CHAPTER – 2

LITERATURE REVIEW

Studies conducted by various researchers and their published work and reports on the topics that are described in the previous chapter are surveyed in detail in this chapter. Emphasis is placed to highlight the salient findings of these research contributions.

2.1. Surface Modifications and Burnishing

Burnishing, as of surface modification technique and to induce beneficial compressive residual stresses, has been attempted and studied by several researchers, including some studies on effects of select burnishing parameters. One such study is by Walter Egger [1], who showed that roller burnishing primarily produces high quality finish in case of forged steel for diesel crank shaft fillet application. This study also showed that such burnishing could result in improving fatigue failure life. On the other hand, Donold Walker [2], Shneider and Nikitin [3] and Vyallo [4] have described comprehensively the burnishing process and enlisted the typical applications of burnished products. These authors have also tried to establish metallurgical properties in some extent and included the effects of burnishing as well as burnishing accompanied by other finishing operation such as turning.

Mukhanov, Golubev [5] presented effects of ultrasonic burnishing to study the oxidations pitting and mechanical properties of steels under static loading. They also studied the effects of burnishing on wear resistance and plasticity effects. On the other hand, Rogozhkina and Azorkin [6] investigated through systematically conducted burnishing tests, the effects on the static and fatigue strength in case of locomotive steels. Their study also attempted briefly to determine the effects of number of burnishing passes.

Employing a number of steels, Shneider [7] investigated the burnishing characteristic effects on various aspects such as surface finish, micro hardness, and wear and corrosion resistance. However, optimization of burnishing parameters were studied by few researchers. Shneider, Feldman [8] developed theoretical formulae to calculate and correlate burnishing process on the basis of bearing surface area. This work has shown that the results are reproducible within 10% of error. In an extension of this work, Braslavskii [9] presented and formulated methodology for calculating bearing surface area in case of burnishing fillets having different fillet radii.

Several researches have also attempted to study the plasticity and plasticity effects including surface texture etc. Some of the important studies are the ones reported by Lunevskii. Serebryakov [10] and Kudryavtsev [11,12] have discussed several Soviet /Russian works in recent years on burnishing on the effects of burnishing on work hardening static strength and fatigue life on components that including welded and machine joints.

Proskuryakov and Kovalenko [13], ShKnevskii and Derevlev [14] have developed and shown a burnishing tool which simultaneously burnished both inner and outer surface of bushes with improved labour productivity and life. Proskuryakov and Berberov [15] investigated and derived a relationship between force, wall thickness and the nominal diameters for sizing of splined bores. In a significant industrial development, Proskuryakov [16] has demonstrated successful burnishing on thin walled components. He also developed empirical relations for elongation and burnishing inference in case of bush blanks.

Koznar [17] Emel'yanov [18] Rozenberg and Posvyatenko [19] investigated the plasticity effects as compared with tool-like machining of unhardened steels. The efficiency of the surface work hardening method in increasing fatigue strength of martenstic stainless steel in assessed by Karpenko [20]. Zhasimov [21] developed an automatic control system for plastic deformation, when components are being burnished. Shneider [22] developed a vibratory burnishing method for improving lubrication - retention in precision joints. Azarevich [23] considered the choice of the deformation force to achieve maximum effect of strengthening and smoothing out of rough spots and process productivity. Bokov and Markus [24] described the durability of steel specimens, which was found to increase by four fold by burnishing as compared to super finished components.

Karpov [25] developed coolants of special grades to monitor basic burnishing process operations. Suslov [26], Igoshin [27] gave the recommendations for selecting the dimension of cemented carbide rings for burnishing process. Proskuryakov and Romanov [28] have given the classification of bore - burnishing processes, as hole burnishing with small to greater interference. Several researches investigated the effect of diamond burnishing on various joints and surfaces for different methods with different properties [29-34].

Braslavskii [35] developed equation for the depth of work hardening of a plastically deferred surface. The experimental work by El-Axir and El-Khabeery [36] established the effects 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 work piece diameter. Hongyun Luo, Lijiang Wang and Chuang Zhang [37] studied the effects of various parameters on the surface roughness of aluminium alloy, burnished with a cylindrical surfaced polycrystalline diamond tool.

