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Enhancing Surface Integrity and Quality through Roller Burnishing: A Comprehensive Review of Parameters Optimization, and Applications.

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Abstract:
Surface integrity is a critical aspect in ensuring the quality of components or products, particularly in industries such as automotive, aerospace, and machinery where superior surface finish and prolonged functionality of cylindrical parts are essential. Burnishing, a chip-less cold working finishing process, enhances the surface finish of machined workpieces through plastic deformation. This review paper delves into various aspects of the burnishing process and its impact on surface properties, drawing insights from multiple research projects. It explores topics including residual stresses, surface roughness, microhardness, cooling strategies, and modeling techniques. Key findings underscore the influence of burnishing parameters such as speed, feed rate, penetration depth, and number of passes on surface roughness and microhardness. Moreover, the process induces compressive residual strains on the workpiece surface, with their magnitude varying based on operational parameters. The choice of cooling methods, including kerosene, minimum quantity lubrication (MQL), cryogenic cooling, and hybrid cooling, significantly affects surface integrity. Various modeling approaches, such as Artificial Neural Networks (ANN), Adaptive Neuro-Fuzzy Inference Systems (ANFIS), and Response Surface Methodology (RSM), aid in predicting and optimizing surface characteristics. Despite the extensive discussion on surface roughness, microhardness, residual stresses, cooling methods, and modeling, out-of-roundness in the burnishing process remains understudied and warrants further investigation. This review contributes valuable insights for enhancing surface qualities in manufacturing applications and deepening our understanding of the burnishing process.

Keywords: Roller Burnishing, Surface Roughness, Microhardness, cooling techniques, Modelling Techniques.

1 Introduction :

The burnishing process is the post-machining process, no material is removed but it is compressed in a way that peak material is in the valley to get a better surface finish and surface hardness. for dimensional accuracy most important parameter in our day-to-day life in the industry. If the material is not removed improving surface and hardness is said to be a burnishing process. In current procedures, flaw quality, surface roughness, surface microhardness, erosion weariness, and lingering stresses have an impact on component execution and life. Crushing, lapping and super-completing. Burnishing is done by rubbing a thoroughly cleaned hardball against the metal surface while it is under tension. The pinnacles of the metallic surface will stretch out indefinitely because of this. During burnishing, a large amount of residual compressive pressure is applied to the workpiece's surface, causing the surface layer's weakness and wear blockage.

1.1 Ball Burnishing :

Ball burnishing is a mechanical finishing technique wherein a spherical or ball-shaped tool is used to apply pressure and enhance the surface finish of metal components. Component hardness, wear resistance, and fatigue life can all be increased by this procedure, which also removes flaws and induces compressive residual stresses. In ball burnishing, the workpiece's surface is repeatedly slid over by a ball-shaped tool under pressure. Smoothing out imperfections and producing a polished finish, the tool's movement causes plastic deformation of the surface material. By compacting the material's surface layer, ball burnishing lowers porosity and enhances surface integrity.

Equations-1 describing the contact mechanics between the ball-shaped tool and the workpiece surface allow for a mathematical analysis of the ball burnishing process. The elastic deformation of materials under contact stress is modeled by Hertzian contact theory, one such equation. Equation below can be used to compute the Hertzian contact stress (σ_{Hertz}) between a flat surface and a spherical indenter:

$$\sigma_{Hertz} = \frac{3F}{2\pi R^2} \ldots .1$$

where, σ_{Hertz} = “Hertzian contact stress”, F= “applied force”, R= “radius of the spherical indenter”

During ball burnishing, equation-1 gives an estimate of the contact stress between the workpiece surface and the ball-shaped tool. To get the right surface finish and characteristics, the ball burnishing process parameters—such as tool material, size, and applied pressure—are optimized when one understands the contact mechanics.

During the process, the deformation element undergoes significant stress. The balls utilized consist of alumina, carbide clay, carbide, fired silicon nitride, fired silicon carbide, and bearing steel. In contrast to roller burnishing, the ball serves as a tool to twist the surface layer, resulting in elevated specific pressure, increased fatigue strength, microhardness, and deeper work hardening layer, all achieved with the same standard power input. The area of deformation is localized around the ball's boring point on the workpiece, characterized by a combination of point and rolling friction between the ball and the workpiece refer to Fig.1. Burnishing equipment is now widely used in non-automotive applications for a variety of reasons. This procedure improves the durability of seal surfaces, increases wear life, and reduces friction and clamor levels.

