Chapter 2: Literature Survey

2. Literature Survey

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Chapter 2

Literature Survey

A detailed study of the existing trend and past exertion in a research area is very important to analyze the problems and their suitable solutions. So, in this chapter an extensive literature survey is done to analyze the state-of-the-art of burnishing. This chapter also illustrates the major objectives of the current research work, along with the gaps in the literature.

2.1 Literature Survey:

The versatility of burnishing process in the improvement of surface properties has attracted great deal of interest among the researchers and engineers. In this section the previous work done by the researchers on the study of the process and its characteristics are discussed. The applications where burnishing has been adopted for improving the surface properties are also listed. This literature survey is categorized into various segments based on the area of burnishing that was considered.

2.1.1. Literature on various burnishing methods and tools

Burnishing can be done in different ways using various tools. But the most widely used tolls are ball and roller. But other unconventional methods of burnishing have also gained popularity. The research work done in this area is discussed in this section.
2.1.1.1. Ceramic and Coated tools:

In most of the applications, balls and rollers of the burnishing process are made of high carbon steel. In some applications these tools were replaced by ceramic balls. F. Klocke and J.Liermann [1] developed burnishing operation, which made use of a ceramic ball which is controlled by hydrostatic force. They determined optimum working parameter ranges for the process. They also determined that the parameter settings were of not much significance in this process, as similar surface qualities were attained over wide range of settings. They also examined the improvement in the surface finish, with various initial surface roughnesses. It was found that upto 50% reduction in peak-to-valley height was attainable with various initial roughness values. They also examined the effect of the process on the workpiece surface zone, using residual stress measurement and structural analysis. Some researchers studied the burnishing process by using coated rollers. Binu C. Yeldose and B. Ramamoorthy [2] compared the effect of the uncoated and TiN coated rollers in burnishing process. TiN was coated on EN31 rollers, by reactive magnetron sputtering. The process parameters considered were, burnishing speed, feed, burnishing force, number of passes and the material considered was EN24 steel. The results showed that the TiN-coated rollers were superior to the uncoated ones.

2.1.1.2. Diamond burnishing:

Diamond burnishing tool was developed and used by many researchers. Hidetake Tanaka et al [3] did study on the usage of such
tool. The workpiece material considered was cylinder shaped high carbon chromium bearing steel. They examined the metallurgical properties of the burnished surface. They concluded that the surface roughness reduces by 10%. They also determined that the depth of the work piece upto which the effect of burnishing was found was less than 4 mm, in the case of quenched material. Xingbo Yu and Lijiang Wang [4] also studied the usage of a cheaper diamond tool. They used a spherical surfaced polycrystalline diamond tool. In their work they studied the effect of various parameters on the surface finish of cast aluminium alloy. They studied the effect of burnishing speed, feed and other parameters of the diamond tool on the surface finish. They studied the advantage of heterosteric burnishing over homothetic burnishing. Similar tool was used by Hongyun Luo et al [5] to study the effect of various parameters on the surface roughness of aluminum alloy. They discussed the effect of various burnishing parameters like speed, feed, cutting fluid etc on the surface roughness. They also studied the existence of outstripping phenomenon in burnishing.

Polycrystalline diamond (PCD) tool was also used by Jianying Liu, Zhaojun Yang [6] to study the effect of elastic controlling parameters on burnishing force, surface roughness and micro-hardness of aluminum alloy workpiece. Pre-tightening force and rigidity coefficient were the chosen elastic controlling burnishing parameters. They concluded that with suitable elastic controlling parameters employed, the surface roughness ($R_a$) can be reduced to
0.08 micron from the original 0.4 microns. The effect of diamond burnishing on the surface quality and corrosion fatigue strength was studied by V. K. Yatsenko et al [7]. The diamond burnishing tool used for this study has a diamond head having a spherical radius of 2.5 mm. The material of the work piece was 40KhNMA Steel. PMT-3 device with a load of 100 g was used to determine the depth of cold hardening. The results showed that cold hardening was 4-6 times greater in burnishing when compared to that of polishing. The residual axial stresses induced by burnishing were also measured. The improvement in the fatigue strength and wear resistance on the shafts of petroleum chains by diamond burnishing was studied by K. T. Aliev and T. I. Aslanov [8]. Khalid. S. Rababa et al [9] presented the experimental results of burnishing with a diamond pressing process with different pressing force (105, 140, 175, 210N). The major findings were that the true stress of material has been increased of about 150 MPa, the surface quality has been enhanced by 12.5%, finally the U.T.S. has been increased by 166 MPa.

With certain deviation from the conventional diamond burnishing tools, Miyazawa Shunichi et al [10] introduced hemispherical diamond slider, which was used as burnishing tool. They introduced Contact Burnishing (CB) to reduce head wear of future hard disk drives. They compared pin wear on disk surfaces with and without burnishing. The results showed that by the introduction of burnishing, pin wear was reduced and the reason for this reduction was considered to be reduction of asperity heights.
2.1.1.3. Laser Burnishing:

Usage of laser beam is a recent development in the field of burnishing. In this type of burnishing a laser beam is used to soften the work piece surface temporarily. Then a conventional tool is used for burnishing. Yinggang Tian et al [11] proposed this method of burnishing with the name laser-assisted burnishing (LAB). This process was named as laser-assisted burnishing because laser beam was used to only soften the workpiece and not for the actual burnishing process. The materials considered for this study were MP35N, annealed and hardened AISI 4140 steel. The authors showed through their experiments that LAB can produce much better surface characteristics like surface finish, hardness and compressive residual stresses, compared to conventional burnishing. Later, other researchers J Radziejewska et al [12] worked on the development of laser burnishing. The material used for this work was carbon steel C45. CO₂ laser of 2.5 kW power was used for this process. They studied the effect of burnishing parameters on various surface characteristics. Deformation in the grains and increase in the micro hardness near the surface were observed.

2.1.1.4. Other burnishing methods:

M.H. El-Axir et al [13] used the moving rest to finish the round machined parts with high accuracy. For this, three ball burnishing tools were designed and constructed along the three original adjustable jaws of the moving rest. Experimental work was carried out on a lathe to study the effect of this new burnishing tool and other
process parameters, such as burnishing speed, force, feed on surface roughness, surface roundness, and reduction of diameter. The results showed that good surface characteristics can be obtained by using this tool with minimum cost.

Disc burnishing was used as the final process for reducing the asperity height, in disc surface finishing by Kawakubo Y. et al [14]. They proposed a burnishing technique, Contact Burnishing (CB) that used hard spherical sliders. The authors showed the effects of CB and Tape Burnishing (TB) on reducing head wear. Pin wear was reduced by both CB and TB techniques. Thamizhmanii S and Hassan S [15] in their work described the process of burnishing using multi-roller burnishing tool fitted in housing and rotated freely in a horizontal axis. The work material used for the study was Titanium alloy Ti-6Al-4V, which was difficult to cut. The results showed that the surface roughness and hardness produced by this process, at high rotation of the spindle along with high feed rate and depth of penetration was superior when compared to other conventional burnishing processes.