Proskuryakov and Kovalenko [38] developed new technology for machining sleeves by combined internal burnishing and diameter reducing. The machining accuracy corresponds to class 2-3 and the roughness parameter is 0.16 μm. After burnishing by this method, the surface micro hardness of part was found to increase by 60%. As a result of strengthening and the achievement of a high quality surfaces, the service life and reliability of machined parts are improved considerably. Combined internal burnishing and reducing tools decrease the surface roughness from 10-20 μm to 0.4-0.6 μm.

Papshev [39] carried out a comparative investigation on the potentialities of diamond burnishing and ball burnishing with an aim to establish areas of their effective application. Work hardened layer after ball burnishing is found to be 1.3-1.7 times greater than that after diamond burnishing. Maximum residual stresses with a diamond of radius 2 mm is 110 Kgf/mm^2 and compared its performance with titanium ball burnishing. Diamond burnishing is advisable when there is higher demand for surface texture, and less stiffness. Ryzhov and Suslov [40] established that the contact stiffness of machine tool slide ways and universal fixture base plates depends not only upon conditions of vibro-burnishing but also upon the initial surface roughness and waviness. Empirical formulae are suggested for surface quality parameters and contact stiffness of parts made of cast iron and steel.

Sorokin and Baer [41] developed a method for combined treatment of surfaces of parts, consisting of the application of an anti-friction coating on a metallic friction surface with roughness 1 to 2 μm, followed by vibratory burnishing to have higher wear resistance roughness of steel and titanium alloys were reduced from 5.5 μm to 0.4 μm. The micro-hardness improvement on a coating was 20-30%. Vibratory burnishing of steel and titanium test pieces with coatings raises the wear-resistance of rubbing pairs by 12-30%. The introduction of this method improved the service life 200-400 percent.

Khvatov [42] studied the effect of the shape and arrangement of the micro roughness of piston rods on the sealing properties of the pairs of seals, manufactured for pneumatic cylinders. Barsegyan [43] has developed a technological process for vibro burnishing, to improve the operational characteristics of various pairs of friction surfaces with due regard for oil capacity of the surfaces. The oil capacity of vibro burnished surfaces is determined by the geometrical parameters of the extruded grooves.

Kholmogortsev[44] described the possibilities and conditions for reducing the initial form error of bores in parts with non-uniform wall stiffness employing surface plastic deformation methods. Tomadur [45] stated that, problems in automotive engine rebuilding solved by adjustable roller burnishing tools fed either manually or by machine.

Ershov [46] presented the experimental assessment of methods in improving the properties of surface of titanium alloys before diamond of loads investigated, the least coefficient of relative adhesion 31 to 36% is obtained, in case of chemical-thermal treatment of titanium alloys in melts of alkaline metal salts. Barsegyan [47] proposed a method of calculating tool impact forces in the vibratory burnishing of helical surfaces. The proposed method of calculating the force with which the deforming element is impacted into the helical surface can serve as a basis for deriving similar methods of calculating forces in the vibratory burnishing of various other types of surface.

Belkin [48] examined the fatigue resistance of plane parts strengthened by surface plastic deformation of various standard sizes and made of various steels. The optimum burnishing force which rises the fatigue limit, increases with test piece thickness. The optimum force also depends on the material of test piece. The effect of strengthening of the plane parts of large thickness can be intensified by applying a peening operation.

Mitryaev and Seryapin [49] examined the influence of surface strengthening by plastic deformation on the fatigue resistance of a titanium alloy VT 9 with a V-shaped notch, and established the relationship with the amount and depth of dissemination of residual compressor stresses bars, under concentration conditions, to the fatigue resistance to destruction. Compared with polishing, strengthening treatment by burnishing and shot blasting increases the fatigue limit of smooth specimens by 14% and 10% respectively. Pleiman [50] discussed the benefits of carbide – rollers burnishing. The increased quality and productivity aspects of roller burnishing were discussed. Niberg [51] investigated into the effect of the average length of the graphite inclusions and of the radius of roller profile on the wear resistance of a pearlitic cast iron which has been strengthened by roller burnishing.. After strengthening by burnishing it is therefore necessary to remove the imperfect layer by a machining operation of the slide ways.

