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The Role of Burnishing Process in Manufacturing Industry -A State-of-the-Art Survey-

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ABSTRACT: Burnishing process is a surface enhancement technique, which improves the surface finish of the component along with surface properties of the component. It is a cost effective process, mostly used in aerospace, biomedical, and automobile industries to improve reliability and performance of the component. In burnishing process, response parameters depends on burnishing process parameters, tool, and material on which burnishing is done. The key driving forces for newer production technologies and material development are strength to weight ratio of materials, performance and reliability improvement. The availability of appropriate manufacturing methods plays a vital role with respect to both material properties, cost. Authors tried to review the research papers of last four decades and progress of burnishing process is discussed.

Keywords: Burnishing Tool, Surface Integrity, Optimization, Stiff Burnishing, Burnishing Process Parameters

I. INTRODUCTION TO BURNISHING

In the present scenario, a major concern in aerospace, biomedical and automobile industry is to manufacture all machine components with complete reliability, maximum safety and predictable performance of the component. This needs development and deployment of predictive analytical models for various manufacturing processes and optimized processes parameters so that we can predict various surface characteristics of the component. In burnishing process, the material is plastically deformed to produce highly finished surface. There is no material removal in this process; surface finish is obtained due to plastic deformation of the material. It is a chip-less process. This offers many advantages over other finishing processes like honing, lapping and grinding. Due to chip-less surface finishing processes, cold working of material is done at relatively high force. The applied force slightly exceeds the yield strength of the material and plastic deformation takes place. Due to plastic deformation of material along with a surface finish of the component, wear resistance, fatigue strength, foreign object property and surface microhardness of the component is get improved.

Burnishing Mechanism

All machined surfaces consist of series of peaks and valleys of irregular height and spacing as shown in figure 1. As a result of uneven surface and high pressure, finishing process at the beginning of operation is extremely intensive but gradually slackens off. In burnishing, the motion of ball or roller deforms the peaks into the valleys, thus makes the surface of component finished one. In certain cases, burnishing is the only method to by which technical requirements of the surface can be satisfied.

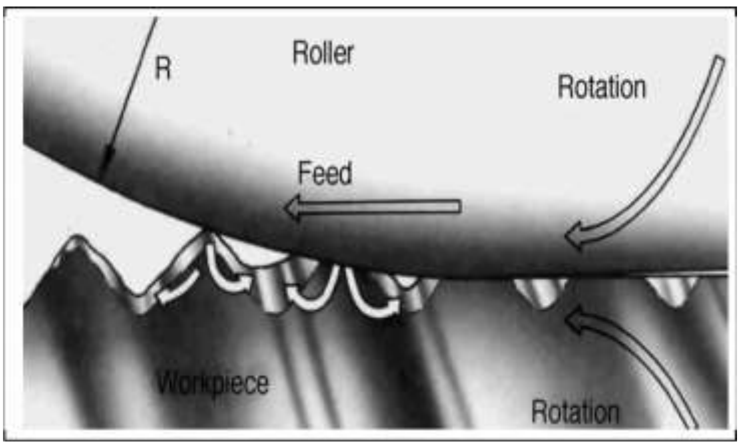

Figure1 Burnishing Mechanism

The effectiveness of burnishing process in the improvement of surface integrity has attracted researchers and engineers. In this paper, work done by researchers on the effect of various burnishing process parameters on surface roughness, surface hardness, wear, fatigue strength, surface integrity on various materials is listed. Also, various types of burnishing tools and ball/ roller material used by researchers to carry out burnishing process are studied. This paper is categorized systematically into various segments based on the burnishing process considered.

II. VARIOUS BURNISHING TOOLS AND MATERIAL USED

Burnishing can be done using various tools. Most of the researchers used ball or roller burnishing tool. Burnishing tools are broadly categorized as a rigid burnishing tool, flexible burnishing tool, and a stiff burnishing tool. Some authors designed and developed their own tools, which gave them better results than conventional tools. The research done in this area is discussed here.