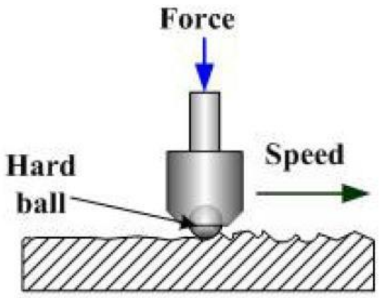


Figure 1 Ball Burnishing Tool

1.2 Roller Burnishing :

As implied by its name, roller burnishing employs a tool equipped with one or more rollers. These rollers are positioned along the periphery of a supporting shank in various configurations for different roller devices. Figure 2 illustrates a schematic representation of a burnishing operation utilizing a single roller burnishing tool. The shank is typically attached to a machine, such as a lathe, milling machine, or machining center. Once the tool makes contact with the workpiece, the rollers on the shank rotate, thereby burnishing the workpiece surface.

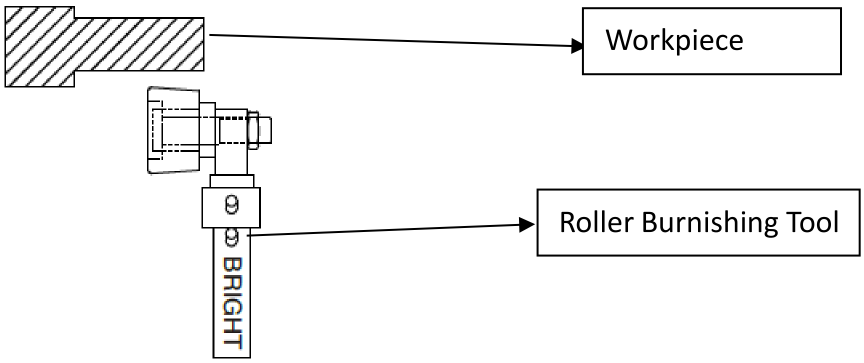


Figure 2. Roller Burnishing

The computation of the contact pressure the roller applies to the workpiece surface helps to clarify the roller burnishing procedure. Comparable to ball burnishing, Hertzian contact theory is frequently applied to determine the contact pressure (P) between the roller and the workpiece:

$$P = \frac{3F}{2\pi R^2} \ldots 2$$

where, *P*= “contact pressure”, *F*= “applied force”, *R*= “radius of the roller”.

This equation-2 provides an estimate of the pressure distribution at the contact interface, which governs the extent of plastic deformation and surface smoothing during roller burnishing. The change in surface roughness (ΔR_a) resulting from roller burnishing can be estimated using empirical relationships, such as the Preston equation:

$$\Delta R_a = \frac{K.P.R^2}{V} \ldots 3$$

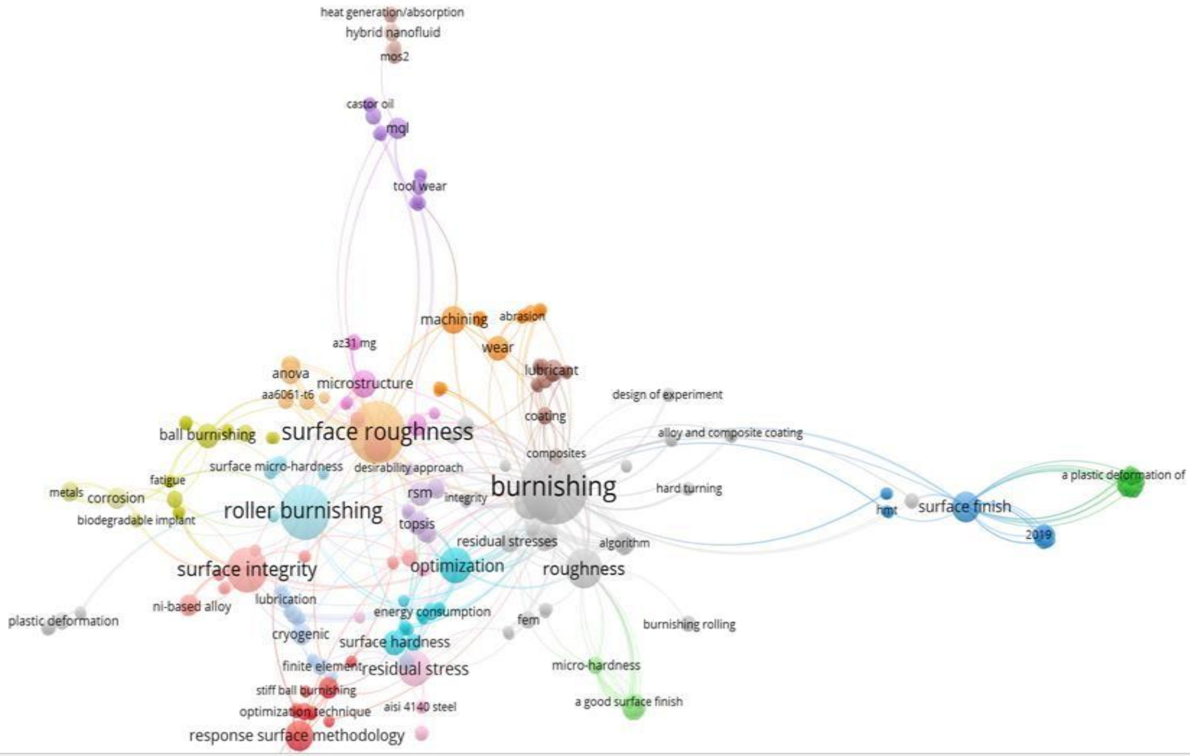
where, ΔR_a= “change in surface roughness”, *K*= “constant depending on material properties and process conditions”, *P*= “constant pressure”, *R*= “radius of the roller”, *V*= “velocity of the roller”.