Ramamoorthy and Radhakrishnan [52] carried an experimental investigation to study the strength of assemblies of interference fit after ball burnishing the shafts. The assemblies were aged for different durations at elevated temperatures and the axial load tests were carried out in an universal testing machine. The surface strengthening of shafts by burnishing and aging of assemblies resulted in considerable improvement of strength. Kotiveerachari [53] determined the depth of plastically deformed layer in burnishing, analytically and experimentally. Expressions were derived for the depth of plastically deformed layer based on the theory of elasticity. To verify the accuracy of these expressions, experiments were conducted on mild steel, aluminium, copper, brass and lead. The maximum deviation of theoretical value of the depth of plastically deformed layer from the experimental one is about 18% in the case of mild steel.

Loh and Tam [54] presented the effects of ball burnishing parameters on surface roughness using factorial design. Experimental work based on 3^4 factorial designs has been carried out. The effects of ball burnishing parameters on the surface roughness of AISI 1045 specimens were established. Loh, Tam and Miyazawa [55] reported the optimization of surface finish produced by the ball burnishing process using response surface methodology. Mathematical model formulated, predicts an optimum surface roughness value [Rtm] of 0.72 μm for a tungsten carbide ball using depth of penetration of 12 μm and feed of 112 μm. The empirical and experimental results agree reasonably well, deviating by about 2.8%. For each set of burnishing conditions, an optimum depth of penetration and feed for giving the best surface finish is clearly evident.

2.2. Burnishing Process

A Scientific description of the burnishing process was provided by several researches. These works also described the burnishing process idealizing as ballizing. Podstrelov [56]and Robinson [57] suggested that the process of ballizing in the best solution for hole tolerances. Downes [58] suggested the process of roller finishing and surface hardening of various parts like steering shafts, rocker shafts, piston rods in hydraulic systems, spinning spindles and belt pulleys etc. Robert Le Grand [59] analyzed the process of sizing of sleeve bearings using roller burnishing.

Kaznar [60] has developed a dynamic roller burnishing head for holes. The head can be easily reset to a different diameter within its range by exchanging the cams and cage in it, ranging from 16 to 200 mm. Chernikov [61] developed roller burnishing tools for simultaneous burnishing of two faces of such components as flanges, couplings, gears etc., output rate of burnishing will be increased by these tools.

Shneider [62] designed an adjustable internal ball burnishing tools for holes ranging from 30 to 400 mm diameter. The range includes three types of adjustable tool [i] for holes 30 to 60 mm dia. [ii] for holes 60 to 130 mm [iii] for holes 130 to 400 mm. Granovskii [63] presented the diamond burnishing tests on nitrided [65 to 66Rc] and hardened components in Cr-Mo-v alloy steel.

Khvorostukhin and Mashkov [64] developed a flexible burnishing tool holders for diamond burnishing in which the actual burnishing tool body itself forms the flexible element. The values of burnishing forces and corresponding deformations are indicated on the body of the tool. Kononenko and Shamlin [65] explained the production methods, designed parameters and manufacture of carbide burnishing units for broaches. The most widely used circular broaches equipped with carbides are of composite, segmental burnishing types and combination broaching and burnishing tools. Due to plastic deformation of components by these broaches, the micro-hardness of the surface layer increases by 30-40%, which in certain cases eliminates heat treatment of the components.

Liing Hwa Yan, Che Chung Wang, Hanming Chow and Yan Cherng Lin [66] investigated the feasibility and optimization of a rotary electro discharge machining [EDM] with ball burnishing for inspecting the machinability of AL203 /6061 al composite using the Taguchi method.

Fang - Jung Shiou and Chien-Hua Chen [67] studied the possible ball burnishing surface finish process of a free surface plastic injection mold on a machining center. Klocke and Liermann [68] presented a study to determine optimum working parameter range. Parameters setting were shown to be non-critical in this process, since constant surface qualities were attainable over wide setting ranges.

Shneider [69] gave a classification of burnishing methods and tools most widely used in industry based on shape of the work piece surface [external and internal, cylindrical, plane and shaped surface] and the purpose of the operation sizing, finishing, hardening or a combination of the above. This data shows the operational possibilities and range of applications of each burnishing method, and the appropriate tool, work piece, surface quality and accuracy and so on. He developed a selection diagram based on the type of production, the shape of the surface, the purpose of the operation and the strength and stiffness of the work piece.

Khudobin Emelyanov [70] described a process for hardening the fillets of crank shafts which ensures an increase in fatigue strength and retains the correct shape of the shaft.