Burnishing process can be incorporated to have feedback mechanism, by which the position of the tool can be corrected, in case of any deviations. Tareq A. Abu Shreehah [16] developed a burnishing tool with a corrective mechanism for tool position. The effect of burnishing feed, tool penetration and number of tool passes on the surface characteristics was established. The results showed that the best smoothness and micro-hardness can be achieved with one tool pass, 0.1 mm/rev of feed and 0.2 mm penetration of the tool. W.Lye
and K.C. Leong [17] discussed the use of expert systems and problems associated with their monitoring in real time of ball burnishing process. They studied the effects of variation in the burnishing parameters on the surface finish and wear resistance of the work piece. S.W. Lye [18] developed a generic intelligent feedback system for ball burnishing process. This feedback system was used for monitoring the undesirable variations in the process. They showed that adopting this feedback technique made the results better and consistent.

A new algorithm was developed by A.I. El-Wahab [19], which can be used on a CNC machine for burnishing complex profiles. This algorithm proposed a new g-code function. The authors presented a case study to support the new algorithm and tool design.

Some burnishing tools had the option to use both ball and roller. N.S.M. El-Tayeb et al [20] designed and fabricated one such tool which has an interchangeable adapter for ball and roller. The work was done on Aluminium 6061 work-piece at different parameters and different burnishing orientations. They studied the impact of the parameters on the surface qualities and tribological properties. It was found that burnishing speed of 330 rpm and burnishing force of 212 N is capable of improving surface roughness as much as 40% and an increase in the roller contact width leads to less improvement in the surface roughness.

Burnishing process can be combined with milling, to generate compressive stresses. Toshiaki Segawa [21] developed a hybrid tool
that can generate compressive residual stress within the machined surface during milling process. This tool has both cutting edges for material removal and a projection pin for burnishing. The results showed that the tool generated compressive stresses on the machine surface, during milling process and the magnitude of these stresses were comparable with those obtained from shot peening.

2.1.2 Literature on optimization of process parameters:

The success of any process lies in the selection of the best value for the parameter from the set of available alternatives. Burnishing is one such process, which involves many process parameters. So the best possible values of these parameters should be chosen. Most of the research work done in the field of burnishing revolves around this point. Some of such research works are discussed in this section.

One of the early researchers in burnishing, B. Kotweerachari [22] investigated the determination of optimum burnishing force. Expressions were derived for obtaining optimal burnishing force based on dimensional analyses and theory of elasticity. To verify these formulae, modeled triangular asperities were machined on aluminium specimens with varying configurations and then burnished at different forces with a roller burnishing tool. The optimum burnishing force was determined experimentally and compared with the theoretically calculated one. The optimum burnishing force obtained by theoretical calculations agrees well with experimental results. This work also includes proposing of five non-dimensional numbers, which can be used to decide the optimum burnishing force.
The most important parameters of burnishing process are force, speed, feed and number of tool passes. Most of the research work for optimization of burnishing process focused on these parameters. A.M.Hassan [23] studied the effects of various burnishing parameters viz force, speed and feed on surface roughness and hardness of cast Al-Cu alloy. The experiments were conducted with a ball burnishing tool. The results showed that an improvement in surface characteristics can be achieved by the application of ball burnishing process on cast Al-Cu workpieces. These authors in their other work [24] studied the effect of both ball- and roller- burnishing on commercially available aluminium and brass. The results show that improvements in the surface roughness and increase in the surface hardness were achieved by the application of both ball burnishing and roller burnishing with the non-ferrous metals under consideration. The author also concluded that ball burnishing seems to give lower surface roughness and greater surface hardness than roller burnishing, even when the burnishing force of the former is smaller.

Taguchi’s orthogonal array technique was used extensively for optimization of the process parameters. Taguchi L18 orthogonal array was used by Fang-Jung Shiou [25] to determine the optimum values of the burnishing process parameters. They used ball burnishing on the free form surface of injection mold. Some of the optimum values of the process parameters were - tungsten carbide ball tool, speed of 200 mm/min, force of 300 N and feed of 40 micro meters. By applying burnishing the roughness of the injection mould was reduced to 0.187
from 0.842 micrometers. Similar optimization technique was used by S.S.G. Lee [26] to determine the optimum parameters for good surface finish on flat AISI 316L stainless steel specimen using ball burnishing. They applied Taguchi techniques for the statistical design of experiments to determine the parameters for better surface finish on flat specimen. They also found that the type of ball material, depth of penetration, burnishing speed and the type of lubricant significantly affect the surface finish of the burnished specimens, at a 99% level of confidence and feed was significant at a 95% level of confidence.

The effect of the process parameters – burnishing force, speed, feed and number of tool passes on the surface characteristics like surface roughness, micro-hardness, improvement ratio of surface roughness, and improvement ratio of surface micro-hardness were studied by El-Taweel T [27]. They optimized these parameters using Taguchi’s technique. ANOVA was used to determine the contribution effect of each parameter on certain considered characteristics. The results showed that burnishing force has a contribution effect of 39% on surface roughness and 42% on micro-hardness. Taguchi’s L9 orthogonal array was used by C. S. Jawalkar [28] to optimize the process parameters for improved surface quality and hardness. The material under consideration was EN-8. Their study revealed that the burnishing operation has no effect on the microstructure of the component. The number of tool passes and speed contribute significantly to the improvement in the surface hardness, due to work-hardening effect.
Rotary EDM with ball burnishing was applied on $\text{Al}_2\text{O}_3$ /6061Al and the machinability characteristics were studied by Biing Hwa Yan et al [29]. Taguchi technique was the tool used for optimization. The tool was designed to have three ZrO$_2$ balls attached behind the electrode, which would result in burnishing immediately after EDM. The parameters chosen for this study were categorized into two groups;

1. Electrical parameters: peak current, pulse duration and non-load voltage

The results revealed that this is a feasible technique for applying rotary EDM along with ball burnishing.

Taguchi’s design of experiments (DOE) technique was used by S J Ebeid [30] to study the combination of electrochemical turning (ECT) with roller burnishing (RB). They made use of non-conductive ZrO$_2$ rollers. The parameters considered for their study were

1. Applied voltage
2. Electrolyte pressure
3. Work piece rotational speed
4. Minimum gap and
5. Burnishing force

The output variables were material removal rate and surface roughness. They performed ANOVA, to study the effect of noise factors on the parameters considered. They concluded that ECT and
burnishing can be combined for higher material removal rates and better surface finish.

Apart from Taguchi’s technique some authors used response surface methodology to determine the optimum values of the process parameters. M.R. Stalin John and B.K. Vinayagam [31] used this technique for optimization of the parameters for tool steel material work pieces.

Optimization of process parameters can also be achieved by using fuzzy logic model. F.Dweiri et al [32] developed a fuzzy logic model to optimize the parameters of roller burnishing, for improved surface finish. The parameters considered were force and number of tool passes. This study was done on pure aluminium and high-machining brass. The results of the optimization using fuzzy logic model revealed that the optimum values for the considered parameters were 25 Kgf and 4 tool passes for aluminium and 30 Kgf and 4 tool passes for brass. These results were then compared to the ones obtained from experimentation, which were with in the acceptable range.