These mathematical formulae-3 shed light on the mechanics of roller burnishing and can direct process parameter optimisation to produce the required surface finish and dimensional accuracy in metal components.

2 Literature Review

2.1 Parameters Affecting the Burnishing Process

The burnishing process is influenced by various parameters that collectively determine the quality and effectiveness of the surface finish. These parameters play a crucial role in achieving the desired outcomes of the process. Key parameters affecting the burnishing process include the applied load, burnishing tool geometry, feed rate, surface speed, and material properties. The applied load determines the level of plastic deformation and compression exerted on the workpiece's surface. Burnishing tool geometry, such as the roller shape and size, affects the contact area and pressure distribution during the process. The feed rate and surface speed impact the extent and uniformity of plastic deformation across the workpiece's surface. Material properties like hardness and ductility influence how the material responds to plastic deformation. Properly optimizing these parameters is essential to achieve the desired surface finish, hardness enhancement, and dimensional accuracy in various industrial applications.



2.1.1 Surface Roughness:

Surface roughness describes variations or anomalies in a material's surface texture. It is a measurement of the minute surface irregularities that might arise from forming, grinding, or machining operations. The surface may show these irregularities as peaks and valleys, which will change the way it looks, feels, and works. Surface roughness is measured by means of parameters like Rt (total height variation), Rz (average peak to valley height), and Ra (arithmetic mean roughness). Because surface roughness affects components' functionality, appearance, wear, and friction directly, it is important to understand and manage it in many industries, including automotive, aerospace, and medical. Optimizing manufacturing procedures and parameters to satisfy particular quality and performance criteria is often necessary to achieve the desired surface roughness. The arithmetic mean roughness (R_a) is one often used empirical relationship. Ra is the mean roughness profile deviation from the mean line over the evaluation length. One can state the Ra formula as:

$$R_a = \frac{1}{n}\sum_{i=1}^{n} |y_i - \hat{y}| \ldots .4$$

where, R_a= “arithmetic mean roughness”, n= “no. of data points in the evaluation length”, y_i= “height of the profile at each point”, $\hat{y}$= “mean height of the profile within evaluation length”. Equation-4 calculates the average absolute deviation of the profile from the mean line over the evaluation length. It's commonly used in characterizing surface roughness in engineering and manufacturing contexts.