General surface geometrical characteristics and its quality was addressed by Khvorostukhin and Mashkov [71]. These authors have addressed both cutting and burnishing by using diamond. The effect of diamond burnishing, polishing and grinding was also addressed by

Yatsenko [72]. The author studied these parameters and also the effect of surface quality on fatigue strength in case of Chromium - Nickel – Molybdenum steel. Automated machines and their use in burnishing was addressed by Barats and Reznikov [73]. With this process of burnishing the surface finish with the class of 11–13 limits are improved with geometrical accuracy.

Machining and technological processes and productivity along with cost aspects in case of burnishing was addressed by Konovalov and Golembievskii [74], Lopez and co-workers [75], John and co-workers [76] and El-Axir [77]. Mlyura [78], Rodnova [79] and Tiurin [80]. Gol'bshmidt and Dynin [81] developed a burnishing tool which is meant for burnishing bores for ball bearing surfaces. This device can perform burnishing in two way manner.

Burnishing the large parts were also attempted in several studies and equipment used for such technological advancements were found to be quite different and the authors are Braslavskii [82], Bukin and Zabrodin [83], Tyurin and Gnibeda [84], Kokhanovskii and Leskov [85] and Koropets [86].

Yarkovets [87], Vsov [88] and Vaidyanathan [89] attempted the mathematical description of burnishing process and equations developed are based on elastic deformation, compressive deformation behavior, variation in reduction in radial load on the rollers and finally work done during burnishing.

Burnishing of different materials with varied properties were addressed by Temple Black [90], Loh and Tam [91], EL-Axir [92]. The influence of burnishing parameters and the work piece characteristics were addressed by El-Axir and Ibrahim [93]. During the burnishing process the possibility of plastic deformation was investigated by Parfenov and Pupin [94]. Walters [95], Braslavskii [96]. Pleshakov [97] investigated the improved fatigue characteristics during burnishing and also optimize the process parameters in order to increase the productivity.

The use of coated burnishing tools was addressed by Dugas [98] and Westerman [99]. Lopnukhov [100] presented the results of experimental research and factory tests with taps of a new design, having combined cutting and burnishing teeth. Yashcheritsyn [101] described the procedure and the equipper for measuring elasto-plastic waves of the squeezed out metal in burnishing operation of steel work pieces. A method has been elaborated to measure a wave directly in the burnishing process by means of photographic recording.

Filonov and Yashcheritsyn [102] examined some characteristics of contact interaction in high speed rolling element burnishing. This makes it possible to point out ways for further improvement of the machine Yatsenko [103] studied the surface quality, wear resistance, and contact damage resistance of specimens in application to the operating conditions of atomic and thermal electric power plant equipment parts after diamond burnishing.

Nee and Venkatesh [104] proposed a theory for predicting the ballizing load under dry and lubricated conditions. The theoretical and experimental values are well coinciding at mid-interferences. With the application of lubricant there is distinct reduction on peak ballizing force. Pande and Patel [105] reported the experimental investigations on vibratory ball burnishing process. Experiments were carried out to study the influence of various process parameters such as burnishing speed, feed, ball force, frequency and amplitude of vibration on the surface finish and micro-hardness of surface layers produced by vibratory burnishing process.

Natapov [106] presented the pneumatic centrifugal burnishing of cylindrical holes. Surface micro-hardness after burnishing was 30-40% higher than before burnishing. Kotiveerachari and Murthy [107] investigated the optimum burnishing force, change in dimension and the variations of tangential and normal forces in the process. Expressions were derived to calculate analytically, the optimum burnishing force size change in burnishing. The accuracy of these expressions was verified by suitably conducted experiments.

Tokio Morimoto [108] described the burnishing of cylindrical mild steel bar by a simple newly designed tool system using a lathe. The influence of the burnishing force, tool feed, burnishing speed, tool size, lubricants, number of passes of the tool and supporting methods for the tool on the roughness of the finished surface was examined. Drofeev [109] discussed the formation of regular micro-reliefs by cycloidally moving burnishing tool.

Nee [110] presented the mechanics of the ballizing process, though efficient and economical, was previously plagued by the uncertainties and difficulties as well as the final bore size can be predicated quite accurately.

Abugov [111] presented the selection of a needle mill mounting for burnishing jobs. An inflexible needle mill mounting reduces the deviation of the surface from roundness, whereas a flexible mounting has practically no effect on the initial deviation from roundness.

