Chapter 7
CONCLUSIONS

From the research work, it is observed that surface modification by layer deposition of EDM electrode material on work piece is successfully done with the same EDM machine used for material removal under certain conditions. Current from 4A to 6A, \( T_{on} = 125-300 \) (\( \mu \)S), with low density of powder metallurgy electrode i.e. 7.15 g/cm\(^3\) to 8.03 g/cm\(^3\) and duty factor 5 to 7 are favorable conditions for material deposition on work piece. The tungsten particle of the powder metallurgy electrode combines with the carbon from the dielectric liquid in which carbon powder in the form of graphite may be mixed, the tungsten carbide layer is formed having better surface characteristics for coating application for dies and punches etc.

This experimental investigation uses electro discharge machine in surface modification of low-carbon steel by using powder metallurgy electrodes. A composition of 75% of W and 25% of Cu was used for preparing the powder metallurgy electrodes and the experimentation is conducted at different parametric conditions like density of electrode, peak-current, pulse-on-time and duty factor. Following conclusions are drawn from this study.

7.1 ELECTRODE DEVELOPMENT SYNTHESIS

- Compaction pressure and sintering temperature are detecting parameters in powder metallurgy process through which tungsten powder electrode compaction is carried out. Density of electrode is directly proportional to compaction pressure and sintering temperature. Still for desirable low density electrode for EDC, electrode material focused compaction pressure and sintering temperature needs to be used. Here compaction pressures of 125 and 188 MPa with sintering temperature of 800\(^\circ\)C are suitable for getting low density powder metallurgy electrode. Low density of electrode material and its more wear during EDC process helps to deposit the worsen electrode material layer on the work piece.

- The coated surface shows two distinctive results when the EDC conditions were adjusted while using a semi-sintered electrode made of W-Cu powders. When the density of electrode and peak current were set to high level, the work piece material is
removed during the process. In contrast, a deposit is formed on the machined surface when the density of electrode and peak current were set to low to medium level. The growth of the WC layer on the work piece tends to stop at a certain thickness according to pulse duration. It is important to concern the effect of heating by each discharge taking consideration of thermal properties of piled layer.

7.2 CORRELATION DEVELOPMENT ANALYSIS

- When the density of electrode and peak current are set to the medium level and pulse duration; duty factor are set to low-level then the thickness of the coating on the surface during the EDC process increases. When the peak current and pulse duration are set to high level and density of electrode and duty factor are set to medium level, the hardness of the coated layer increases. When the density of electrode is set to high level, and peak current, discharge duration, duty factor are set to low-level, the roughness of the coated layer decreases.

- In this study the responses like Layer Thickness ($R^2$ (Adj.) = 96.64), Layer Hardness ($R^2$ (Adj.) = 94.67) and Surface Roughness ($R^2$ (Adj.) = 94.28) are modeled and analyzed through response surface methodology (RSM). A central composite design (CCD) in RSM consisting of four variables like Electrode Density, Peak Current, Discharge Duration and Duty Factor have been employed to carry out the experimental study. The predicted values match the experimental values reasonably.

- The response parameters can be varied by selection of appropriate EDC process parameters. As per the analysis of variance the predominance of the process parameters is sensitive to the responses namely Layer Thickness, Layer Hardness and Surface Roughness. The descending order of predominance of parameters for layer thickness is Peak Current, Density of Electrode, Duty Factor and Discharge Duration. The descending order of predominance of parameters for Layer Hardness is Density of Electrode, Peak Current, Duty Factor and Discharge Duration. The descending order of predominance of parameters for Surface Roughness is Discharge Duration, Duty Factor, Density of Electrode and Peak Current.
The response surface optimization study concludes that the global solution obtained through response optimization is peak current = 6 A, density of electrode = 7.436 g/cm³, discharge duration = 125 (μs) and duty factor = 7 with predicted responses, layer thickness = 100.1568 μm, layer hardness = 1574.18 Hv and surface roughness = 7.29 μm and having composite desirability = 0.80

7.3 COATING MECHANISM AND ITS CHARACTERIZATION

- EDC mechanism is detected by relatively higher wear of low density porous electrode material rather than workpiece material removal. At even low peak currents, the electrode material gets worsen due to weak bonding of molecules and the worsen electrode material gets melted at high temperature and combines with the decomposed carbon from the hydrocarbon dielectric during EDC.

- The spark is generated when the gap between the electrode and the workpiece reaches its optimized position and the gap voltage reaches at its peak. The compound of worsen and melted electrode along with decomposed carbon from dielectric forms a deposited layer on the work piece surface. Thus, the work piece surface material also gets sufficiently heated so as form a permanent and hard layer of tungsten carbide on its surface by developing the molecular bonding between electrode material, decomposed carbon and the workpiece surface. At the end of discharge the deposited layer gets immediately chilled and resolidified as the work piece and the dielectric carries away the generated heat. This is the process of annealing of the layer in the dielectric liquid.

- The surface modification through EDM using semi-sintered electrodes is a promising process which generates an adequate surface modification with coating layer thickness ranging 50–157 μm, deposited successfully on the work surface only in 3- 5 minutes. The Rₐ values of the work surface were obtained in the range of 2.315–13.19 μm. The layer is much harder than the base material. At the hardest zone the micro hardness is of the range 1150 Hv to 1602 Hv.

- Microscopic study of the deposited coating with the help of metallurgical microscope, Scanning Electron Microscope, Energy Dispersive X-Ray analysis and X-Ray Diffractive analysis characterize that the deposited layer majorly consist of worsen tungsten from electrode material, decomposed carbon from dielectric liquid and base
material of the workpiece forming compound of WC, W2C, W3C, FeC, Fe2C along with Cu and inter-metallic compound of tungsten and iron (Fe2W) in the coating.

7.4 VALIDATION AND APPLICATION

- It is confirmed that the life of the anvil treated by Electrode Discharge Coating using powder metallurgy Tungsten electrode increases considerably. It is expected that the performance of dies, anvils and cutting tools etc can be improved by applying this coating method. Thus, we can industrialize this method as an alternative technology to other conventional coating methods.

7.5 FUTURE SCOPE

- Electro discharge coating is relatively new area and the technology pool associated with it could be further enriched. The research work concerning to coating substrate interface, adhesion, tribological behavior etc can be carried out further.
- Synthesis on electro discharge coating with mixing of powders in the dielectric liquid can also be tried for composite coating.