H. Luo et al [1] investigated the nonferrous metal in the process of roller burnishing.

Results show that the process of the surface finish was improved. Z. Pu et al [4] researched the process with varied materials. Its analysis shows that varied materials having parameters such as burnishing speed, burnishing feed, depth of penetration, and several tools pass seriously affect the roughness of the surface. Numerous research support the use of roller burnishing tools to refine an aluminum alloy. M. Nemat et al.'s study [5] concentrated on how burnishing factors like speed and feed decrease might improve surface finish by reducing surface roughness. H. Basak and associates [6] Applications for aluminum alloy can be found in the automotive, medical device, and aviation design industries. The aluminum alloy's surface is mirror-like before it is machined, but some marks remain after because of the alloy's high ductility. In order to forecast surface hardness and roughness, K.A. Patel et al. [7] employed a carbide roller burnishing tool and examined the various optimizing techniques. Using a roller burnishing method on al6061-T6 material, Barahate, V. et al. [9] varied the burnishing parameters, while assessing the roughness of the surface, microhardness, and out-of-roundness. The outcome demonstrates that decreasing feed reduces surface roughness. The selection of factors that are particularly important for increasing microhardness, decreasing surface roughness, and improving the material AL 6061-T6 alloy was studied by M.M. El-Khabeery et al. [14]. The outcome demonstrates that if we use high speed and deep penetration, surface roughness will grow. Conversely, moderate burnishing speed and high penetration depth improve surface roughness. El-Axir, M et al. [15] investigated the roller burnishing tool to improve surface characteristics such as roughness, and microhardness, and their effect on the four-parameter to check the tolerance and fit. it suggests that the burnished characteristic of the surface affects the resistance to failure. Sequera, Kurkute, V et al. [18] investigated the surface roughness by using the RSM (Response Surface Methodology) method with material AL63400, for optimizing the used CCD (central composite design) matrix and to analyze by ANOVA. The parameters are speed, feed, and force, and the result is obtained for the surface roughness of the feed. Solanki, R. G., et al. [19] experimented on Al 6061 for surface roughness on a solid cylindrical workpiece and designed the matrix by Taguchi by using the L25 array and performance on a lathe machineIn this study, feed, speed, interference, and number of passes are the parameters. It was observed that the minimum surface roughness is obtained at minimum speed. minimum feed and maximum no. of passes and is verified by a confirmatory test. Prasad, K. R. [20] conducted a study on the optimization of the external roller burnishing process applied to magnesium silicon carbide metal matrix composite (Mg-SiC MMC) using response surface methodology (RSM). The aim was to enhance the surface finish and hardness of the composite. The researchers employed RSM to design experiments and analyze the effects of burnishing parameters like burnishing speed, feed rate, and force on the surface finish and hardness. Through experimentation and statistical analysis, optimal parameters were identified to achieve the desired surface finish and hardness of the Mg-SiC MMC. This study contributes to the understanding of the external roller burnishing process for improving the properties of metal matrix composites. Babu, P. R. et al. [22] studied the different burnishing parameters and their effects on surface integrity. The different materials used and co are with the optimizing technique on surface roughness result shows that the burnishing speed is 535rpm, feed is 0.063mm/rev and force is 200N for EN8 material and EN2, EN31 alloy speed 355 rpm, feed 0.095mm/rev and force 200N for the best result of surface roughness and is verified by the values obtained by Taguchi optimization method. Maheshwari, A.S et al. [23] investigated methods to eliminate surface irregularities, such as peaks and valleys, resulting from the burnishing process on AA6351 material. A conventionally flexible tool was devised to minimize such irregularities and enhance surface characteristics owing to its high stiffness. The experimental design utilized a central composite design within the framework of response surface methodology for thorough analysis. Findings indicated that the depth of cut significantly influenced surface roughness, while speed and number of passes were crucial for microhardness. Surface integrity, encompassing both surface and metallurgical textures, is vital for workpiece functionality. Burnishing, as a post-machining procedure, involves the movement of a roller across the workpiece surface, inducing contact stresses and plastic deformation in the surface layer. Consequently, improved surface roughness is achieved, accompanied by alterations in both surface and metallurgical textures. Through meticulous parameter optimization, burnishing can effectively enhance surface characteristics, contributing to the enhanced performance and durability of workpieces across various applications. Tadic et al. [25] investigated how to get superior surface finishes in manufacturing processes by using a high-stiffness burnishing tool that was specifically built for that purpose. The goal of the research was to improve surface finish quality by using creative tool design and application. The authors examined the efficacy of the high-stiffness burnishing tool in producing improved surface finishes through