Sogoyan [112] illustrated a disc tool for burnishing worm thread surfaces in a lathe. The proposed disc tool design and basic parameter calculation method in the paper can be used for hardening other types of helical surfaces. Abul'khanov [113] presented a device for diamond burnishing holes in diameters from 6 mm upwards. Soundararaj [114] presented that skiving followed by roller burnishing will reduce the manufacturing time of hydraulic and pneumatic cylinder by 80-90% when compared to that of boring followed by honing operation.

Komaraiah [115] designed two different oscillatory tool posts for burnishing on milling machine and on lathe. Experiments were conducted to study the effect of different process parameters of oscillatory burnishing on surface finish and hardness of mild steel, stainless steel, aluminium, brass, copper, titanium alloys, mar-aging steel and nimonic 80A. At attempt is also made to develop a procedure to estimate the forces in burnishing. Loh and Tam [116] reported on the optimization of the surface finish produced by the ball burnishing process, using the response surface methodology [RSM] technique.

Rajesham and Tak [117] presented a study on the surface characteristics of burnishing components. They reported the development of roller type burnishing tool together with some experimental results concerning roughness and micro hardness of surfaces of alloyed aluminium components. The surface finish has improved and the bearing ratio has increased after burnishing in a single pass.

Cheshev [118] described a tool for burnishing intermittent external cylindrical faces. The tool is of simple design and can be used for burnishing parts made of materials with unstable mechanical properties. Loh and Tam [119] presented the statistical analysis of the effects of ball burnishing parameters on surface hardness. A 33% - 55% increase in hardness can be obtained. Leon Kukielka [120] presented and discussed the conditions for the pre-machining and for the subsequent burnishing rolling processes that ensure a very-high quality product.

Beiss [121] explained the roller burnishing as a finishing process in powder metallurgy parts. Parts can be roller burnished with defined rolling forces or with fixed geometry. Loh and Tam [122] carried experiments on a vertical machining centre to establish the effect of four ball burnishing parameters, depth of penetration, feed, ball material and lubricant, on the burnishing force, and hardness of the AISI 1045 specimens. Deshingkar [123] presented the study of effects of speed, feed, ball size and pressure on burnishing process. The effect of vibratory burnishing also investigated. The statistical inferences show that burnishing process improves surface finish and surface hardness of components.

Lai and Nee [124] studied the properties of repeatedly ballized holes. The surface finish of the ballized holes was found to have improved by as much as 97% after three passes of the ballizing processLoh and Tam [125] investigated the process of ball burnishing the tool steel, in place of the traditional methods of finishing a surface, giving the worst surface finish. Tungsten carbide ball gave the best and most consistent surface finish. Grease was a better lubricant than cutting oil. By varying the burnishing speed, the burnishing forces varied also, and these forces showed no obvious relationship to the surface finish of the burnished work piece.

2.3. Roughness Studies

This section attempts to focus on various studies related to the surface modifications, the principals and processes of burnishing residual stress resulting from surface modifications burnishing in particular and surface roughness characteristics. The detailed descriptions of the studies are here under furnished.

The experimental investigations of proskuryakov and Men'shakov [126] explained the deformation of the micro- ridges and approximate pressure recommendation for various methods of finish machining metals by burnishing. Their investigation is specially based in enlarged imitation ridges. In order to machine precision holes, Proskuryskov, Kylikovskii and Pozdnyakova [127] developed a hole burnishing tool which become a substitute for broaching grinding and homing operations. The inter changeable burnishing rings have been built up by this tool. Many experiments have been carried out to study the character of heat distribution over the surface of the tool and component in the contact zone and to determine the burnishing forces. These experiments have been done on a horizontal broaching machine, using sulphonoted oil as coolant.

The investigation of Alekseev [128] helps in three ways: [a] to determine the effectiveness of ball burnishing flat surfaces; [b] to establish optimum burnishing conditions , improving the wear resistance of the surface layers in comparison with other methods of surface finishing; and [c] to find the quantitative characteristics and shape of worn surfaces In order to get better surface finish.

Karasev [129] studied the roller burnishing process in which he described the practical experience with this method in the production of piston rods. In the process of roller burnishing the hollow shaft material is in a volumetrically stressed state because of the irregular hydrostatic compression during burnishing, the plastic flow of the metal was neglected. Burnishing the piston rods [hollow] reduces the time required to prepare the rod surface for chromium plating and productivity enhanced five times greater.