2.1.3 Literature on study of process parameters:

The process parameters have immense effect on the end results of any manufacturing process. So, extensive work was done in this area of burnishing to study the effect of various parameters on the surface and material characteristics of the components. In this section some of such research works are discussed.
Experimental work was conducted on vertical machining center to establish the effects of various burnishing parameters on the surface finish of ASSAB XW5 steel (high carbon high chrome steel) by N.H.Loh, S.C.Tam and S.Miyazawa [33]. The process parameters considered were burnishing speed, ball material, lubricant, burnishing forces and feed. The authors concluded that, tungsten carbide ball gave the best and most consistent surface finish. Grease was found to be a better lubricant than cutting oil. A.M.Hassan et al [34] in their work studied the effect of speed, feed, force, number of tool passes and ball diameter on the surface roughness and hardness of two different non ferrous metals. They also studied sub-surface hardness and micro structure under specific conditions was studied. They found that the burnishing force and the number of tool passes were the most predominant parameters, which have significant effect on the work pieces during the burnishing process.

M.H. El-Axir [35] carried out experimental work on a lathe to establish the effect of four roller burnishing tool parameters; namely burnishing speed, depth of penetration, burnishing time and the initial hardness of five different materials on the surface hardness, the out of roundness and the change in workpiece diameter. They found that all input parameters have a controlling effect on the three output responses, with different percentages. The results showed that most important factors controlling the diameter and out of roundness of the work piece are depth of penetration and the burnishing time. It was also found that there was considerable reduction in the micro-
hardness with an increase in the burnishing speed. Also, the initial hardness of the component has effect on the out of roundness of workpiece.

Apart from the conventional parameters, Tokio Morimoto [36] examined the influence of the tool size, lubricants and supporting methods for the tool on the roughness of the finished surface, using cemented carbide ball, in ball burnishing. The author concluded that the burnishing process can be carried out at speeds of upto 400m/min. The roughness of the machined surface, of above $R_{\text{max}}=8 \mu m$, was found to have decrease to $R_{\text{max}} < 1 \mu m$ when burnishing with one pass of the tool, whilst it reduced to $R_{\text{max}}<0.1 \mu m$ when burnishing with repeated passes of the tool. T. Marimoto [37] also studied the effect of lubricant oil on burnishing process. The oils considered for this study were low viscosity JIS-VG 10 and ores containing sulfur and phosphorus as additives. The study was done using six kinds of ball tool; cemented carbide, bearing steel, silicon nitride, silicon carbide, and alumina ceramic ball tools. Based on the experimentation he concluded that tricresyl phosphate used as a phosphorus additive has an excellent effect of reducing roughness of the burnished surface when the cemented carbide, silicon nitride ceramic and bearing steel ball tools were used. Similar work on study of effect of lubricant on burnishing process was done by U M Shirsat [38]. The other parameters considered for this study were force, speed and feed. Design of experiments was used for optimizing the parameters. The lubricants considered were SAE-30, Kerosene, 5%
and 10% graphite by weight in SAE-30. The results showed that SAE-30 as a lubricant gives best results by reducing the surface roughness by 600 - 700%.

The effect of other additional parameters like initial surface roughness, hardness of the work piece and the ball diameter of the burnishing tool were studied by Adel Mahmood Hassan [39]. The materials considered were free machining brass and cast Al-Cu alloy, both being non-ferrous. The study revealed that the considered parameters influence the burnishing process significantly. R. Rajasekariah [40] studied the effect of ball burnishing on the surface characteristics like surface hardness, finish and wear resistance. The effect of the process parameters like load, feed, ball diameter and initial surface roughness of the components were analyzed. Some of their conclusions were:

1. High degree of strain hardening was produced on the surface of the burnished component;
2. Burnishing load was the main factor affecting the wear resistance and the work hardening of the processes components. The effect of burnishing parameters on non-ferrous materials - Brass and Aluminium was studied by P. Ravindra Babu et al [41]. The parameters considered were speed, depth of cut, number of tool passes etc and optimized the values for improved surface finish.

The effect of tool material on burnishing process was studied by Tokio Morimoto [42]. They concluded that cemented carbide tool
produces the smoothest surface. Silicon nitride tool ball is slightly inferior to the cemented carbide tool. They also stated that the effect of lubricant on burnishing process depends on the tool material. Tokio Morimoto [43] also studied the effect of the tool material on the burnishing process, five types of ball tools, i.e. cemented carbide, silicon nitride, silicon carbide, alumina ceramic and bearing steel were used. The cemented carbide ball tool accomplished the best results among all types of ball tools used; silicon nitride ceramic ball tool also produced a smooth surface. Neither carbide nor alumina ceramic tool gave satisfactory results.

2.1.4 Literature on study of improvement in surface properties:

It is a well known fact that burnishing is a finishing operation, which improves the surface finish. There are many other surface characteristics that get affected by burnishing. These characteristics include wear resistance, corrosion resistance, micro hardness, micro structure, fatigue life, induced compressive stresses etc. It is because of these effects, burnishing has gained more popularity. In this section the previous research work done by various authors is reviewed, where the main point of focus is improvement in the surface properties of burnished components.

Surface finish is the most important property that gets enhanced by application of burnishing. Liviu Luca et al [44] studied burnishing of hardened steel components to improve their surface finish. They concluded from their work that initial roughness has the most important influence on the final roughness and bearing length
ratio improves for burnished surfaces. They also concluded that roughness comparable to grinding could be obtained through burnishing. Roller burnishing of internal surfaces of mild steel specimen to improve surface finish was studied by P Ravindra Babu et al [45]. As part of this study they proposed two tools to perform the internal roller burnishing. They studied the impact of burnishing speed on the surface roughness and surface hardness.

Cold working of the surface by burnishing improves the hardness of the work piece upto certain depth. N.H.Loh, et al [46] studied the effect of ball burnishing parameters on the surface hardness of flat AISI 1045 specimens. The experiments were done based on the 34 factorial designs. The results showed that depth of penetration, feed, lubricant and ball material have significant effect on the surface hardness. There was 33 – 55% increase in hardness of the specimen. The effect of process parameters on the hardness of AISI 1045 specimen was studied by N.H. Loh, et al [47]. The process parameters considered were depth of penetration, feed, lubricant and burnishing ball material. They also studied the distribution of hardness beneath the surface. The results showed that the hardness was increased by 68%. They also concluded that the layer just beneath the surface has maximum hardness after burnishing. Liviu Luca [48] also studied the effect of the burnishing parameters on roughness of hardened steel component of hardness 64 HRC. The tool used for this study had a ball, which was controlled by the hydrostatic pressure of the fluid.
The capabilities of burnishing process to work harden annealed steel bar was investigated by Tokio Morimoto [49]. The effect of the process parameters like force, number of tool passes on work-hardening was studied. This work also studied the damage caused to the burnishing tool surface. Electron probe micro analyzer was used for this purpose. The results showed that burnishing force has the maximum effect on the work-hardening. The effect of burnishing on work hardening was evident upto a depth of 200 µm, below the surface. S. Rajesham [50] studied the effect of ball burnishing on the surface hardness of alloyed aluminium. The outer race of the deep groove ball bearing was used as the burnishing tool for this study. The results showed that an improvement in the micro-hardness was evident upto a depth of 0.45 mm, below the burnished surface.

Roller burnishing of titanium alloy using a multi roller burnishing tool was studied by S. Thamizhmnaii et al [51]. The results showed that the hardness and surface finish were improved by the application of burnishing and also compressive residual stresses were induced, which can improve the fatigue life of the components. Adel Mahmood Hassan, et al [52] conducted similar study on commercially available aluminium and brass. The results showed that application of roller burnishing improved the surface finish and hardness of the considered workpieces and force and number of tool passes were the most predominant parameters to control the response variables.