experimentation and analysis. Their research provides insightful information that may be used to improve the quality of surface finish in manufacturing applications, which will ultimately improve the overall performance and quality of the product. Adel Mahmood San et al.'s [26] examines the effects of roller burnishing nonferrous materials, such as brass and AL, with dimensions of 300 mm by 28 mm. The parameters include speed, which is 230 RPM, feed rate of 0.1 mm/rev, and the number of passes, which ranges from 1 to 5, with dry machining. The outcome demonstrates that both burnishing processes help to improve roughness. M.H. El-Axir et al. [28] experimental work on the effect of four roller burnishing tools on 2014 aluminum alloy, 50 to 90 HB having diameters 9mm and length 87 mm and parameters burnishing speed1.04 TO 2.341 m/s, depth of penetration0.4 to 1.2 mm, the out-of-roundness and the change in workpiece diameter and the burnishing condition is lubricated. the result shows an Examination of the effects of burnishing apparatus on surface roughness in burnishing process parameters plays a key role for out of roundness and change in diameter. Yinggang Tian et al.[29] experiments on the roller burnishing tool with laser-assisted burnishing of an AISI4140 material with a diameter of the workpiece is 23 mm, it is shown by this observation that LAB can give surface finish, F. Dweiri et al.[30] show the optimization technique to investigate the surface finish by studying the parameters burnishing force and no. of passes remaining should be constant Two materials are investigated and predicted by the fuzzy model, the result shows 25kgf force for aluminum and 30kgf with brass give the better improvement in the surface finish with four tool passes for both material. Malleswara Rao et al. [32] evaluate the material of aluminum with a roller burnishing tool having length220 and diameter42mm to find the optimum values of surface finish, skill operators are not required. Adnan Akkurt et al. [33] compare the roller burnishing tool with another finishing process of the internal hole of material AISI 304 Austenitic The results indicate that the roller burnishing technique produces the greatest results in other finishing processes. Stainless steel is widely used in the automotive and aeronautics industries. The impact of roller burnishing on the mechanical properties and surface quality of o1 alloy steel was examined by Khalid S. Rababa et al. [34]. Following the experiment, the material's actual stress increased by roughly 150 MPa, and the surface quality increased by 12.5%. H. Tang et al. [5] show the optimization technique of ANN to find the surface quality using roller burnishing with parallel and cross burnishing orientation on aluminum 6061 and response of training perform e and prediction performance was 0.809 and 0.710, respectively. By using a roller burnishing process with parameters for burnishing speed, depth of penetration, and number of passes, A. A. Ibrahim et al. [36] analyzed the surface integrity of composite materials. Double passes of burnishing, a depth of penetration of 0.12 mm, and a burnishing speed of 72 mm/min improved surface roughness. Kundan Kumar et al. [38] showed the improvements in the surface integrity of AL2014 having dia.50mm and length of 100 mm. increased fatigue behavior under dynamic loadings. Anish P. Borkar et al. [39] enhance the INCONEL 718 surface integrity using a single roller burnishing tool the parameters are speed, feed and no.of passes have been found the surface roughness is reduced by 3.66 microns o 0.31micron and compared with the machining and post-machining process for the suggested material of 34CrMo4 steel. About the process, coolant is not used, only a dry burnishing process is applied. For improved surface roughness of aluminum alloy 6061 with parameters of 40 mm diameter, maximum 850 RPM speed, feed 0.024 to 0.104 mm, depth of penetration of 2 mm to 8 mm, and dry roller burnishing technique, Kiran A. Patel et al. [40] employed the Taguchi optimization approach. The outcome demonstrates that in order to The most important aspects are burnishing depth, spindle speed, and reducing surface roughness. The experimental impact of roller burnishing parameters on TA2 alloy was investigated by X. L. Yuan et al. [41]. Surface roughness can be predicted using response surface methods and Box-Behnken experimental design approaches. The results indicate a decrease in surface roughness. Okada Masato et al. Using minimum quantity lubrication of aluminum-based alloy, ASTM 2017 (2017), and carbon steel, ASTM 1055 (1055) material with speed 100 m/min and 200 m/min, force 45,119, 240, 298 N, and feed 0.25,0.50,1 mm/rev, [43] create and investigate the burnishing characteristic of roller burnishing.The outcome demonstrates that carbon steel or alloys based on aluminum can have their surface integrity improved by using inclined roller burnishing. Kiran A. Patela et al. [44] compare the two methods on AA6061 material having a diameter of 40mm using a roller burnishing tool for predicting the surface roughness. Methods are RSM and ANN, parameters are speed 50, 250, 450 ,650, 850 rpm, feed 0.024, 0.044, 0.064, 0.084 ,0.104 mm/rev and no. of passes are 1,2, 3, 4, 5. The outcome demonstrates that the ANN model outperforms the RSM approach in terms of prediction. According to the aforementioned study, a large number of researchers have examined surface roughness in relation to several parameters. According to the understanding presented above, speed is a key factor in reducing surface roughness. Roughness increases as speed does, and vice versa. The factor influencing surface roughness is speed.