An inertia type ball burnishing tools were presented by Rybakov[130]. It is very easy to make these tools. These tools can be made and used on lathe, vertical drilling and fine boring machines. Rybakov got satisfactory results when he tested these tools on grey, alloyed and high strength cast irons.

In order to increase the plastic deformation rate together with high accuracy of the burnishing surface Shapovolov [131] has developed an expanding roller type burnishing tool. This allows working rollers of any shape to be set at any angle relative to the component axis. We can apply this tool for rolling internal and external surfaces. Burnishing output will be increased with the use of this tool. A high quality surface finish can be obtained at all fields due to the absence of shear deformations. Larger savings in the plastic deformation process can be achieved with a scope of standardization and universal application of the tool.

Proskuryakov and Valyaev [132] recommended means to select specific type of tools, lubricants and deformation rates in internal burnishing holes. They carried out investigations to determine the relations between bore surface finish wall thinness "S" of the components with interference "I", initial roughness of the bore "RZ" and also determined the distribution of the interference among the ring sections of the tool.

A universal elastic multi ball burnishing tool was described by Andriyashin [133]. This tool helps us to finish low stiffness components by this tool with balls of surface size to accommodate components rating from 10-32 mm diameter. It is confirmed by the test results that this type of tool can be recommended for burnishing components of various sizes to fine a surface finish within class 9-10 limits.

Rosenberg [134] studied the surface finish of bores after internal broach- burnishing. A correlative improvement is noticed in surface finish of preliminary machining and in surface quality after broach – burnishing without quality difference in the amount of plastic deformation. After broach burnishing, the surface quality is not considerably increased by lubricants.

Klocke and Liermann [135] discussed the use of the structure analysis and residual stress measurements to examine the effects of the process on the work piece surface zone after hard turning and burnishing process.

The self generation of corrugations on metal surfaces in rolling contact were studied by Johnson and Gray [136]. They theoretically studied this concept using a computer. Simulation and experimentally in a rolling contact disc machine. When the system was in the contact resonance mode, vibrations were noticed, probably being excited by surface irregularities. In case the damping is low and high the vibration may be severe enough to cause plastic indentation of the surface in one revolution which then amplifies the vibration in the next revolution. A stability map was used to indicate the ranges of loads, damping and surface roughness for which corrugations would be expected to develop. Pleshakov [137] showed the effect of burnishing force, longitudinal tool feed, and the radians of the diamond tip on the state of the surface layers of creep resistant nickel based alloys.

Kangun [138] developed the relation which will determine after broach burnishing. Kangun's equations serve as a means of calculating the residual height of the asperities after broach burnishing as a function of the initial surface texture. In order to have simultaneous cutting and hardening, a combined tool with a toroidal hardening roller was developed by Poduraev [139]. The test results established the reduction of surface roughness after machining from 14-17 μm to 0.13 – 0.7 μm. It has become clear that this machining process could ensure 3-5 times more productivity than ball burnishing of burnishing with a diamond tool. This process established optimum values for burnishing parameters.

The role of surface texture was described by Whitehouse [140] as a control of the manufacturing process. It was observed that the texture has only a marginal effect in a severe wear regime for unlubricated surfaces. Khvorostukhin [141] estimated the complex influence of material strength and surface topography on working ability through wear tests of a nitride steel roller, hardened cast iron block pair. The working surface was finished using the processes of grinding, polishing, diamond burnishing with a stationary tool, with a rotating tool, and with a combined tool. In order to maximize wear resistance of surface adequately, these processes can be used in various methods of finishing.

A system of vibratory burnishing of helicoids was described by Barsegyan [142]. This system recommends the selection of the kinematics and dynamic parameters of the machining conditions when burnishing operation is carried out on screw parts. It was observed that burnished screws had been in service 2.5 to 3 times longer than those with ground ones.

The depth of plastically deformed layer on burnishing was estimated in the presentation of Kotiveerachari [143]. Expressions were derived for the stress at any point below the asperity when the applied load is normal tangential or inclined. Experimental verification of these calculated values the stress was also done. The deviation of the around 20% from these stresses, the depth of plastically deformed layer was estimated. The hardening of machine tool parts by forming a regular surface micro relief was presented by Kirichek [144].