It is a very rare circumstance that a surface finishing processes results in the improvement in the strength of the component. With a
vision to analyze the strength improving capabilities of burnishing, Adel Mahmood Hassan [53] applied ball burnishing on commercial purity aluminum and brass specimens. They used 10mm carbon chromium balls for the burnishing process. They studied the effect of ball burnishing on proof stress, ultimate tensile strength and fatigue strength. The results showed that there was certain improvement in the considered properties. K. Palka [54] studied the effect of ball burnishing on the structural and mechanical properties of stainless steel. They used optical microscopy and X-ray diffraction to do this study. The corrosion resistance test was performed using the potentiodynamic anodic polarization. The results showed increase in open circuit potential because of decrease in the coarseness. Anodic polarization results revealed that breakdown and repassivation potentials decreased with increase in burnishing load. The X-ray diffraction results showed that there was an increase in the content of Fe-α with increase in burnishing force.

Tensile stresses induced by machining and forming processes cause many adverse effects. So the elimination of these tensile stresses and induction of **compressive stresses** by burnishing was studied by Paul S. Prevey [55]. The authors in their study applied burnishing to eliminate or reduce the tensile stresses in AA7075-T6 components, without varying the environment and component design. The results showed that the induction of compressive stresses improved the resistance against salt fog pitting and corrosion fatigue. Jeremy E. Scheel et al [56] used burnishing to introduce compressive
stresses into the fusion welds to mitigate the stress corrosion cracking (SCC). The materials on which this study was conducted were 304 stainless steel and alloy 22. Results showed that the weldments treated with burnishing could resist SCC better than the unburnished weldments.

Another property that gets enhanced by burnishing is wear resistance. Adel Mahmood Hassan [57] studied the effect of ball burnishing on the wear resistance of brass components. The burnishing process was carried out under different burnishing forces and number of tool passes. The authors designed a simple wear-testing device to study the wear resistance of the components. They also optimized the considered process parameters for attaining maximum wear resistance. The results showed that there was considerable improvement in the wear-resistance of the considered brass component. D. Srinivasa Rao et al [58] established the effect of burnishing parameters like feed, speed, force, ball diameter and lubricant on surface hardness, and wear resistance of HSLA dual-phase steel specimens. The result showed that all the considered parameters have considerable effect on the surface hardness and wear resistance.

The induction of compressive stresses and improvement in hardness results in the enhancement of Corrosion resistance. The effect of burnishing on corrosion resistance was studied by Ubeidulla Al-Qawabea [59]. The material considered was A53 steel and the corrosion environment was HCl Solution. As part of this work, the
authors also investigated the effect of burnishing on micro-hardness, weight loss, micro-structure and potentiostatic polarization. Improvement in stress corrosion cracking of duplex stainless steel was investigated by J. Labanowski [60]. The work pieces were subjected to corrosion test by using Slow Strain Rate Test technique in inert and aggressive environments. The results showed that burnishing improves the resistance against stress corrosion cracking. This improvement mainly depends on the magnitude of the cold working underwent by the surface.

Fatigue strength of the components greatly depends on the compressive stresses induced. The literature survey done earlier in this section reveals that burnishing process results in compressive stresses induced in the surface layers. Michael J Shepard [61] explored the fretting fatigue performance of Ti-6Al-4V after isothermal exposure. The test coupons were processed by low plasticity burnishing shot peening and electro polishing. The thermal stability of the compressive residual stress fields produced by shot peening and burnishing was investigated. The improvement in high cycle fatigue (HCF) performance of AZ80, by roller burnishing was studied by P Zhang [62]. The results showed that there was about 110% improvement in the fatigue strength, when burnished at optimum conditions. They also concluded that when compared to shot peening, burnishing lead to better improvement in HCF strength of AZ80 specimen. The reasons for this improvement were lower surface
roughness, greater degree of work hardening and induced compressive residual stress.

2.1.5 Literature on theoretical modeling and simulation:

Manufacturing industry always strives towards reduction in the time and cost of the production process. It is always preferred to develop a model of the process, by which the results attainable can be analyzed before actual implementation. Similar strategy can be applied to burnishing process also. Extensive work was done in the field of burnishing, to develop mathematical models which can be used to study the applicability of the process. In this section some of such research works are discussed in brief.

A second-order **Mathematical model** was developed by *M.M.Khabeery* [63] to show a relationship between the process parameters of the burnishing process; speed, depth of penetration and number of tool passes. The technique used for deriving this model was ‘Group method of data handling (GMDH)’. They also studied the effect of roller burnishing on 6061-T6 aluminum alloy. The response variables analyzed were surface finish, improvement in the hardness and induction of residual stresses.

The relationship between the parameters of ball burnishing was explained by a mathematical model by *A.M.Hassan* [64]. The technique used for developing this mathematical model was ‘Response surface method’. The same technique was used by *N.H. Loh* [65] to develop a mathematical model to compare the process parameters –
speed, feed and depth of penetration. They made use of design of experiments method of analysis in their study.

A relation between depth of penetration and feed of ball burnishing process was developed by N.H. Loh [66] in the form of mathematical model. They optimized these process parameters for improved surface finish. These results obtained from the mathematical model were in good accordance with the actual experimental values.

Two mathematical models which discuss the interaction between the process parameters and their effect on surface finish and hardness were developed by M. Fattouh [67]. These models can be used to derive the optimum values of the parameters, for a given response variable. They studied the effect of ball burnishing on surface roughness and hardness of 70/30 Cu-Zn alloy. They studied the effect of various parameters on these response variables.

K. Skalski [68] proposed a mathematical model of the burnishing process along with its solution. The material considered for this modeling has elastic plastic properties. The stick-slip friction between the workpiece and the tool is taken into consideration in this study. The results from this mathematical model were used to simulate the process and to analyze the deformation of the contact area. M.H. El-Axir [69] proposed a mathematical model to predict the hardness and surface finish produced by roller burnishing process. The material considered was ST-37. The process was conducted using
a lubricant. They presented the relationship between process parameters speed, force and the residual stresses induced.

Mathematical expressions were developed by C.Y. Seemikeri et al [70] for surface finish, roughness, surface integrity and fatigue life of AISI 1045 steel using full factorial design of experiments. They studied the depth of material zone that was affected by burnishing in-terms of micro-hardness and compression. They related the surface hardness and surface finish to the fatigue life of the components.

**Finite element analysis** is a modeling and analysis technique that has gained astonishing adoption in many areas of manufacturing. Burnishing is no exemption for this. A good amount of work was done in modeling and analyzing burnishing operation. W.Beres [71] developed 2D and 3D finite element model of the ball burnishing process, to analyze the improvement in the fatigue life. The material that was studied was Ti-6Al-4V. Diameter of the ball, depth of indentation and feed were the parameters considered. The results showed a good synchronize with the previously published data. Remigiusz Blaszkow et al [72] described the contact problem and the algorithm for solving it, using finite element method based on updated LaGrange method. This modeling enabled to analyze the distribution of contact pressure, concentration of stress and strain.

2-dimensional and 3-dimensional FEA models of roller burnishing were developed by Y.C. Yen [73]. The deformation in the surface layer and induced residual stresses were determined and compared with the initial (unburnished) values. Also, these values
were validated against the experimental results. The effect of roller burnishing process parameters on surface finish and residual stresses was analyzed by Partchapol Sartkulvanich et al [74] by using a 2D and 3D FEM models. The parameters considered were force speed and feed. The results obtained from the FEM were compared against the actual experimental data, and this comparison showed that FEM prediction was within the acceptable range.