Ball or Roller Material:

In most of the research work and applications, balls or rollers of burnishing tool are made of high carbon steel. Loh et al.[1] considered the effect of four parameters on the surface finish of AISI 1045. They studied the effect of ball material, burnishing force, depth of penetration and feed. Ball material tungsten carbide gave better surface finish than ball bearing steel in combination with other parameters. Morimoto and Tamamura [2] studied the effect of various ball materials on burnishing process. They studied the effect of five types of ball materials silicon carbide, bearing steel, alumina ceramic, cemented carbide and alumina ceramic on burnishing process. It was found the cemented carbide ball tool gave most finished surface and surface of cemented carbide ball was hardly damaged in long distance burnishing. Klocke and Liermann [3] used the ceramic ball for burnishing operation. They found an optimum range of burnishing parameters to get required surface quality. It was observed that 30 to 50% reduction in peak-to-valley height was achievable with various initial surface roughness values. They also determined residual stress developed on the surface. Shiou and Chen [4] studied the effect of four parameters ball material, speed, feed and burnishing force for improving the surface roughness of plastic injection mold steel PDS5. The optimal burnishing parameters found were tungsten carbide ball, the burnishing force of 300 N, the burnishing speed of 200 mm/min and feed of 40 µm. Yeldose and Ramamoorthy [5] used TiN coated and uncoated rollers for burnishing process. The burnishing process parameters used were speed, feed, number of passes, burnishing force and workpiece material was EN24 steel. Results show that coated rollers were better than uncoated rollers for improving surface finish.

Table 1 Ball/Roller Material and Workpiece Material

Sr. No.	Reference	Ball/roller material used	Workpiece material
1	Ghani [6]	Coated carbide tool	Titanium alloy
2	Morimoto [7]	Cemented carbide, bearing steel, silicon nitride, silicon carbide and alumina ceramic	Steel and brass
3	Shiou [4]	Tungsten carbide	Mould steel PDS5
4	John [8]	Tungsten carbide	Tool steel
5	Revankar [9]	Carbide	Titanium alloy
6	Hassan [10]	Cemented carbide	Brass and Al-Cu alloy
7	Shiou [11]	Tungsten carbide and silicon nitride	OFC 101
8	Leong [12]	Tungsten carbide	Not mentioned
9	Ulutan [13]	Coated and uncoated carbide tools	Titanium and nickel based alloy
10	Kumran [14]	Polycrystalline Diamond Tool (PCD)	Al-alloy 6351 matrix reinforced with 5 wt. % silicon carbide & 5 wt. % boron carbide
11	Rodriguez [15]	Tungsten carbide	Aluminum A-92017 and Steel G10380
12	Grzesik [16]	Ceramic ball	41Cr4 steel
13	Loh [1]	Tungsten carbide and ball bearing steel	AISI 1045
14	Abrao [17]	Tungsten carbide	AISI 1060
15	Tadic [18]	Ceramic, chrome carbide, high chromium structural steel	Al-Alloy EN AW-6082 (AlMgSil) T651
16	Celaya [19]	Ceramic ball	AISI 1045
17	Sequera [20]	Ceramic ball	Inconel 718
18	Thamizhmnaii [21]	Multi-roller burnishing tool	Titanium alloy
19	Klocke [3]	Ceramic ball	100Cr6
20	Grochala [22]	Ceramic ball	X42crMo4 steel
21	Neslusan [23]	Ceramic	Bearing steel
22	Hamadache [24]	Polycrystalline Diamond Tool (PCD)	Rb-40 steel
23	Zhang [25]	Silicon nitride, ceramic	17-4 PH stainless steel
24	Abdulstaar [26]	Hard Metal Ball (HG6)	AA5083
25	Jinlong [27]	Polycrystalline Diamond Tool (PCD)	AA 2024 T3
26	Gharbi [28]	Not mentioned	Aluminum 1050 A rolled sheet
27	Maheshwari[29]	Carbide Ball	Titanium Alloy
28	Wagner [30]	Ball bearing steel	Titanium, aluminum, and magnesium alloy

29	Esme [31]	Not mentioned	AA7075
30	Malleswara [32]	Chromium steel roller	Aluminium alloy
31	El-Axir [33]	Carbon Chromium ball	Aluminum alloy 2014
32	Rodriguez [34]	Tungsten carbide ball	Aluminum A92017 and steel G10380.
33	Rodriguez[35]	Silicon nitride ceramic	AISI 1045 Steel
34	Maheshwari[36]	Carbide ball	AA 6351

From above table and literature, we can say that for alloy steel, ceramic balls were used by most of the researchers, for titanium and nickel-based alloy carbide balls or rollers were more suitable and for aluminum alloy, carbon chromium balls or carbide balls were used. The combination of ball/roller and the workpiece can be selected on the basis of the difference between their hardness.

