BY REVERSING THE PROGRESSION OF WELDING

1) In this research, the friction welding process was improved by reversing the progression of welding by designing a new joint geometry. In new joint geometry welding is initiated from the inner region and it progresses to outer region. The shape of new joint geometry helps in uniform heat generation at the weld interface and it facilitates in destruction and removal of oxides and other contaminations from the inner region of weld interface. The uniform temperature, removal of oxide layer, and progression of welding from inner to outer region, helped in preventing the formation of unbound zone at the inner region of the weld interface which results in better weld strength.
2) The weld strength of new joint geometry is compared with regular joint geometry. It was observed that the weld strength of new joint geometry was more than the regular joint geometry. The ultimate tensile strength with new joint geometry for Al 6061 to SS 304 was 278.56 MPa whereas for regular joint geometry it was 254 MPa. Similar trend was observed in weld combinations of Al 5052 to SS 304, Pure Al to SS 304, Al 6061 to copper and pure Al to copper.

3) The new joint geometry provides better and uniform weld strength along the bond line which was a major issue in the regular joint geometry. Regular joint geometry does not provide the uniform weld strength, weld strength is less in inner region (center portion) when compared to outer region because of unbound region, entrapment of oxides and other contaminations in the inner region.

4) In new joint geometry the material consumption was less than regular joint geometry. It helps in material cost saving by 46% to 56% when compared to regular joint geometry.

5) The weld interface temperature of new joint geometry was less than regular joint geometry (at optimum conditions). It was observed that the weld interface temperature with new
joint geometry was 54% to 87% less than regular joint geometry.

6) In new joint geometry of Al 6061 to SS 304, weld strength increases as friction time increases from 0.5 second to 1 second then it decreases as friction time further increases from 1 second to 3 seconds. The material consumption and weld interface temperature increases as friction time increases.

7) In new joint geometry, burrs are formed along with flash which helps in destruction and removal of oxides and other contaminations from the weld interface, thus it enhances the weld strength.

MACRO STRUCTURE, MICROSTRUCTURE AND MICROHARDNESS ANALYSIS

8) In microstructure analysis, it is observed that new joint geometry prevents or controls the formation of intermetallic compounds. In new joint geometry, either no intermetallic compounds were formed or a very thin layer of intermetallic compounds was formed with almost uniform thickness, where as in regular joint geometry the intermetallic thickness increases as the radial distance increases from centre (Along weld line) and again it decreases. The thickness of intermetallic
layer follows heat generation pattern except at the periphery
due to squeezing out of intermetallic compounds during upset
phase and the intermetallic thickness increases as friction
time increases due to increase in temperature.

9) In weld combination of aluminum alloys to SS 304 and
Copper, it was observed that the grain size of Al alloys was very
fine at the weld interface due to mechanical crushing of grains
during the course of wearing of the surface layers of the metal
resulting from friction and plastic deformation. The grain size
decreases as the distance from the weld line decreases. There
is negligible change in microstructure of SS 304.

10) In new joint geometry, the heat affected zone (HAZ) near
the weld interface was less than regular joint geometry.

11) The X ray diffraction technique was used to identify the
intermetallic compounds formed during the welding process.
The intermetallic compounds for weld combination of Al 6061 -
Copper are Al₂Cu₃, AlCu₄ and CuAl₂ and the intermetallic
compounds for weld combination of Al 5052 - SS 304 are
FeAl₂ and AlFe.
12) Experiments are conducted as per design of experiment approach to characterize the friction welding process for Al 6061 to SS 304. It was observed that rpm, forging pressure and friction pressure have maximum influence on the tensile strength. The weld strength decreases as rpm and friction time increases. Weld strength increases as forging pressure increases. Forging time has least effect on weld strength.

13) Friction time has maximum influence on upset and weld interface temperature. The upset and weld interface temperature increases as friction time increases.

14) Mathematical model was developed to predict weld strength, upset and weld interface temperature in terms of weld parameters.

15) Acceptance criteria was developed for friction welding of Al 6061 to SS 304. Data acquisition system was developed for on line monitoring of friction welding process. Excellent weld strength was obtained when upset was in between 7 mm to 9 mm and weld interface temperature was in the range to 150°C to 300°C.
EFFECT OF UPSET CONDITION ON WELD STRENGTH, INTERFACE TEMPERATURE AND MATERIAL CONSUMPTION

16) In friction welding, it was observed that, the optimum selection of weld parameters such as rpm, friction pressure, friction time, forging pressure and forging time are not sufficient to achieve sound weld but selection of proper upset condition like application of upset pressure in constant feed or rapid feed and application of upset pressure (0.6 seconds) before braking or after braking are extremely important, without this sound weld cannot be achieved. In friction welding of Al 5052 to SS 304 maximum yield strength of 180.79 MPa and maximum ultimate tensile strength of 227.82 MPa was obtained when upset pressure is applied after breaking and under rapid feed.

FINITE ELEMENT ANALYSIS OF FRICTION WELDING PROCESS FOR DISSIMILAR MATERIALS

17) Finite element thermo mechanical model was developed using ANSYS and Abaqus which helps to predict the weld interface temperature, deformation and stresses. The temperature predicted by FE model helps in controlling intermetallic compounds formation. Maximum temperature predicted for weld combination of Al 6061-SS 304 was 223.89°
C. and the maximum stress observed was 115 MPa. It was observed that the finite element results were closely matching with the experimental values. The finite element also helps in determining optimizing optimum parameters and ways to improve the design and manufacturing of special purpose weld machines.

IMPROVEMENT OF FRICTION SPOT WELDING PROCESS

18) A new friction spot welding process with new joint design was developed to overcome the problems associated with friction stir spot welding process and refill friction stir spot welding presses. Maximum weld strength of 3.54 KN was obtained with new friction spot welding process for Al 6061 sheet and steel sheet (with steel rod as filler material) and this is higher than conventional friction stir spot welding process due to direct welding of steel sheet to steel filler material, interlocking feature of new design, large contact area and effective destruction and removal of oxides layer from the weld interface.

19) The microstructural analysis of new friction spot welded specimen shows excellent weld joint without any weld defects. It was observed that a very fine grain size is obtained at the weld interface due to mechanical crushing of grains during the course of wearing of the surface layers of the metal resulting
from friction and plastic deformation and the grain size decreases as distance from weld line decreases.

20) Better shear strength is obtained by new friction spot welding with copper filler rod when compared to friction stir spot welding process. In new friction spot welding of Al 6061 sheet to Al6061 sheet (with copper as filler material) has maximum shear strength of 3.21 KN.

**10.2 FUTURE SCOPE OF WORK**

1. Design of experiment can be used to characterize the new friction spot weld process.

2. Mathematical model can be developed to predict shear strength of spot welding.

3. Finite element analysis of new friction spot welding process can be done to optimize the weld strength.