In the recent past, Bougharriou A. [75] proposed a finite element model, to understand the fundamentals of burnishing. The material considered was carbon steel. FEM was used to estimate the response variables – roughness and residual stresses. The results from FEM were in good accordance with the experimental data. Very recently another FEA model was proposed by F Klocke [76] to predict the induced stress by roller burnishing process. The results were compared with the actual values, which were obtained by burnishing at different parameter values and different materials. The influence of these stresses on strain hardening on fatigue strength was examined.

Tribology theory was used by Y. C. Lin et al [77] to propose a burnishing factor $L_b$, which explains the reason for getting same results from burnishing, when operated at various conditions and parameter values. They explained the mechanism by which the burnishing process improves the surface finish, which is basically because of asperity deformation. Extensive experimental work was carried out to justify the burnishing factor.
Jian-yong Liu et al [78] investigated the method of reliability assessment of burnishing process by using probabilistic modeling. This investigation was done both theoretically and experimentally. The reliability of rigid burnishing process and elastic burnishing process were analyzed and compared with the methodology proposed.

A slip line field model was used by A. J. Black et al [79] to develop an equation, which can be used to estimate force, depth of burnishing layer and the plastic strains in this layer of burnishing operation. Experiments were conducted and the values obtained from the equation were compared against the actual experimental values, which were in good agreement.

2.1.6 Literature on applications of burnishing:

A process would gain attention only if it can be applied in the real-life production process. Also, it should have the capability to operate in combination with some other processes, so as to reduce the cycle time. Burnishing has both of these features, which encouraged people to adopt it. Burnishing has enormous number of applications, which were listed, analyzed and studied by many researchers in the past. In this section some of such works are discussed.

Burnishing was applied on the components that were shot peened by Adel Mahmood Hassan [80]. From the results it was found that the burnishing process further improves many surface characteristics, like hardness, fatigue life and corrosion resistance. This work was performed on the non ferrous materials – Aluminium and Brass. From these results the authors concluded that, for further
improvement in the surface characteristics, burnishing can be applied on shotpeened components. *S.S.G. Lee et al* [81] presented the procedure for creating the CAD model of the mould and defined a path for the burnishing tool. The results showed that the surface finish obtained was 70% more than the one obtained from milling.

Burnishing process can be used for restoration of the **corrosion fatigue strength** of components that are exposed to corrosive environment. John *T. Cammett* [82] experimented by applying burnishing on corroded surfaces without removing the damaged layer. The components were then exposed to salt fog environment and the results showed that the corrosion fatigue strength was restored by the application of burnishing. *N. Jayaraman, et al* [83] investigated the application of burnishing to improve the corrosion fatigue performance of alloy-450 stainless steel. They studied the optimization of the process for improved surface finish. They carried out this study in an acidic salt solution. They concluded that the life of the component can be improved by application of burnishing, because of induction of compressive residual stresses. Extensive work was done by Jeremy *Scheel, et al* [84] to study the application of shot peening and burnishing for improving the stress corrosion cracking in salt fog exposure, on the high cycle fatigue (HCF) performance of several aircraft aluminum alloys. They also applied these surface finishing techniques on pre-corroded specimen. The results showed that low plasticity burnishing (LPB) showed better performance in improving the corrosion and fatigue strength.
LPB was applied to the first stage fan blades of the gas turbine engine, to induce compressive stresses on the leading edge, so as to improve the damage tolerance. The results showed that the process improved damage tolerance up to a depth of 1.3 mm. They also studied the improvement in the fatigue life through fatigue performance modeling. The application of low plasticity burnishing to improve the life of the components subjected to various damage mechanisms, like corrosion, pitting, fretting and foreign object damage (FOD) was studied by Paul S. Prevey [85]. The results showed that the induction of thermally stable compressive residual stresses was the reason for the improvement in the life of the components that undergo burnishing. The materials tested were IN718, 17-4Ph stainless steel and Ti-6-4. Further, LPB was applied to gas turbine engines to improve fatigue life by Paul S. Prevey et al [86]. As burnishing produces thermally stable compressive residual stresses, it improves the fatigue life of the components, as compared to that of the shot peening and laser shock peening. The results showed that the deep layer of compressive stresses can completely mitigate FOD up to 0.25 mm deep in Ti-6-4, IN718 and 17-4PH steel.

Paul S. Prevéy [87] applied LPB, shot peening and low stress grinding on 17-4PH stainless steel. They studied the improvement in the high cycle fatigue (HCF) performance and fatigue strength. Results showed that the LPB dramatically improved both the properties, when compared to the other two processes. The reason for this improvement
was found to be the induced compressive stresses, which mitigated the FOD and corrosion fatigue.

Damage tolerance of the aero-turbine engine made of titanium and nickel was improved by applying burnishing (Thomas S. Migala [88]). The improvement in the damage tolerance in the compressor sections was analyzed. They also concluded that LPB can improve the corrosion fatigue performance of 4340 steel and 7075 -6 aluminium. They presented the fatigue, corrosion fatigue and damage tolerance results. LPB was applied on the modular neck taper junction of a Ti-6Al-4V total hip prosthesis by Prevey P.S. [89]. The results showed that the high cycle fatigue life was enhanced by the induction of compressive stresses. The results also showed a complete elimination of fretting fatigue failures by application of LPB.

Friction stir welded plates, which ended with tensile stresses, can be processed with burnishing to relieve the tensile stresses. P. Prevey et al used LPB on AA2219 plate [90] and Al 2219-T8751 alloy [91], for improving the corrosion fatigue performance. Stress distribution was analyzed using x-ray diffraction and the results showed that high compressive stresses were induced in the weld stir zone. Fatigue and corrosion fatigue tests were performed and the results showed improvement in both these properties. Paul S. Prevey et al [92] investigated application of LPB on IN718. Thermal stability at the engine temperatures is compared with conventional shot peening. The results showed that LPB can be applied as an alternative
for Laser Shock Peening (LSP), which is quite expensive. Also the surface finish obtained is superior to the one obtained by LSP.

Burnishing can be applied as a continuation process of electrochemical finishing. P S Pa [93] designed a finish-tool that includes an electrode and a nonconductive burnishing-tool. The workpiece considered for this study was a model toy missile. This technique produced a cost-effective and efficient surface finishing process.

In certain applications, where higher wear and corrosion resistance is needed, burnishing process can be employed. Wojciech Labuda [94] studied the application of burnishing on the angular momentum pumps, to improve their wear and corrosion resistance. These pumps are often used in ships. Neck wear, which is a very common damage in pumps, is addressed. This study includes the optimization of the burnishing process parameters, force, speed and feed, for better surface finish. The material of the pump shafts was stainless steel type X5CrNi1810.

For finishing of sculptured surfaces, burnishing can be applied. Adrián Rodríguez, et al [95] applied continuous burnishing (CB) and patch burnishing (PB) for burnishing the sculptured surfaces. The results showed that CB can improve the hardness better than PB. But PB allows applying maximum feed rate, for quicker processing rate, but the surface roughness was on the higher end. Fritz Klocke et al [96] studied the influence of process and geometry parameters on the surface layer after roller burnishing of IN718. The development of well
funded process knowledge about the correlation of the process parameters, the processed geometry and the surface layer state was the main objective of their study.