III. BURNISHING PARAMETERS

Generally, ball or roller burnishing tool is used by most of the researchers. Some researchers developed their own burnishing tool other than a conventional tool and tested them successfully. In burnishing process, many parameters are involved. The success of any process depends on the selection of process parameters and their optimum values. Most of the research work in burnishing evolved around the effect of process parameters on various surface properties of material, tool and workpiece combination, the coolant used and tool. In the initial phase, rigid burnishing tool was used by researchers. Then flexible burnishing tool is used by most of the researchers up to 2013. And in 2013 stiff burnishing tool was introduced and used to improve the surface integrity of the material.

Hassan and Al-Bsharat [37] designed a simple ball burnishing tool having carbon chromium steel ball. Burnishing was done on non-ferrous metals and effect of process parameters (speed, feed, force, the number of passes, ball diameter) on surface roughness, Surface hardness and microstructure of the material studied. Axiret. al [33] investigated the effect of internal ball burnishing process parameters namely speed, feed, depth of penetration and number of passes on the surface finish of Aluminium alloy 2014. Carbon Chromium ball with 8 mm diameter was used for burnishing. A. Sequeraet. al [20] studied the effect of ball burnishing on surface integrity of Inconel 718. Burnishing process parameters considered were speed, feed, burnishing pressure and ball size. Hassan et. al [38] found the effect of number of passes and burnishing force on brass components. Carbon chromium steel balls were used for burnishing. Hassan and Maqableh [10] investigated the effect of burnishing parameters on brass and cast Al-Cu alloy. They had used carbon chromium ball for burnishing. It was found that initial surface roughness and surface hardness have significant effects on response parameters. Lubricant and ball diameter also plays an important role. Axir [39] studied the effect of burnishing process parameters namely speed, feed, number of passes and force on surface roughness and surface microhardness on Steel-37. The initial surface roughness of 4.5 µm (Ra) reduced to 0.5 µm after burnishing. A specially designed roller burnishing tool was used. Roller bearing was used as a roller for burnishing tool. Khabeery and Axir [40] studied the effect of milling roller burnishing parameters on the surface integrity of 6061-T6 aluminum alloy. Burnishing parameters considered were speed, depth of penetration and number of passes under lubricated condition. It was found that a number of passes and depth of penetration plays a vital role in improving surface finish, surface microhardness and surface integrity of the material. A. Lycons and Nemat [41] carried out experimental analysis on the effect of burnishing parameters speed, feed, force and number of passes on surface topography of mild steel and aluminum. They developed special purpose tool for burnishing. They found that reduction in feed or speed increases surface hardness of both materials. Surface improvement up to 70% was found. Martin [42] investigated roller burnishing process to introduce required compressive residual stress on the surface of material. The analysis involved series of incrementally applied pressure loading and finite element method. Luca et. al [43] used hydrostatic burnishing tool for finishing of hardened steel. A ceramic ball having 6 mm diameter was used for burnishing. They found that initial surface roughness plays a vital role in improving the surface finish of the material, and as feed increases surface roughness also increases. Axir and Khabeery [44] explored the influence of orthogonal burnishing parameters (speed, depth of penetration, initial hardness and burnishing time) on brass, aluminum alloy and carbon steel using specially designed roller burnishing tool. The author concluded that depth of penetration increases the surface hardness of the material and decrease out of roundness. Yen [45] developed 2-D FEM cutting model for uncoated tools and tool wear modeling. The author used ball burnishing considering speed, feed, burnishing pressure and ball diameter as process parameters for surface enhancement of the material. Shirsat and Ahuja [46] carried out parametric analysis of combined turning and ball burnishing on the T-40 