Vibratory burnishing was for hardening slide ways in place of scraping. Consequently labor costs in machining parts the compound rest slide of multi- spindle lathe were reduced by a factor of 9.6, and their life was increased by 30%. The results of vibratory burnishing of the main tools slide swivel pin were statistically analyzed. This analysis showed that wear resistance of the friction pair was increased by 30%, and the incidence of jamming of the main slide pin- carriage pair was reduced by a factor of 4, stylus life was 150 km, or 50 hours.

The intended performance characteristics of the surface were discussed by Clark and Grant [145]. The study covered the powerful analysis tools that can discriminate the subtle differences between performing and non-performing surfaces and also how these tools can be used to develop specifications and process controls to produce consistent surface quality. The study also shows how these used in conjunction with each other results in the ability to produce quality surfaces with consistent performance for a broad range of applications.

2.4: Residual stresses

According to the Papshev [146], the thermal stresses that arise due to burnishing affect the depth to which the compressive stresses exist. As a result the residual compressive stresses occur at depths greater than those caused by plastic deformation. This fact has been substantiated experimentally by a number of investigations. In some cases the stresses are due to deformation. There the cooling of the component can cause delayed residual tensile stress in the thin surface layer. This kind of effect was noticed during investigations of specimens burnished at very high pressure.

Burnishing force is the factor that affects the stress state [magnitude and spread depth of residual stress]. A strain gauge type new dynamometer head was developed by Shteinberg [147] to measure and record simultaneously the axial force and torque in internal burnishing. A study was carriedout by Shapiro and Frolov [148] about the effect of surface hardening on the fatigue strength of specimens with stress concentrators in the form of circular grooves.

When the malleable iron was roller burnished with a force of 120kgs, a feed rate of 0.2 mm/rev and a speed of 600 rev / mm[in three passes] the fatigue limit was enhanced by 40-60 % and stress are developed the distribution of which is similar to stress distribution after surface hardening by other processes.

Proskuryakov [149] took into account the residual axial stress to investigate explain the relationships between the stress deformed condition in the material and the accuracy of the burnished holes. The test pieces were made of steel 45. The holes were broached with molybdenum disulphide as a lubricant using push and pull methods. The investigation revealed that the axial residual stresses at the surface of the hole [upto 0.1 mm depth] are compressive becoming tensile upto approximately mid thickness of the wall and then again becoming compressive.

Bokov [150] developed an attachment with a d.c. electromagnet to ensure a constant normal component of burnishing force over the whole groove profile of ball bearing race grooves with a provision of changing their force automatically. Bokov used this attachment to burnish the grooves of the components of several production batches of journal and thrust bearing application.

A new tool was developed by Toshiaki Segawa Hiroyuki Sasahara, Masaomi Tsutsumi [151] to generate compressive residual stress within the machined surface concurrently with the milling process. The tool improved the fatigue strength and resistance to stress corrosion cracking of the machined components, if compressive residual stresses are induced into the surface. According to Lindemann and Zhang [152], the high cycle fatigue performance of A280 can be improved upto 110% at the optimum condition by roller burnishing which is more effective than shot peening in enhancing the fatigue life of A 280.

Paul and co-workers [153] substantiated that the fatigue life improvements through surface modification technologies of shot peening, laser shock peening and burnishing. Shepard et al. [154] successfully explored the fretting fatigue performance of Ti- 6Al-4V after isothermal exposure in test coupons burnished, shot peened, and electro polished base line conditions. Prevey and co-workers [155] suggested that substantial fatigue life improvement can be achieved through surface enhancement technologies like shot peening, laser hock peening and burnishing.

Beres and Patnaik [156] analyzed the low plasticity burnishing process using finite element modeling. Filimonov [157] presented the investigation conducted on shafts with ‘spoon’ shaped keyways, that resisting the development of fatigue cracks. The endurance limit of 50 mm diameter roller burnished shafts of steel in the press fit is 15 Kgf/mm^2 higher than the endurance limit of unstrengthened shafts of the same steel with a keyless fit. Roller burnishing increased the endurance limit in this specific case by not less than 150%. Under optimum conditions, the fatigue strength in a keyed press fit connection of carbon steel shafts was increased by three times and that of normalized structural Chrome-Nickel steel by four times.

Ivanets [158] presented the design of attachment intended for strengthening treatment of cylindrical work piece. Brinksmeier[159] discussed the determination of mechanical and thermal influences on machined surfaces by micro hardness and residual stress analysis. It is reported about the fundamentals of these techniques, their experimental execution and the accuracy to be expected. The combined application offers the determination of causes for the generation of the surface state.