*Sugita N. et al* [97] proposed ultra-precision machining of tungsten alloy maximizing burnishing between the cutting tool and workpiece during cutting by combining strengths of the crystal grain and binder phase. *Masami Masuda* [98] performed micro grooving using burnishing tool. They made use of force controlled micro grooving for their study. The quality of the form tools can be improved by using burnishing process. *L.N. Lopez De Lacalle et al* [99] stated that acceptable surface roughness can be obtained by using large depth of cut in the ball-end milling operation and small radial depth of cut in burnishing. They also concluded that numerical controlled programming of ball burnishing is relatively less critical and needs less care.

### 2.1.7 Miscellaneous literature:

Other research works done in the field of burnishing are discussed in this section. A literature survey on various types of burnishing and its parameters on surface roughness were presented by *N.H.Loh and S.C.Tam* [100]. The parameters considered were force, speed, feed rate, lubrication, ball material & diameter, work piece material, pre machine roughness and frequency of oscillation.

90% of surface layer thickness is displaced forwards of a roller motion in burnishing, while a thin contact zone undergoes a backward displacement. This is because of the softening of the contact zone due
to over-heating of material. This effect is responsible for peeling and cracking of surface layer during the burnishing process. W.Gambin [101] studied this seizing effect in the roller burnishing process. Plastic analysis of the process was presented, taking into account the seizing effect. S.S.G.Lee [102] reported ball burnishing of a free-form surface made from AISI 1045 medium-carbon steel. They made use of CAD tool – CATIA solid modeler to generate the free form model. The NC code generated from this tool was then fed to CNC vertical machining center. This machine was used to do milling as well as burnishing. The results showed that the surface finish upto 0.29 μm can be obtained by burnishing a free form surface.

A thermal based tool sensor was developed for ball burnishing by K.C. Leong [103]. They made use of embedded thermocouple concept for building this sensor. They also discussed the suitability of using other techniques of determining the contact temperature such as the tool-work thermocouple, thermo-vision and metallographic techniques. They built a prototype of the tool sensor based on the embedded thermocouple method. Results showed that the sensor was able to detect the raise in temperature of the ball during burnishing.

A comparative study of diamond pressing (DP) and roller burnishing (RB) was done by Ubeidulla F. Al-Qawabeha [104], on the surface texture of the components. The materials considered were three different carbon steels - low, medium, and high. They concluded that the RB is better than DP for low carbon steel, in terms of its effect on the micro hardness and surface roughness. But for medium and
high carbon steel DP was better than RB in terms of its effect on the micro hardness; RB was better than DP in terms of its effect on the surface roughness. So, RB was found to be better in surface roughness and DP has better results in surface micro hardness relative to ground surfaces. Similar comparative study was done by A. Drechsler et al [105] between shotpeening and roller-burnishing on various titanium alloys. They varied rolling force over a wide range and studied the response variables like surface topography and hardness. The results showed that both the processes improved the fatigue performance of titanium alloys.

The addition of copper and the burnishing process on the Zn-5% Al (Zamak5) cast alloy was reviewed by Safwan M.A et al [106]. The effect of addition of copper and burnishing on microstructure, hardness and surface roughness were analyzed. It was found that the hardness was increased by about 18% and also the other characteristics were improved.

Machining efficiency of 34CrMo4 steel with roller burnishing tools was investigated by Stoic, I. Lackovic et-al [107]. Experimental tests of cutting outputs have been done on specimens prepared for final machining process to estimate the rate of roughness decrease, and diameter increase. Roughness values before and after roller burnishing process were compared. They found that surface roughness has significantly lowered after roller burnishing.

A second order mathematical model was developed by Dabeer P. S. et al [108] to associate the burnishing force, speed, ball diameter
and number of tool passes. They used Surface response methodology to derive the optimal values of the process parameters. The mathematical model can be used to determine the values of the parameters at which burnishing has to be performed for a given surface finish.

Djordje Vukelic et al [119] tried to gain an insight into the burnishing process from the microscopic aspect, with primary focus on material flow and roughness variations. The analysis of results obtained by the measurement of the surface roughness and the super-positioning of the profiles obtained by burnishing with various burnishing forces, significantly contributed to the explanation of the roughness peaks’ deformation phenomenon. Investigations presented in this paper open a number of new directions, such as the testing of a stiff tool system with various work piece materials and burnishing regimes, with different surface roughness as the result of the initial machining.

Deepak Mahajan and Ravindra Tajane [120] did literature survey with main focus on ball burnishing. They concluded that most of the work was done on aluminium and steel, where as much scope is there to work on polymers. They also stated that surface roughness and micro-hardness are the popular measured variables.

Nikunj k Patel, Kiran A Patel [121] reviewed the parametric optimization of process parameters for roller burnishing process. They concluded that there is wide acceptability of process parameters in the field of roller burnishing which improves metal surfaces quality –
surface roughness and surface hardness. They also concluded that roller burnishing can be effectively used in many fields such as automobiles, machine tools aerospace industries etc.

*Ghodake A. P.* [122] reviewed the effect of burnishing process on the behavior of engineering materials. Their conclusions include – force and number of tool passes are the important parameters to improve ductility of materials. Burnishing greatly affects frictional coefficient and improves wear resistance of materials.

### 2.2 Gaps in the literature:

Extensive research work was done in the field of burnishing by many researchers. The key areas of concern were studying the effect of burnishing on the surface characteristics like surface finish, hardness, compressive stresses, wear resistance, corrosion resistance and fatigue life. The process parameters that effect these end results were analyzed and optimized using various tools like Taguchi’s technique, fuzzy logics etc. Some authors derived expressions to calculate the end results like surface roughness and hardness for a given set of process parameters. Mathematical modeling and finite element analysis, both 2-dimensional and 3-dimensional were done to analyze the process and their end results.

The extensive literature survey carried out by the author reviews the work done in many areas of burnishing. But still there are certain areas where research work has to be continued for bridging the gap. The optimization of processes parameters was targeted for better surface finish and hardness. But none of the work attempted to
optimize the parameters for improved corrosion resistance, wear resistance and induced compressive stresses.

The previous work reveals that the corrosion resistance of burnished components was tested in aggravated environments like salt fog test. But none of the research works focused on testing the resistance in normal atmosphere. This could be because the corrosion rate in this case is very low and prolonged testing is needed, which is a time consuming and tedious task. Also, in most of the application the corroding media would be brine solution. So the comparison of the corrosion behavior of burnished and unburnished components in brine solution was not discussed. Very less work was done to study the improvement in the wear resistance. From the literature review, it was noticed that only brass and steel were the materials tested for improvement in wear resistance. Hardly any work was done to study the improvement in the wear resistance on other materials like copper and aluminium which are widely used in industries.

The reduction of porosity and elimination of imperfections from the surface layers has effect on improvement in the electrical properties of the components. Burnishing process reduces the porosity of the component because of close compaction of the material on the surface. It also eliminates minor imperfections on the surface. But no past work was done to investigate the effect of burnishing on the electrical conductivity.

One of the important properties that explain the suitability and adaptability of a component in wearing applications is bearing ratio
and the bearing area curve parameters. These parameters depend completely on the surface roughness profile of the components. Burnishing, being a surface finishing process is expected to improve these parameter by considerable amount. But no work was done in this area by any of the researchers.