lathe. A special tool was developed for combined turning and ball burnishing operation on the lathe. Effect of speed, feed, force and lubricant on surface roughness and surface hardness of aluminum alloy was studied. They found that, due to combined operation, the time required was less and microhardness increases with increase in force up to certain limit. Axir and Ibrahim [47] designed and developed center rest burnishing tool and analyzed the effect of speed, feed, and force on surface roughness out-of- roundness and change in diameter of the workpiece. They found that burnishing force and feed plays important role in improving surface characteristics of the material. Luca et al. [48] studied the effect of burnishing parameters on the surface roughness of hardened steel using a hydrostatic tool having silicon nitride ceramic ball. Burnishing parameters considered were hydraulic pressure, speed, and feed. It was found that influence of hydraulic pressure plays important role in improving surface finish. H. Luo et al. [49] analyzed the effect of burnishing parameters on burnishing force and microhardness with the theoretical analysis. The burnishing boundary condition was analyzed theoretically and cylindrical PCD tools were designed accordingly. It was found that as burnishing feed and depth increases, burnishing force increases. Surface hardness increases with increase in depth of penetration. Hamadache et al. [24] evaluated ball and roller burnishing effect on surface roughness, surface hardness and wear resistance of Rb-40 steel. Applied force and number of passes were the decisive parameters in both ball and roller burnishing. Roller burnishing was proved to be more effective for surface roughness when initial surface roughness was about 3 µm and ball burnishing for surface hardness. El-Tayeb et al. [50] studied the effect of roller burnishing contact width and burnishing orientation on tribological behavior and surface quality of Aluminum 6061. It was found that burnishing speed and force were capable of increasing surface finish of workpiece, but there was very less effect of contact width of the roller in improving surface finish. Roller burnishing improved surface hardness by 20 to 30%. Small roller produced less coefficient of friction during tribotest. Korzynski [51] developed and validated the force and the surface roughness relationship for burnishing using the spherical tool. It was observed that burnishing force not only depends upon workpiece material (42CrMo4) and geometry of contact area between workpiece and tool, but it mainly depends on initial surface roughness of the workpiece. Moshkovich et al. [52] developed new methods of depositing solid lubricating films based MoS_2 and WS_2 by using different types of burnishing on steel surfaces. Thamizhmanii et al. [53] used multi-roller burnishing tool for burnishing non-ferrous metals like aluminum, copper, and brass. The surface roughness and surface microhardness were improved at high speed, feed rate and depth of penetration. Lopez [54] presented his work on the effect of burnishing parameters on heat treated steel and Incol-718 milled surfaces. It was found that radial width of cut during burnishing developed high-grade surface finish and residual compressive stresses. Cold working was higher in Incol-718 than steel. Tadic et al. [18] used high stiffness burnishing tool for increasing geometrical and dimensional accuracies of openings. It was observed that along with surface roughness, cylindricity, and roundness of openings improved with an increase in depth of penetration. Tadic et al. [55] investigated the influence of tool stiffness on the surface roughness of aluminum alloy. It was found that burnishing force, the number of passes and initial surface roughness of work piece gives correlation with the increase in the surface finish of the material. Vekelic et al. [56] developed the relationship between surface roughness and optimal depth of penetration using specially designed high stiffness tool. It was proposed that to get the better surface finish, depth of penetration should be the maximum peak height of the initial surface roughness. Fattough and Khabeery [57] studied the effect of burnishing on residual stress distribution of 7075 aluminum alloy. It was found that residual stress improves with increase in burnishing force and speed. Residual stress was maximum at the surface and decreases as depth increases.

