CHAPTER 6

CONCLUSIONS

The following are the conclusions derived from this research work:

6.1 MICROSTRUCTURE

- The microstructures of multicomponent laser borided specimens have three distinct regions namely (a) boride layer (b) transition zone (c) base material.

- The multicomponent laser borided specimens treated at higher energy densities of laser beam were thick, flat (non-acicular) and more homogeneous as compared with continuously pack borided and interrupted pack borided layers.

- Homogeneity of the multicomponent boride layer increases significantly with increase in energy density of laser beam.

- Generally dendritic microstructure was observed.

- Time required for the formation of boride layer is very less in the case of laser boriding as compared with continuously pack borided and interrupted pack borided layers.
6.2 BORIDE LAYER THICKNESS

- The average thicknesses of continuously pack borided and interrupted pack borided layers were approximately 101 µm and 63 µm treated at 950 °C for 3 h. The multicomponent laser borided layers became thicker as compared with continuous pack borided and interrupted pack borided layers. The multicomponent boride layer thickness was found in the range of 101 - 402 µm.

- The thicknesses of the transition zone were found in the range of 518 – 1037 µm approximately.

- The multicomponent boride layer thickness increases significantly with increase in energy density of the laser beam.

6.3 PHASES FORMATION

- XRD studies confirmed the formation of iron borides, chromium borides, nickel borides, iron carbides, chromium carbides and undissolved $B_4C$ depending on the energy density of the laser beam.

- By increasing the energy density of the laser beam, more amounts of iron borides and iron carbides were found in the multicomponent laser boride layer due to more dissociation of $B_4C$ in to boron and carbon.

6.4 SEM AND EDS ANALYSES

- Good mixing of boron, nickel, chromium and iron was observed from EDS results. Small fraction of carbon was also found in multicomponent laser borided layer.
• Transition zone was rich in carbon due to carbon segregation from boride layer to transition zone and accumulate beneath the boride layer.

6.5 MICROHARDNESS

• Surface hardness of the multicomponent boride layer was in the range of $2190 \text{ HV}_{0.05}$ - $1390 \text{ HV}_{0.05}$ due to in-situ formation of hard boride phases. The hardness of continuously pack borided and interrupted pack borided specimens were in the range of $1858 \text{ HV}_{0.05} - 1234 \text{ HV}_{0.05}$ and $1556 \text{ HV}_{0.05}$ to $1437 \text{ HV}_{0.05}$ respectively.

• It has been observed that the surface hardness of multicomponent borided specimens decreases while the energy density of the laser beam was increased. However, very smooth hardness gradient was observed in the case of specimens treated at higher energy densities as compared with continuously pack borided and interrupted pack borided specimens.

6.6 TOUGHNESS OF BORIDE LAYERS

• It has been concluded from the impact toughness values and percentage of ductile shear areas in the fractured surfaces of charpy impact test that the interrupted pack borided specimens are more ductile as compared to continuously pack borided specimens. The multicomponent laser borided specimens treated at higher energy densities are more ductile as compared to interrupted pack borided specimens.
- Interrupted pack borided specimens showed more ductile shear regions as compared to continuously pack borided specimens. Multicomponent laser borided specimens treated at higher energy densities showed more ductile shear regions as compared to interrupted borided specimens. With increase in energy density of the laser beam, the ductile shear region is found to increase.

- From the fracture toughness (\(K_c\)) measurements, it has been observed that cracks observed at high loads in the case of multicomponent laser borided layers as compared with continuously pack borided and interrupted pack borided layers. For multicomponent laser borided layers developed at higher energy densities, cracks were not observed even at 68.6 N load.

- The fracture toughness of continuously pack borided layer was in the range of 2.51 – 3.23 MPa. m\(^{1.2}\). The fracture toughness of interrupted borided layer was in the range of 3.49 – 4.91 MPa. m\(^{1.2}\). The fracture toughnesses of multicomponent laser borided layers were in the range 13.8 – 18.3 MPa. m\(^{1/2}\). The results clearly indicated that fracture toughness of multicomponent laser borided specimens was significantly high as compared with continuously pack borided and interrupted pack borided specimens.
6.7 WEAR LOSS

- The wear loss of continuously pack borided specimen was significantly low as compared with AISI 1020 steel, interrupted pack borided and multicomponent laser borided specimens treated at different energy densities.

- The wear losses of the multicomponent laser borided specimens treated at lower energy densities were low as compared with interrupted pack borided specimen. This may be due to the presence of undissolved B$_4$C in the laser borided layer.

- The wear losses of the multicomponent laser borided specimens treated at higher energy densities were high as compared with continuously pack borided and interrupted pack borided specimens due to material softening occurs at higher energy densities of laser beam.

6.8 CORROSION RATE

- The corrosion rate of continuously pack borided specimen was high as compared with interrupted pack borided specimen and some cases (specimens treated at energy densities i.e., 31 x $10^6$ J/m$^2$ and 47 x $10^6$ J/m$^2$) of multicomponent laser borided specimens. Corrosion rate was found to vary from 22.06 mpy to 100.3 mpy in the case of multicomponent laser borided specimens.

- It has been observed that corrosion potential (E) is shifted towards more positive in the case of multicomponent laser borided specimens. Hence, it has been concluded that
multicomponent laser borided specimens protect the surface more in the anodic region than the cathodic region as compared with AISI 1020 steel, continuously pack borided and interrupted pack borided specimens.

- The corrosion rate of multicomponent laser borided specimen was 3 -17 times lower than AISI 1020 steel. Interrupted borided specimen showed marginal improvement in corrosion resistance as compared to continuously borided specimen.

6.9 SCOPE FOR FUTURE WORK

- Further experiments can be carried out to completely homogenise the multicomponent boride layer to further improve the toughness.

- Multi-pass laser boriding can be attempted on nickel and chromium electroplated steels to improve the toughness.

- Multicomponent laser boriding can be attempted using other alloying elements such as aluminium, titanium, silicon, vanadium, molybdenum.

- Study on effect of alloying elements on laser boriding can be attempted.