2.3 Motivation:

There are innumerable materials available for use in the industries. The selection of a material for any application depends on the environment and physical conditions of operation. The most economical material that can sustain the working conditions would be selected. Some of the most commonly used materials are mild steel, aluminium, copper and brass. These materials have their own advantages and disadvantages. In the current research work an attempt is made to burnish the components of these materials, so as to minimize the drawbacks and increase the applicability. A detailed discussion on the applications of these materials and the general problems faced are discussed here.

Mild Steel:

Mild steel is one of the most common forms of steel. It comes under the low carbon steel category, where the content of the carbon is between 0.05 – 0.15%. Though mild steel is inferior to many other forms of steel, it still finds many applications in the industries because of its relatively low cost. Some of the applications of mild steel and the problems faced are listed below.
1. **Pipes and storage tanks**: Mild steel is used as a primary material for pipes and tanks in many applications, like firefighting sprinkler system, domestic and industrial water supply system, refrigeration industry etc. The main reason for this is that it has the best cost/benefit ratio. The water that is circulated through these pipes or stored in tanks is generally unfavorable to the surface. The result of this would be corrosion of the internal surfaces. Also, when abrasive-suspended fluids are circulated, the internal surface is subjected to wear. This results in the weakening of components. The external surface of the pipes is exposed to the outside atmosphere. In some cases, when the pipes are submerged in the ground or under water, the corrosion rate of the external surface can be more aggressive than the internal surface. This leads to more rapid failure of the tanks and tubes. Figures 2.1 and 2.2 shows the corrosion and scaling of mild steel pipes and tanks.

![Figure 2.1: Corrosion of mild steel pipes](image)
2. **Cooling Towers**: Cooling towers are used to cool the water by using air. In this process, water is admitted in to the towers at the top, which then flows down the tower. At the bottom of the tower the cool water is collected and fed back to the cooling system. The hot water that is admitted into the cooling water is circulated through steel pipes. The high temperature of water and exposure to atmosphere causes the steel pipes to corrode. Figure 2.3 shows the cooling tower sprinklers that are rusted.

3. **Marine diesel engine’s cooling system**: These engines are very large assemblies that generate huge amount of heat during operation. The cooling system of these engines generally uses sea water as coolant, in the secondary circuit, where the primary coolant is cooled by the sea water. The presence of salts in the sea water causes the cooling system (figure 2.4) to
corrode very rapidly. This reduces the efficiency of the cooling system, which has a negative impact on the performance of the engine.

Figure 2.4: Corrosion of marine diesel engine’s heat exchanger.

4. **Rollers in mining conveyor systems**: Traditional mild steel rollers of the conveyor system have to be replaced very frequently because of corrosion and wear. The atmospheric environment and the working conditions in the coal mines are very unfavorable for the normal mild steel, which are subjected to corrosion and abrasive wear. Figure 2.5 shows a roller rusted and weared-out after being employed in the conveyor system.

Figure 2.5: Corrosion in mild steel rollers of coal conveyor system
5. **Other applications:** Other applications of mild steel are automobile parts, reinforcement metal for construction, furniture, road signs, machine parts etc. These components are made of mild steel because of its low cost.

**Burnishing of Mild steel:**

Most of the mild steel components that are listed here are being replaced with more corrosive resistance materials like reinforced plastics or other advanced materials. In some cases they are painted to prevent corrosion. By either of these approaches, the initial cost of the equipment increases. The maintenance cost also increases for the painted components, because the components exposed to abrasive environments would lose the paint and thus have to be repainted. So there is a need for a process that minimizes the initial cost, eliminates the maintenance cost and improves the corrosion and wear resistance. Burnishing is one such process that can be employed to improve the corrosion and wear resistance with very less initial cost and no maintenance cost. Burnishing process also induces compressive stresses, which increases the load carrying capacity. In certain applications like pressurized tanks and circulation pipes, the induction of compressive stresses increases the load carrying capacity. Hence, in this thesis the improvement in the corrosion and wear resistance of the roller burnished AISI 1020 mild steel components is studied along with the induced compressive stresses.

**Aluminium:**
Aluminium is the most abundant metal in the earth’s crust. Its low weight, high electrical conductivity, good corrosion resistance made way for its wide spread applications. Aluminium is also used in alloy form in automobile and aero-space applications. In its pure form aluminium is reactive, less wear resistant. Some of the applications of aluminium are listed below.

1. **Electrical conductors:** A very large proportion of high voltage power lines utilize aluminium on weight grounds. Alloys of 1000 and 6000 series are most widely used in electrical conductivity applications because of their low weight. These alloys have good corrosion resistance. But prolonged exposure to the corrosive environments causes corrosion of the aluminium conductors in the form of pitting, which is shown in figure 2.6.

![Figure 2.6: Pitting on aluminium electrodes at higher temperatures in bio fuel](image)

2. **Condenser tubes, Engine blocks and Fins:** High thermal conductivity of aluminium enabled it to be used in condenser tubes, engine blocks and fins. Series 1000 alloys, which have very high thermal conductivity, are used in such applications. If the strength of the components is of more importance, other alloys are used. Figure 2.7 shows the scale formation on aluminium engine block
3. **Food containers:** 1000 series alloys of aluminium are very widely used in food packaging industries. Huge containers with inner casing of 1200 alloys are used for storage of food products in cold storages and transportation of sea foods. These alloys may be subjected to pitting if the duration of the storage is more. Brine water is generally used as a storing media for sea foods. When the duration of the storage is prolonged, aluminium reacts with brine solution to cause pitting. Vinegar is another corrosive solution, which causes pitting on the aluminium surfaces, if stored for longer duration. Also, the internal surfaces of these containers get weared out because of the repeated usage.

4. **Building and architecture:** Aluminium is used in building for a wide range of applications. Some of these include roofing, windows, pre-formed shapes for doors, decorative items etc. In some oil industries, aluminium is used in construction of the off-shore structures. In these applications, the marine atmosphere causes deterioration of the aluminium structures, over a period of time. Figure 2.8 shows pitting of aluminium.
5. **Ladders and access equipments:** Aluminium is used for ladders and access equipment because of their low weight. 1000 and 6000 series are more widely used in such applications. But the ladder’s surfaces wear out because of frequent usage and rubbing.

6. **Gas cylinders:** Compressed gas cylinders, upto 50 liters capacity for storage of CO\textsubscript{2}, air, oxygen etc are made of aluminium. These cylinders are generally used when the overall weight has to be reduced. 6000 series alloys are generally used for these applications.

7. **Other applications:** Alloys of aluminium are used extensively in automobile and aviation industries. The properties of these materials are much superior to the pure form. Scale formation and pitting is very common in the automobile application, like alloy wheels, which is shown in figure 2.9.
Burnishing of aluminium:

In most of the applications mentioned above, aluminium is primarily used for its good corrosion resistance and electrical conductivity. But over prolonged period of time, it was observed that aluminium also undergoes crevice corrosion and pitting, when exposed to severe circumstances like marine atmosphere, perishable food products, chemicals, brine etc. Aluminium is losing some of the applications because of its very low wear resistance. So there is a need to improve the corrosion and wear resistance of aluminium components, to extend its scope of usability in industries. So in this thesis, the effect of roller burnishing on improving the corrosion and wear resistance of AA1200 aluminium alloy is studied. Effect of burnishing on the electrical conductivity is also studied, so as to prove that burnishing does not diminish the electrical conductivity, but enhances it further.
**Copper:**

Copper is characterized by high ductility and very high electrical and thermal conductivity. It is used extensively in the manufacture of electrical and thermal conductors. When exposed to atmosphere or reactive liquids, copper undergoes corrosion to form a layer of scale. Copper being a soft and ductile material, its wear resistance is also on the lower side. Some of the applications of copper and the trouble faced are discussed in this section.