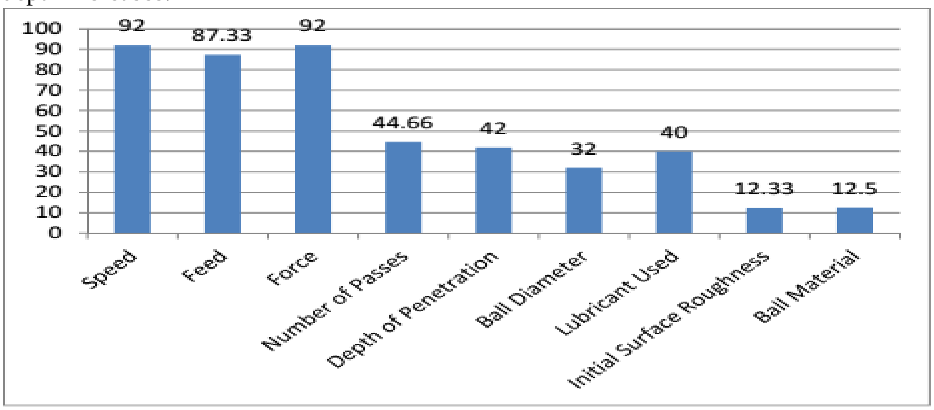

Figure 2Percentage of Parameters Used By Various Researchers

Table 2 Summary of Burnishing

Author	Burnishing Tool	Workpiece Material	Input parameters	Response parameters	Methodology	Remark
Hassan [38]	Simple burnishing tool with carbon chromium ball	Aluminum alloy, Brass	Number of passes and burnishing force	Surface Finish	RSM	Optimum surface finish obtained at a force of 203 N.
Shirsat [46]	Combined turning and ball burnishing tool	Aluminium Alloy	Speed, Feed, and force	Surface Roughness and hardness	Factorial Design	Surface Improvement was 600-700%. Microhardness

						increases with increase in burnishing force up to certain limit.
Hassan [10]	Simple burnishing tool with carbon chromium ball	Brass, Al-Cu alloy	Speed, feed, load and number of passes	Surface Roughness and hardness	RSM	Initial workpiece properties play important role in improving surface roughness and hardness.
Hassan [37]	Simple burnishing tool with carbon chromium ball	Non-ferrous metals	Speed, feed, force, number of passes and ball diameter	Surface Roughness hardness and microstructure	RSM	Grain size was elongated.
Banh [58]	Burnishing Tool with double spring mechanism	STAVAX	Lubricant, force, step-over, number of passes and speed	Surface Roughness and superficial surface hardness	Grey-based Taguchi method	Surface roughness was improved by 91% and superficial surface hardness improved by 8%.
Rajesham and Tak [59]	Conventional burnishing tool	Aluminium Alloy	Force, feed, and speed	Surface Roughness microhardness	Experimentati on	Burnishing tool was developed
Al-Qawabah [60]	Roller burnishing tool	Zamac5 Cu-Alloy	Feed and force	Surface roughness, hardness, and microstructure	Not mentioned	Enhancement of 18% in hardness was observed.
Shreehah [61]	Ball Burnishing	CuZn39Pb2	Speed, feed, force and number of passes	Surface roughness and microhardness	Orthogonal central composite experiment design	High surface microhardness and surface finish can be obtained at spindle speed 75 m/min and a number of passes 4, at low feed and low burnishing force.
Esme [31]	Ball burnishing	AA-7075	Speed, feed, force and number of passes	Surface roughness and microhardness	Grey relational analysis and Taguchi	Grey relation analysis in combination with Taguchi technique can be used for continuous improvement in product quality.
El-Axir [62]	Newly designed Ball Burnishing tool	Al-alloy 2014	Speed, feed, depth and number of passes	Out of roundness and micro-hardness	RSM with Box and Hunter method	Depth of penetration in the range of (0.025 to 0.045 mm) and number of passes 3 gives better surface microhardness
Ibrahim [63]	Ball burnishing	Carbon Steel	Speed, feed and force	Surface finish and out of roundness	DOE and Fuzzy logic	Surface roughness is reduced to 0.2 µm from 2.5
Sagbas [64]	Ball Burnishing	Aluminum alloy 7178	Speed, feed, number of passes and force	Surface Roughness	RSM with Desirability function approach	Burnishing force and number of passes plays key role in improving surface finish
Grzesik [65]	Ball Burnishing	AISI 5140	Force, feed, ball diameter and lubricant	Surface Roughness	DOE and Optical images	Surface finish improves by 40%
Dabeer [66]	Ball burnishing	Aluminium	Speed, feed, force and ball diameter	Surface roughness	RSM	Optimum surface finish obtained at 425rpm speed, ball diameter 7 mm, 70 N force and tool passes 2.
Bougharriou [67]	Ball burnishing	AISI 1042	Feed, depth of penetration	Surface roughness, residual stresses	FEM	Finite element model shows improvement in surface finish and compressive

