Chapter 5

Conclusion and Future Work

This research work was intended to study the effect of various process parameters of roller burnishing operation on the mechanical and metallurgical properties of ferrous and non-ferrous materials. Some of the surface characteristics that were enhanced by burnishing were analyzed. The overall conclusions that can be drawn from this work and the scope to extend this work in future are presented in this chapter.

5.1 Conclusions:

The aim of this research work was to bring out the merits of roller burnishing operation by carrying out extensive experimental and analytical work. The major properties of the components that were studied were wear and corrosion resistance. The results of the work showed that the roller burnishing process, when applied at optimal conditions, provide fabulous results, thereby qualifying it to be a candidate for implementation in the manufacturing industry, as a surface finishing operation.

The major conclusions that can be drawn from this work are listed below, highlighting the major contribution.

1. Tool related parameters – tool material, roller diameter and number of tool passes were optimized for improved surface finish.
Design of experiments (DOE) and Taguchi’s L4 orthogonal array (3 factors at 2 levels) was used for this purpose (Section 4.1.1). Number of tool passes was found to be the most predominant factor on the surface finish. The results of ANOVA showed that all the parameters were significant by more than 90% for all the four materials – mild steel, aluminium, brass and copper.

2. Optimization of burnishing process parameters (burnishing force, rotation speed, tool feed) was done for improved corrosion resistance, using DOE and L’16 orthogonal array (Section 4.1.2). The corrosion media was 10% brine solution and the duration was 30 days. The parameter that had the highest relative factor strength on the corrosion resistance was burnishing force. Analysis of variance showed that force, feed and speed were all significant by 99% for both mild steel and aluminium.

3. The surface hardness and its distribution beneath the burnished surface was measured using x-ray diffraction (Section 4.2). The surface hardness improved by 13% for mild steel, 28% for aluminium, 11% for brass and 32% for copper. The depth upto which the improvement in hardness was evident was also determined, which was found to be 1.1, 1.2, 0.9 and 1.0 mm for mild steel, aluminium, brass and copper respectively.

4. X-ray diffraction was used to determine the distribution of compressive residual stresses in the burnished components (Section 4.3.1). Maximum compressive stress was induced on the burnished surface and its value decreased to zero after certain
depth. The magnitude of compressive stress on the surface and the depth up to which the compressive stresses were induced were found to be 567 MPa and 1.68 mm for mild steel, 72.5 MPa and 1.44 mm for aluminium, 158.4 MPa and 1.68 mm for brass, 210.7 MPa and 1.92 mm for copper.

5. Finite element analysis was performed on a 3-D static model (Section 4.3.2), to validate the stress intensity and distribution obtained from x-ray diffraction. The result showed that the deviation in the results obtained from FEA was 9%, 4%, 16% and 19% for mild steel, aluminium, brass and copper respectively.

6. The microstructure of burnished and unburnished surfaces was analyzed using an optical microscope at a magnification of 100X (Section 4.4). The grain size was measured and the microstructure was photographed. It was found that the grain size of the burnished surface was refined by about 50% for all the four materials.

7. The effect of burnishing on corrosion resistance of the components exposed to the normal atmosphere was investigated (Section 4.5.1). Components were exposed to normal atmosphere in three geographical areas (industrial, marine and rural) of unique characteristics, for a period of 1 year; so as to analyze the corrosion rates during all four seasons of the year. The improvement in the corrosion resistance was between 65 – 75% for mild steel, 50 – 54% for aluminium, 29 – 37% for brass, 53 – 62% for copper, in different atmospheres. These results
demonstrated the ability of burnishing in improving the resistance against corrosive atmospheres, like pollution of industrial area, humid and salty environment of coastal area, hot and dry environment of rural area.

8. The corrosion rate of burnished and unburnished component was measured in brine solutions with different concentrations of NaCl: 2, 4, 6, 8 and 10% by weight (Section 4.5.2.). The test duration was 45 days. The improvement in the corrosion resistance was between 52 – 62% for mild steel, 60 – 75% for aluminium, 35 – 37% for brass and 53 – 58% for copper in different brine solutions.

9. Mathematical equations were formed using the data obtained from corrosion test in brine, which can be used to calculate the corrosion rate of the components in brine solutions of different NaCl concentrations. Further experimental work was done to validate the values calculated using these equations. The results showed that the deviation in the calculated values when compared to the experimental values was between 5.6 to 13.4% for 12% brine solution and 6.5 to 14.9% for 1% brine solution.