1. **Electrical Applications:** Approximately 65% of copper produced all over the work is used in electrical applications. Copper has the second highest electrical conductivity, only after silver. So the components intended for such applications should be processed carefully, making sure that the electrical conductivity is not reduced.

2. **Motor rotor:** Copper is used extensively as motor rotors. Its low cost and relatively higher strength, thermal and electrical properties enabled it to be used as rotor in the electric motors. Figure 2.10 shows the cross section of a motor with copper rotor. But these rotors are subjected to corrosion and wear.
3. **Heat Exchangers**: Heat exchangers used in thermo-electric power stations are made from copper. The steam at high temperatures is circulated through the copper heat exchangers to condense into water. The high temperature of steam and the chemical reaction by coolant water causes corrosion and scaling of the heat exchanger, which is shown in figure 2.11. This will reduce the efficiency of the heat exchangers.

4. **Storage tanks and circulation tubes**: Corrosion is a very common phenomenon in copper storage tanks and circulation...
tubes (figure 2.12). The pH value of the liquid circulated affects the corrosion rate of the copper components.

Figure 2.12: Corrosion of copper tubes

5. **Other Applications:** Copper has many other applications, like coins, sculptures, aquaculture etc. In most of these applications, copper components are exposed to varying atmospheric conditions. These variations lead to the corrosion of the components, which deteriorate the strength. Figure 2.13 shows corrosion and scaling of some of the copper components.

Figure 2.13: Corrosion of copper components.

**Burnishing of copper:**

Copper tend to oxidize when exposed to normal atmosphere. Long term exposure generally results in the formation of gray-green patina. This is because of the attack of sulfur components in the atmosphere. In some of the applications, the surfaces can be coated with protective layers like paints etc. But in applications like heat exchangers, motor rotors, engine blocks etc where the surface has to dissipate heat and conduct electricity should not be coated with non-
corrosive materials or insulators. In such applications, the surfaces of the copper components can be burnished to improve its corrosion and wear resistance, with no compromise in electrical and thermal conductivity. Burnishing process also induces compressive residual stresses, which increase the capacity of the pressure vessels. So, in this research work the effect of roller burnishing on corrosion resistance, wear resistance and electrical conductivity of C14310 copper components is studied.

**Brass:**

Brass is an alloy of copper and zinc, with minor percentages of other elements. The addition of zinc improves many mechanical properties, when compared to pure copper. Brass has good strength, machinability, ductility, hardness, thermal and electrical conductivity. There are many applications of brass in the industries and domestic life. But when subjected to severe working conditions and exposed to stern environment, brass is subjected to corrosion and wear. Some of these applications are listed below.

1. **Bearings and liners:** Brass has good wear resistance, so it finds numerous applications in bearings and cylinder linings. But under severe working conditions, the applied load causes the surfaces of the brass components to wear (figure 2.14), which reduces the life of the bearings and cylinder liners.
2. **Pumps and turbine blades**: The casings of the pumps and the turbine blades are subjected to abrasive wear when the fluid contains suspended particles. These components also suffer from corrosion when circulating reactive liquids like brine solution, which is shown in figure 2.15.

![Figure 2.14: Wear of brass bearings liners](image)

3. **Heat Exchangers**: Brass is a very good thermal conductor. Hence heat exchangers, which need to dissipate heat quickly, are made using brass. But under the high temperature working conditions, the heat exchanger tubes (figure 2.16) suffer from corrosion.

![Figure 2.15: Corrosion of brass turbine blades](image)
4. **Fasteners:** Fasteners such as bolts, nuts, screws etc are made from brass. These fasteners when exposed to atmosphere undergo corrosion, which make them weak. These fasteners undergo stress corrosion cracking, because of the heavy loads applied on them. Figure 2.17 shows the corrosion of brass fasteners.

![Fasteners](image)

Figure 2.17: Corrosion of brass fasteners

5. **Bullet Shells:** One of the major applications of brass is in the manufacturing of shells for bullets. These shells need to be maintained in protective enclosure, to prevent them from corrosion. When exposed to humid or marine atmosphere, the shells corrode forming a layer of scale. Figure 2.18 shows the bullet shells with scale formation.
6. **Other applications:** Many domestic home appliances like door knobs, taps and other bathroom fittings are manufactured using brass. Brass is also used in coins and decorative items. Over a long duration, these components undergo scaling, due to the attack by atmospheric elements like pollutants, moisture, etc.

**Burnishing of brass:**

Brass is one of the most widely used materials in the industries and domestic home appliances. It has relatively good corrosion and wear resistance than the ferrous alloys. But under severe working conditions, the components are subjected to abrasive wear and scaling. These problems can be eliminated by applying burnishing operation. The brass fasteners such as bolts, rivets can be processed by burnishing, which improves their corrosion resistance and also stops them from undergoing stress corrosion cracking, by inducing compressive residual stresses. Hence in this thesis the improvement in corrosion resistance, wear resistance, bearing ratio and compressive stresses of brass components is studied. The brass considered for the study is C34000 or CuZn35Pb1 medium leaded alpha brass.
2.4 Research objectives:

Roller burnishing has undergone many changes and improvements in order to produce better surface finish and other surface properties. The improvement in these surface conditions have to be further analyzed and presented which would enable bringing the burnishing process out of the research laboratories into the production floor of manufacturing industries. With this objective in mind, this research work endeavor to study the improvements in the surface characteristics, in a more realistic manner. The present research work includes the study of effect of roller burnishing on both ferrous and non ferrous metals.

The main objectives of the present research work are listed below:

1. Optimize the tool related process parameters – tool material, tool diameter and number of tool passes for improved surface finish.
2. Optimize the process parameters – burnishing force, tool feed and spindle speed in order to improve the corrosion resistance of both ferrous and non-ferrous materials in brine solution.
3. Analyze the burnished surface with x-ray diffraction and determine the hardness and residual stress distribution.
4. Build a 3-dimensional finite element model to analyze the distribution of the compressive stresses in the burnished component.
5. Examine the microstructure of burnished and unburnished components to determine the refinements and realignment in the grain structure and its effect on the material properties.

6. Study the corrosion behavior of ferrous and non-ferrous materials in normal atmospheric conditions, in three geographical locations – industrial, marine coastal and dry rural areas.

7. Study the corrosion behavior of roller burnished components in brine solutions of various concentrations of NaCl.

8. Derive mathematical equations from the data obtained from the experimental work, which can be used to measure the corrosion rate of components of various materials in different concentrations of brine solution.

9. Investigate the improvement in the abrasive wear resistance of roller burnished components.

10. Develop mathematical equations to facilitate the determination of the wear rate of the components of the various materials, at a given wear force.

11. Determine the depth of burnishing affected zone (BAZ) and stress affected zone (SAZ) based on the results obtained from wear test, x-ray diffraction and FEA.

12. Investigate the effect of burnishing on the electrical conductivity of aluminium and copper components.

13. Study the improvement in the bearing ratio and other bearing parameters of burnished brass specimen.