						residual stresses
Vukelic [56]	Stiff burnishing tool (Steel Ball)	Tempered steel, 36CrNiMo4	Speed, feed and depth of penetration	Surface roughness	Statistical Analysis	Depth of penetration equal to maximum peak height of initial surface roughness gives better surface finish
Tadic [55]	Stiff burnishing tool	Aluminum alloy EN AW-6082	Feed, number of passes and force	Surface Roughness	Statistical Analysis	Stiff burnishing system significantly affects surface roughness
Revankar [9]	Ball burnishing tool	Titanium Alloy	Speed, feed, force and number of passes	Surface roughness and hardness	Taguchi Robust design	Burnishing feed and speed are the significant parameters for minimizing the surface roughness, whereas burnishing force and number of passes play important roles in maximizing the hardness.
Balland [68]	Roller burnishing	11SMn30	-------	Surface roughness	Finite Element Analysis	Efficiently used full 3D simulation for the burnishing process. 3D finite element model of the industrial burnishing process is proposed.
Zhang [69]	Ball burnishing	17-4 PH stainless steel	Pressure, speed, and feed	Residual stresses and roughness	RSM	Burnishing transforms tensile residual stresses into compressive residual stresses in which pressure plays an important factor.

For flexible burnishing tool, most of the researchers used speed, feed, force and number of passes as burnishing process parameters. Apparently, the burnishing process is a simple process, which can be carried out by an unskilled worker. But in burnishing process, many parameters are involved and there is an interaction (linear as well as non-linear) between process parameters. So, it is very difficult to find optimum values of process parameters. One of the important burnishing process parameters is a force. Force required for plastic deformation of material depends on ball/roller material, workpiece material and the most importantly contact area between ball/roller and the workpiece. So, as material changes, the optimum values of the process parameter of material also get changed. In stiff burnishing tool instead of force, depth of penetration is used by the researchers.

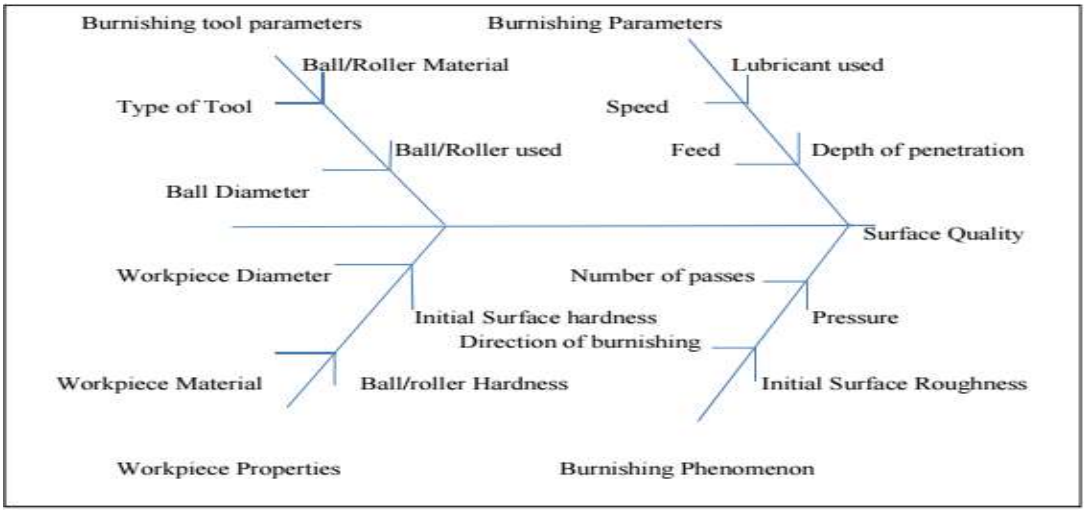

Figure 3 Fishbone Diagram for Burnishing Process

IV. THEORETICAL MODELING ANDSIMULATION

In the present era of manufacturing, industry always want to cut down time and cost of the production process. For this purpose, industry prefers to make a model of the process, so that end results can be analyzed before actual implementation of the process. Similarly, many researchers developed the mathematical models which can be tested for applicability of the process based on ball/roller material, workpiece material, and initial surface roughness.

