CHAPTER 6

CONCLUSIONS AND FUTURE SCOPE

The following conclusions were arrived for the DB samples low-carbon steel grade AISI 1018 with AISI 304L base metal with AISI 304L steel interlayer.

- The diffusion-bonded samples processed at 900 °C exhibited the maximum tensile strength of 340.5 MPa. At low temperature, the bond strength was lower due to the lack of diffusion and poor contact between the surfaces. At 950 °C, the strength of the joint decreased due to grain coarsening of the base metal.

- The diffusion coefficient values were estimated for ‘Cr’, ‘Ni’ and ‘Mn’, which were higher than the values reported by previous authors due to increase in bonding time.

- At 900 °C, the maximum hardness value of 402.2 VHN at the steel to interlayer AISI 304L interface was observed. The increase in hardness value was observed in all the samples processed at 950 °C due to the diffusion of ‘Cr’ into steel and the formation of Cr$_{23}$C$_6$, CrC and Fe$_3$C at the interface and adjacent region.

- XRD reports revealed the formation of Mn$_3$Si, Cr$_3$Ni$_5$Si$_2$, and ‘α’ phase in the interface. These compounds were not affecting the bond strength. They imparted dispersion
The fracture took place at the low-carbon steel grade AISI 1018 base metal region. The low-carbon steel grade AISI 1018 was the weakest component in the joint in comparison with AISI 304L and interface. The reason was grain growth in low-carbon steel grade AISI 1018 side.

The optimum parameters for DB of low-carbon steel grade AISI 1018 with AISI 304L steel with AISI 304L interlayer was a bonding temperature of 900 °C, holding pressure 10 MPa and a bonding time of 90 min.

The following conclusions were arrived from the experiment on the DB samples of duplex stainless steel SAE 2205 with medium–carbon steel AISI 1035.

Diffusion bonding of DSS with medium carbon steel AISI 1035 was successfully carried out in the temperature range of 850-975 °C, bonding pressure 20, 30 MPa and bonding time 60, 90 min.

The DB samples processed at temperature of 975 °C, a bonding time of 90 min and a holding pressure of 20 MPa yielded a maximum shear strength of 360.9 MPa.

The statistical analysis of the data using MINITAB 15 trial version resulted in arriving at the optimum temperature range for bonding as 950-975 °C, bonding pressure 20 MPa and a bonding time 90 min.
The DB samples exhibited a shear strength of 79.6% and 88.7% for the base metals DSS and AISI 1035 steel respectively.

The width of the reaction zone and shear strength of the joints were increased with respect to rise in temperature.

The maximum shear strength had direct relationship with the surface contact area, process parameters such as temperature and bonding time. The contact area increased with respect to rise in temperature and holding pressure at higher temperatures. At the process parameter 950 and 975 °C and holding pressures 20 and 30 MPa, 100% contact between the contact surfaces was achieved and resulted in higher bond strength.

As the surface contact area increased the shear strength also increased, this was due to the formation of a void free interface at higher DB temperature and pressure.

The diffusion coefficient values were estimated for Cr, Ni, Si, Cu, Mo and Mn. The diffusivity of above said elements into AISI 1035 from SAE 2205 duplex stainless steel was increasing with respect to increase in bonding temperature.

A maximum microhardness value of 634.9 VHN was obtained at the interface for the samples processed at 975 °C. The strength of the joints was not affected due to the presence of carbides and intermetallics at the joint region for the samples processed at the temperatures above 950 °C. These hard phase particles imparted dispersion strengthening effect.

The EDAX and XRD analyses confirmed the presence of compounds such as ‘σ’, CuFe, FeNi, Fe₂Si, Mn₃Si, MnV,
Fe₂VSi, CrC, FeC, FeN, CrN, CrO₂ and FeO₂. The formation of these compounds did not impair the shear strength of the joints.

- Volume diffusion mechanism in the grain matrix and along the grain boundaries for various elements was evidenced in the diffusion-bonded joints. Interstitial elements ‘C’ and ‘N’ diffuses faster and deeper than other elements on either side of the diffusion couple. The diffusion of ‘C’ and ‘N’ in the study revealed interstitial diffusion mechanism.

- The optimum parameters for diffusion bonding of DSS to medium carbon steel AISI 1035 was bonding temperature of 975 °C, holding pressure 20 MPa and a bonding time of 90 min.

The following conclusions were arrived for the DB samples Ti-6Al-4V to AISI 304L.

- Diffusion bonded samples processed at temperature 900 °C, bonding time 60 min and holding pressure 4 MPa followed by annealing for 2 h at 750 °C, exhibited a maximum tensile strength of 242.6 MPa.

- The DB samples possessed tensile strengths of 41.6% and 25.3% of the base metals AISI 304L and Ti-6Al-4V respectively. The decrease in mechanical properties was attributed to the higher rate of phase transformation and the development of new phases at higher bonding temperatures.

- The estimated diffusion coefficient values indicated that the diffusivity of ‘Ti is higher than ‘Fe’.
Maximum hardness value of 781 VHN was obtained for the DB samples processed at 950°C and annealed for 2 h. The increase in hardness was due to the formation of hard and brittle intermetallic compounds at higher temperatures.

A flat surface and even contact was obtained by deforming surface asperities with impulse pressures applied at 750 °C to get even diffusion across the interface.

The XRD analysis confirmed the phase transformation and the formation of ‘ß’ phase, Fe₂Ti, Mn₂Ti, TiNi₂, Ti₂Si₂, Fe₂V₃, Ti₃Ni₄, Fe₃Al₂Si₄, Al₆Ti₉, Al₄CrNi₁₅ and Fe₂Ti₄O at the joint region. These phases were observed to impair the mechanical properties of the DB samples at higher bonding temperatures.

Substitution and Interstitial diffusion mechanism along the interface of various elements was evidenced in the diffusion-bonded joints. Vacancy diffusion mechanism was prevalent in this case because of jumping of ‘Ti’ and ‘Fe’ atoms to occupy the vacant site created due to thermal energy supplied during diffusion bonding.

6.1 FUTURE SCOPE OF RESEARCH WORK

Compressive superplastic diffusion bonding of low-carbon steel grade AISI 1018 with AISI 304L with AISI 304L interlayer with and without interlayer may result in reduction in bonding time. Thick slabs can be produced with this technique in the temperature range of 900-950 °C.

Diffusion-boned laminated sheets between low-carbon steel grade AISI 1018 and austenitic stainless steel can be produced for corrosion resistant applications and armour plates.
- Taguchi’s method using orthogonal array will be used as future work for the material combinations such as AISI 304L bonded with AISI 1018 steel with AISI 304L interlayer and Ti-6Al-4V bonded with AISI 304L.

- Compressive superplastic diffusion bonding of medium-carbon steel to DSS without interlayer may be carried out at lower bonding time.

- Diffusion-bonded laminated sheets between medium-carbon steel and duplex stainless steel can be produced.

- Compressive superplastic diffusion bonding of Ti-alloy with austenitic stainless steel may result in reduction in bonding time.

- Compressive superplastic diffusion bonding of dissimilar ferrous alloys in partial vacuum conditions and in argon inert gas environment can be tried.

- Superalloys can be diffusion-bonded with compressive superplastic diffusion bonding technique, in partial vacuum conditions to achieve very high quality bonded interface and very high bond strength.

- Superalloys can be diffusion-bonded with compressive superplastic diffusion bonding technique, in argon inert gas environment to achieve very high quality bonded interface.

- Aerofoils made with superalloys can be produced with compressive superplastic diffusion bonding technique.