2.1.2 Microhardness:

A material's resistance to small-scale, usually microscopic, indentation or penetration is measured by its microhardness. It offers information about the toughness, resilience, and wear resistance of the material. Via the Vickers hardness test, microhardness is one frequently measured parameter. In order to determine the hardness value, a pyramidal diamond-shaped indenter is pushed into the surface of the material under a predetermined load and the indentation's size is measured. The following equation-5 calculates Vickers hardness (HV):

$$HV = \frac{1.854 \times F}{d^2} \ldots 5$$

where, F= “applied force in Newtons (N)”, d= “average diagonal length of the indentation in millimetres”

Researchers H. Luo et al. [1] looked into the nonferrous metal used in roller burnishing. The outcome is a solid surface with enhanced corrosion resistance. The effect of roller burnishing 316L stainless steel on its hardness of a surface was examined by Tugay, I. O. et al. [11]. The surface hardness is improved by 45% of a detected 0.8mm after the burnished surface, according to the results. El-Axir, M. et al.'s study [15] examined the roller burnishing tool's ability to enhance surface properties such microhardness and roughness, as well as how these qualities affected four different metrics to assess fit and tolerance. It implies that the resistance to failure is influenced by the surface's burnished quality. Conduct a lathe machine experiment to determine how burnishing tool parameters, such as burnishing feed, burnishing speed, burnishing time, depth of penetration, and the prior burnishing hardness of five different materials, affect out-of-roundness and hardness. The result shows that depth of penetration and no. of passes affect roundness also if we increase the speed of the burnishing tool the microhardness, and roundness are increased the hardness of the workpiece is reduced. Increasing the burnishing speed decreases the hardness and change in workpiece diameter, increase in burnishing speed of more than 1.5m/s increases the out-of-roundness. Depth of penetration is increased, the microhardness and change in workpiece diameter increases but out of roundness is decreases. for the best result, the researcher suggests a low depth of penetration with a high burnishing time. For out-of-roundness best result apply the high depth of penetration with low burnishing time. Sequera, Kurkute, V. et al. [18] investigated the microhardness by using the RSM (Response Surface Methodology) method with mate rial AL63400, for optimising used CCD (central composite design) matrix and to analyse by ANOVA. The parameters are speed, feed, and force, and the result is obtained that the microhardness was force are the most important parameters. Prasad, K. R. et al. [20] the hardness is increased by parameters are 57.9996 HV. Anish P. Borkar et al. [39] enhance the surface integrity of INCONEL 718 using a single roller burnishing tool, the hardness is also improved from 539Hv to 588 Hv. Kundan Kumar et al. [40]study the parameters for finding the microhardness and compare them with machining and post-machining processes for the suggested material of 34CrMo4 steel. About the process, coolant is not used, only a dry burnishing process is applied. Kiran A. Patel et al. [40] Microhardness of aluminum alloy 6061. The outcome demonstrates that the two most crucial factors for increasing the microhardness by 28% over pre-machined surfaces are spindle speed and burnishing depth. . The burnishing characteristic of roller burnishing was created and analyzed by Masato Okada et al. employing carbon steel (ASTM 1055-1055) and minimum quantity lubrication of aluminum-based alloy (ASTM 2017 (2017)). The workpiece hardness is enhanced by 126 to 323HV, according to the results. According to the research, a number of researchers examine surface roughness using several metrics. According to the understanding presented above, the three most crucial parameters that increase hardness are speed, depth of penetration, and number of passes. Increasing the number of passes causes the tool to rotate more, which increases compressive force on the workpiece's material and increases hardness.

2.1.3 Residual stresses:

Internal strains known as residual stresses persist in a material long after the stress's original source—such as thermal expansion or external loading—has been eliminated. The fatigue life and cracking proneness of the material can be greatly impacted by these stresses, as can its mechanical characteristics and performance. Reliability stresses can be mathematically described by means of equations obtained from solid mechanics concepts. Stress and strain are related by the use of constitutive and equilibrium equations, for example. But precise residual stress computation frequently calls for intricate numerical simulations or experimental methods like neutron or X-ray diffraction.

Based on the temperature distribution and the coefficient of thermal expansion of the material, one simplified equation estimates residual stresses resulting from thermal processes, such welding. The residual stress magnitude is related by equation-6 to parameters including the material properties and the temperature gradient.

$$\sigma_{residual} = E.\alpha.\Delta T \ldots .6$$

where, $\sigma_{residual}$= “magnitude of the residual stress”, E= “elastic modulus of the material”, α= “coefficient of thermal expansion”, ΔT= “temperature gradient”.