Altan et al. [70] developed FEM model to study the effect of burnishing process parameters on surface finish and residual stresses. Among feed rate and burnishing pressure, burnishing pressure plays a vital role in improving surface finish and amount of residual compressive stresses. Analytical study and finite element modeling were done by Bougharriou [71] on an AISI 1042 workpiece. The simulation was done to study the effect of burnishing parameters (penetration depth, ball diameter, and initial surface quality) on surface roughness and residual compressive stresses. Lei et al. [72] proposed an analytical model to predict surface finish after burnishing and verified it successfully by experimentation. It rivals that burnishing force was directly proportional to reduce surface roughness. Bougharriou et al. [73] developed an analytical model which can predict surface profile by burnishing after turning. It was found that analytical results were in-line with experimental results. Sayahi [74] et al. done the two-dimensional and three-dimensional finite element analysis of burnishing process. Three-dimensional models predict residual stresses. Results were successfully validated with experimental results for surface roughness and compressive stresses. Tao Zhang et al. [69] formulated a second-order empirical model to predict surface roughness and compressive stresses considering burnishing parameters namely pressure, speed, and feed for 17-4 PH stainless steel, an aerospace alloy. Tadic et al. [18] used high stiffness ball burnishing tool for increasing geometrical and accuracies of openings. Cylindricity and roundness errors were reduced as the depth of penetration increases. FEM analysis was done for stress field distribution in the workpiece. Gharib et al.[28] investigated improvement in ductility of 1050A rolled sheets of aluminum due to newly developed ball burnishing tool. A quadratic mathematical model was developed considering speed, feed, and force as burnishing parameters to predict surface roughness. It was observed that burnishing improves the ductility of material but hardness remains same. Hornbatch et al. [75] studied the effect of low plasticity burnishing (LPB) on Ti-6AL-4V femoral hip stems. Results of finite element model were validated by experimental values. It was observed that fatigue strength of the workpiece was increased by 40%. Rodriguez et al. [35] used deep ball burnishing to improve the surface quality of material. Finite element model of ball burnishing was used to predict residual compressive stresses produced on the surface of the material. It was found that pressure plays a vital role in improving surface quality. Grochala et al. [22] investigated the effect of burnishing after milling and stresses at the surface. FEM model of the milled and burnished surface was developed. It was observed that after burnishing surface roughness was reduced and stresses were developed on the surface.

V. SURFACE INTEGRITY

It is observed that most of the researchers focused on surface roughness, surface hardness, wear resistance, the fatigue strength of the material. But merely improving any of the above property of the material is not sufficient to improve life and performance of the component. To improve life and performance of the component, we need to increase the surface integrity of the material. Surface integrity considers not only geometric (topological) aspects of the surface but it also considers physical, chemical, mechanical, biological and metallurgical characteristics and properties. According to J.PauloDavim, no proper definition of surface integrity is available to date. Though surface integrity is a very important consideration in the manufacturing process, not a single source is able to give how to measure it practically [76]. Its purpose is to make sure required service properties of surfaces in component and manufacturing process, as a manufacturing process, directly affect these properties.

Zhang and Liu [25] studied the effect of sequential turning and burnishing on the surface integrity of Cr-Ni based stainless steel. It was concluded that surface roughness, topography, residual stresses and microhardness of the material get improved due to plastic deformation of the material. Burnishing parameters were optimized based on required surface integrity. Grzesik [16] presents the effect of ball burnishing on surface integrity of hardened 41Cr4 steel parts. It was investigated that ball burnishing not only improves surface roughness but also increases service properties of the component. Zak [77] done the research on the effect of ball burnishing on hard material for improving surface integrity. It was observed that substantial modification took place at surface and sub-surface of the material. Grzesik and Zak [65] presented novel sequential process of turning with and without cryogenic cooling of the component and ball burnishing operation. From results, it was observed that burnishing can be controlled additionally by cryogenic pre-cooling of the component. Neslusan and Krzysztof [23] investigated the effect of super finishing, cutting and burnishing on the surface roughness of bearing steel parts. It was observed that burnishing can improve bearing properties of surfaces on hardened components. Purushothaman and El-Tayeb [78] employed radial basis function to predict surface integrity of components after burnishing.