Egorov and Mitryaev [160] discussed the effect of diamond burnishing on endurance of parts with stress concentrators. It is shown that fatigue strength can be increased by setting up residual compressive stresses in the material, especially in the region of stress concentrators. It was concluded that diamond burnishing reduces the sensitivity of the material to stress concentration. Hardening by diamond burnishing in the vicinity of stress concentrators increases the fatigue strength of components made of creep-resisting steels and alloys by 15-100% depending on the type of stress concentrator.

Brinksmeier [161] presented a report to show the possible sources for development of residual stresses. Measurement of residual stress distributions generated by some important machining processes has been made. The detrimental and favorable influences of residual stresses on components were also discussed. Nee and Venkatesh [162] presented a mathematical analysis of the ball burnishing process, based on friction and plasticity theories in the prediction of the final dimensions of a ball burnished hole.

Busel and Kritskii [163] studied the strain-broaching process. Equations were derived for calculating radial forces in the strain-broaching of components of any metals. The accuracy obtained with this equation is $\pm 10\%$. In order to make practical use of these equations, it is necessary to know only the hardness of the metal, the dimensions of the work piece and the broaching rates. Kotiveerachari and Murthy [164] attempted to investigate the optimum burnishing force in burnishing of metallic surfaces. Based on dimensional analysis as well theory of elasticity, expressions were derived for optimal burnishing force. The optimum burnishing force was determined experimentally and compared with the theoretical one.

Meguid and Klair [165] considered an elasto-plastic finite- element analysis of simultaneous indentations of a bounded solid, by two smooth flat, rigid punches under plane strain conditions. Fattouh and EL-Khabeery [166] determined the residual stress distribution in the surface region of solution treated and aged 7075 aluminium alloy work pieces that are orthogonally burnished under lubricated condition, using a deflection etching technique. The residual stress at the surface is low compressive and increases rapidly with an increase in depth beneath the burnished surface to a maximum compressive then decreases gradually with further increase in depth becoming vanishingly small tensile or compressive. The maximum residual stress and depth of the stressed region increase with an increase in burnishing feed, force and an increase to some extent in burnishing time.

Lai and co-workers [167] investigated the effect of the residual stress on the fatigue performance of a ballized hole. The fatigue life was, expectedly, observed to increase with the increase in interference, but when the ballized hole was broken, the fatigue life decreased to below that of an unballized specimen having approximately the same range of surface roughness. The result showed that when the hole is complete compressive residual stress is induced at the hole surface, but when the hole is broken the compressive stress is redistributed to give rise to a state of tensile stress at the hole surface.

Oh and Nee [168] analyzed the stress state of ballized hole using the theory of plasticity and Von Misses yield criterion predicts a resultant compressive stress state. Experimental investigation with varying interferences into the resultant stress state of a ballized hole in medium carbon steel concurs with the theoretical predictions. The stress remains tensile but gradually decreases towards the edge of the plate.

Effect of residual stresses as obtained by pre straining in case of aluminum and lithium alloys was addressed comparatively by Eswara Prasad and co-workers [169-175]. These workers have addressed the aspects of such pre-straining and its resulted residual stresses on the strength deferential, cyclic stress response in compression and tension as well as fatigue life. Such pre strain principally was employed to enhance the precipitation of beneficial S-phase in aluminum-lithium alloys [196-180]

2.5 Optimization Techniques

The Taguchi methods are cost effective compared to conventional parameter studies [181]. The Taguchi approach is a systematic and efficient method for design of experiments that uses orthogonal array to minimize the number of experiments to arrive at a solution [182]. To accomplish this in an effective, statistically and proper fashion, the levels of the factors are varied in a strategic manner, the results of the particular test combinations are observed and the complete set of results are analyzed to determine the influential factors and preferred levels will potentially lead to further improvement [183].

2.6. Chapter Summary

Various studies reported in the open literature regarding the surface modifications, the principles and the process of burnishing, residual stresses that result from surface modifications [especially burnishing] and surface roughness characteristics are detailed and described in this chapter. Though not discussed in a fully systematic manner (in view of large number of disjoint studies), an attempt is made in this chapter to bring out the principal findings of large number of investigations in four major sections namely surface modifications, burnishing process and surface characteristics – roughness and residual stresses.