El-Khabeery et al. [14] investigated how a roller burnishing procedure affected the residual stress, microhardness, and surface roughness of the AL 6061-T6 alloy material. The residual tension on the surface of the workpiece material was calculated by the use of a deflection etching technique. Babu, P. R. et al. [21] investigated the AL6061-T6 material utilizing a range of parameters, including as feed, depth of cut, and number of tool passes. The workpiece is 30 mm in diameter after pre-machining so that XRD may be used to measure residual stress, microhardness, microstructure, and surface roughness. As the number of passes increases, material deterioration remains unaffected. The results show that, in optimal circumstances, the maximum depth of cut and number of passes result in a decrease in surface roughness and an increase in microhardness. M.M. El-Khabeery et al. [27] The parameters of speed (63 mm/min to 160 mm/min), depth of penetration (0.05 mm to 0.25 mm), and number of passes (1 to 5) with the additional lubricant used during machining demonstrate that compressive residual stress decreases as speed increases while increasing depth of penetration and number of passes. Tian Yinggang et al. [29] Compressive residual stresses were raised by laser-assisted burnishing on the AISI4140 Workpiece surface. Ibrahim, A. A. et al. [36] The value of residual compressive stress and the burnishing speed of Al2O3/A356 Composites material both rise with an increase in burnishing passes, and the microhardness of the material subsequently drops marginally.

According to research by Rodríguez, A. et al. [45], compression changes after burnishing because residual stress and axial stress are different. After burnishing, it appears that the distributions of residual stresses, both axial and circumferential, are different. Particularly, the compression peak is distinct. Since the creation of the numerical model. According to Thamizhmanii et al. [54], roller polishing is a very useful method that may be used to impart fatigue life and compressive stress in addition to improving surface hardness and roughness. They achieved this by developing various sliding speeds/spindle speeds, feed rates, and penetration depths on square titanium alloy material while utilizing a multi-roller burnishing tool. For a material of this caliber, burnishing is a challenging procedure, and the titanium alloy is challenging to machine. By raising the burnishing settings, the piece's surface also acquired defects and microcracks. Shiou, M. Salahshoor, et al. [53] investigated a material Mgca3O the burnished surface is more valuable when giving more force, improves the compressive residual stress and no spalling has occurred. Ibrahim, A. A. et al.'s investigation into the properties of Al2O3/A356 [51] reveals that improving the number of rollers burnishing passes improves compressive residual stresses. To generate residual stresses tool radius and burnishing forces, Maximov et al. [50] examined the impact of the roller burnishing process parameters on surface roughness, hardness, and residual stresses of D16T Al alloy for aviation application. Anis Rami et al. [47] Innovated the modeling of the hybrid turning and burnishing tool apply on an AISI4140 steel. The result shows that the residual stress compared with the numerical simulation with XRD, for feed and burnishing direction may give optimum residual stress. Roller burnishing is a technique that G Rotella et al. [12] described for controlling the surface characteristics of stainless steel that is additively produced. The chosen process parameters have been meticulously examined to enhance the material's surface integrity. The hardness, microstructure, residual stresses, and roughness of the surface were assessed. The microstructure of the AM sample is unaffected by the cold procedure in terms of recrystallization or grain rearrangement, according to the results. Conversely, the procedure yields a deep compressive residual stress state and a favorable impacted layer, leading to a notable enhancement in the overall performance of the product. The high cycle fatigue life of the burnished components has been proven, in fact, proving the efficacy of burnishing in raising overall product reliability.

2.1.4 Cooling techniques:

Cooling techniques refer to ways to remove heat from a material or system in order to keep or control its temperature. Applications for these methods are many and include industrial processes, electronics cooling, and thermal management in engineering systems. Thermodynamics and heat transfer concepts can be used to mathematically characterise cooling processes. Newton's law of cooling is one often used equation to model cooling. It connects the rate of heat transfer to the temperature difference between the object and its surroundings:

$$Q = h.A.\Delta T \ldots 7$$

where, Q= “rate of heat transfer”, h= “transfer coefficient”, A= “surface area through which heat is transferred”, ΔT= “temperature difference between the object and its surrounding”.

The process by which heat is transferred by convection between a solid surface and a fluid (such air or water) is simplified by this equation. Heat sinks are devices made to effectively dissipate heat away from a surface; forced convection is the use of fans or pumps to improve heat transfer; and phase change cooling is the use of changes in phase, such as evaporation or condensation, to absorb or release heat.