10. The effect of burnishing on improving the wear resistance was analyzed (Section 4.6) by conducting abrasive wear test at various wear forces ranging from 40 N to 320 N in steps of 40 N. The improvement in the wear resistance of burnished components at different wear forces was between 58 and 83% for mild steel, 50 – 92% for aluminium, 57 – 82% for brass and 53 – 80% for copper.
11. The data obtained from the abrasive wear tests were used to formulate mathematical equations (Section 4.6.1), which can be used to arrive at the weight loss suffered by the components subjected to abrasive wear at different wear forces. Further experiments were conducted to validate these equations and the deviation in the calculated values was between 2.5 – 10% for all the four materials considered.

12. One of the significant achievements of this work is determination of depth of burnishing affected zone (BAZ) (Section 4.7). This value was determined from the results obtained from hardness distribution and wear test. The value of BAZ was found to be 1.1, 1.24, 0.96 and 1.09 mm for mild steel, aluminium, brass and copper respectively.

13. Electrical conductivity of the components was measured using the eddy currents testing method (Section 4.8). The improvement in the electrical conductivity after burnishing was found to be 4.7% for aluminium and 5.8% for copper components. The improvement in the electrical conductivity was only minimal because the effect of burnishing is evident only on the surface and not on the core of the component.

14. Abbott-Firestone curve or bearing ratio curve, which is a very useful tool to determine the bearing performance of the components, was drawn for unburnished and burnished brass components (Section 4.9), using the surface roughness profile. The results showed that the percentage of peak volume reduced
from 10.7 to 7.96 by burnishing. The load bearing volume also increased from 91.7 to 94.54, after burnishing. Thus burnishing can be employed as surface finishing process to increase the load carrying capacity of brass components in bearing applications.

5.2 Significant research contributions:

The following are the significant research contributions from this work:

1. The process parameters proposed by this work can be used for burnishing the components so as to maximize their life in corrosive environments (Section 4.1).

2. The experimental data presented in this work provide the necessary testimony to prove the versatility of burnishing in improving the corrosion (Section 4.5) and wear resistance (Section 4.6) of components. This enables the engineers to implement roller burnishing in manufacturing industries as a surface finishing process.

3. The corrosion rate of burnished components determined in the two most common corrosive environments (brine and normal atmosphere), facilitate the engineers in determining the life of components exposed to these environments (Section 4.5).

4. The depth of stress affected zone (SAZ) (Section 4.3.4) and burnishing affected zone (BAZ) (Section 4.7) were determined for four of the most widely used materials in the industries. These values can be used to determine the safe working conditions
and the service life of the burnished components in wear and fatigue applications.

5. Mathematical equations were defined for determining the corrosion rate in brine solution (Section 4.5.2) and abrasive wear rate (Section 4.6.1). These equations become handy in determining the life of the components which are subject to corrosion and wear.

Taking into consideration the results presented in this research work, burnishing can be proposed as a very economical and desirable surface finishing process. This process is very economical because of the reduction in production cost and increase in the service life of the components in wear and corrosive environments. Hence the author recommends burnishing as a surface finishing operation in the industrial applications.

5.3 **Scope for future work:**

This research work can be extended further in many directions. Some of these are enumerated here:

1. Optimization of process parameters for improved surface finish and corrosion resistance were analyzed. This optimization scheme can be extended for improved wear resistance, hardness, compressive stresses and bearing ratio. This optimization can also be extended by taking into consideration other tool related parameter that were not optimized this study.

2. In this study, the corrosion behavior was analyzed in brine solution and normal atmosphere. This can be extended to acidic
(HCl, H$_2$SO$_4$ etc) and basic (NaOH, KOH etc) solutions. Also the effect of burnishing on the corrosion rate in electrochemical reactions can be studied.

3. The effect of burnishing in improving the resistance against galvanic corrosion can be studied.

4. Thermal analysis of burnishing process can be taken up to study the effect of heat treatment, if any, on the surface characteristics.

5. Since compressive stresses are induced by burnishing, its effect on crack initiation and propagation can be analyzed, by applying burnishing on a surface which has surface cracks. The increase in the load carrying capacity and service life, by burning the components with surface flaws (like cracks, pits etc) can be studied.

6. The effect of burnishing on improving the thermal conductivity of materials can be investigated.

7. The finite element analysis performed in this work did not take into account the changes in the physical and mechanical properties with increase in temperature. Better results can be obtained by upgrading this FEA model to consider the changes in the properties at elevated temperatures.

8. Phase transformation in the materials was not studied as part of the microstructure analysis on this work. Further studies can include this to determine if any phase changes happen during
burnishing. Scanning Electron Microscope (SEM) can be used to analyze the microstructure in a more detailed manner.