VI. OPTIMIZATION OF BURNISHING PARAMETERS

Optimization of parameters to achieve required value of response variable is very important. Many researchers optimized burnishing parameters for improving surface roughness, surface hardness, wear resistance and fatigue strength separately, but very few researchers tried to optimize burnishing parameters to improve surface integrity as a whole.

Sagbas [64] used desirability function for optimization of burnishing parameters to improve the surface roughness of 7178 aluminum alloy. A second order regression model using response surface methodology was developed to predict surface roughness. Babu et al. [79] optimized burnishing parameters using Taguchi technique. It was observed that burnishing depth increases the surface hardness of the material. El-Taweel et al. had done the analysis and optimization of burnishing process for improving surface roughness and hardness using Taguchi technique. The best surface roughness for brass material was obtained at 49 m/min speed, .15 mm/rev feed, 150N force, and a number of passes three. Revankar [9] employed Taguchi technique for optimization of burnishing parameters to improve surface roughness and hardness of titanium alloy. It was found that surface roughness improves with an increase in burnishing force and number of passes and same is the case for hardness but with an increase in speed, hardness decreases. Esme [31] used grey based Taguchi technique for optimization of burnishing process to improve surface finish and surface hardness of AA7075. John and Vinayagam [8] investigated the optimized burnishing parameters to improve surface roughness and hardness using response surface methodology for tool steel. Dweiri et al. [80] used fuzzy modeling for optimization of roller burnishing parameters to improve the surface finish of non-ferrous components. It was observed that as burnishing force increases surface roughness decreases. Jawalkar and Walia [81] used Taguchi method for optimization of roller burnishing process parameters to improve surface finish and surface hardness of the En-8 material. It was observed that burnishing speed, feed, and a number of passes contributes maximum in improving surface finish.

VII. DISCUSSION AND CONCLUSION

- It is observed that due to a lot of interaction between burnishing process parameters, researchers are getting different values of process parameters for the same response of the different material. Many researchers had tried to optimize burnishing process parameters for improving surface finish, surface microhardness, wear and fatigue strength of the material. Some researchers had tried to optimize the process parameters to improve surface integrity of the material.
- From the available literature, authors are unable to find guidelines regarding, how to measure surface integrity.
- Various kind of burnishing tools are developed by researchers and got required results. Burnishing can be used for internal as well as external surfaces of components. Burnishing can be done by the unskilled worker and is cost effective and environment-friendly process, as it is a chip-less process.
- In the initial phase, rigid burnishing tools were used, in which flat roller or ball pressed against the workpiece to get required finish. Flexible burnishing tools were used by some researchers, in which helical compression spring was used by most of the researchers. And nowaday’s high stiffness spring is getting used by few researchers, which gives better surface finish, out of roundness, close tolerance of the component.
- Most of the researchers used the term burnishing in their research, burnishing is used to get the better surface finish only.But when the surface requirement is surface finish as well as surface hardness, fatigue strength, wear resistance need to be improved and residual compressive stresses are to be induced, deep rolling is to be done.
- There is need of a set of burnishing parameters which can give required response, irrespective of material.
- The surface integrity can be defined as surface modification due to the manufacturing process, required for the particular application. So, parameters like surface microstructure, residual stress etc., which are difficult and costlyto measure and a little bit difficult to analyze can be avoided, if not required.
- The generalized finite element model can be get developed, which can give us a set of burnishing process parameters for the required response.
- The stiff ball/roller burnishing tool can open a new direction for burnishing process. In stiff ball burnishing based on the initial surface roughness of the material, depth of penetration of the tool can be decided, and it will be independent of material.

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