Arvind Ghodake et al. [17] investigated the roughness and hardness of a material of AA6351 by using Kerosene as a coolant, output shows that roughness is improved by 60% microhardness is improved Process factors' effects on residual stresses, microhardness, and surface roughness during the slide burnishing of high-strength aluminium alloys from 144.9 HV to 150.1 HV. Coolant is used for reducing the heat during process with the help of ANOVA and regression analysis. M.M. El-Khabeery et al. [[27] investigate the surface integrity of the material 6061-T6 aluminium alloy, hardness 170 to 173 HV. Masato Okada et al. [43] developed and analyzed the burnishing characteristic of roller burnishing using minimum quantity lubrication of aluminum-based alloy, ASTM 2017 (2017), and carbon steel, ASTM 1055 (1055) material Result shows that workpiece hardness is improved by 126 to 323HV. Rotella, G. et al. [48] studied the performance of the burnishing process with the help of different lubricants to find the surface integrity. The output shows that the lubricant affects parameters like hardness will increase by the coolant as a cryogenic is used, Minimum Quantity lubrication reduces the surface roughness. for reducing wear resistance cryogenic coolant and coated tools play an important role in the hardness.[49] experimented on tungsten carbide (69 HRC) & [50] EN-9 Grade Alloy Steel (10HRC), [51] AA6082-T6and AA603 parameters are burnishing force, feed, width, and several passes to find the surface roughness and hardness by using a soluble oil, Kerosene as a lubricant. Caudill, J et al. [52] evaluated the surface integrity of parameters like speed, feed, number of passes, and coolants. there are four types of coolants used for the analysis of the effect of parameters on the burnishing process of material Ti-6Al-4V alloy, the coolants are flood cooling, minimum quantity lubricants, cryogenic cooling, and hybrid cooling or lubricants analysis, and which coolant is given importance. the results show that cryogenic increases the strength of the material and the hybrid coolant reduces the surface roughness. for microhardness concern all the lubricants are increased. minimum quantity and flood cooling is used in burnishing the marks will see. Using liquid nitrogen as a coolant, B. Huang et al. [54] conducted experiments to examine the effects of roller burnishing of Al 7050-T7451 alloy. The surface alterations of Al(B4C) p Metal Matrix Composites (MMC) workpiece material after burnishing with a TiAlN-coated WC roller were covered by E Shankar et al. [31]. The burnishing speed, type of lubrication, number of burnishing passes, and coating were the input factors. The findings indicate that, in the case of Al-5 weight percent (B4C) p, the coating on the WC roller improved the workpiece's hardness following burnishing under all circumstances. When Al-10 weight percent (B4C) p was used, the coating had no effect on the workpiece's surface hardness. Burnishing Al-5 weight percent (B4C) p in dry conditions required the use of uncoated rollers to achieve the lowest possible surface roughness and highest possible surface hardness during the third pass. Using coated rollers lubricated with kerosene decreased the number of passes needed to obtain the necessary surface characteristics.

2.1.5 Modeling Technique:

Modeling techniques are methods of representing real-world events, systems, or processes using mathematical and computational techniques. Among the several disciplines in which these methods are indispensable are engineering, physics, economics, and biology. As they represent connections between various variables and parameters inside the system under study, mathematical formulas are essential to modeling. For example, differential equations arising from basic principles like Maxwell's equations of electromagnetism or Newton's laws of motion are frequently used in physics models. Equations describing supply and demand dynamics or economic growth may be included in economic models.

The Finite Element Method (FEM), a popular modeling method in engineering, is one way to simulate the behavior of materials and structures under various loading conditions. To get the system's overall response, FEM breaks the system into smaller components and equation-8 describing the behavior of each element repeatedly.

$$K.U = F \ldots 8$$

where, K= "stiffness matrix representing the stiffness of the elements", U= "vector of nodal displacements", F= "vector of nodal forces".

Stalin John et al.'s research [2] on EN-9 grade alloy steel yielded the ideal surface properties after developing a mathematical model for the response surface methodology. The outcome demonstrates a 90% reduction in surface roughness and a 41% improvement in microhardness. Nguyen, T. T. et al. [3] innovated the goals in terms of Internal Roller Burnishing parameters by utilizing an adaptive neuro-based fuzzy inference system (ANFIS). the result of the optimization process. The outcome demonstrates the significance of the anticipated ANFIS model for suggested applications responses. The most effective method for burnishing performance is model comparison. Nguyen, T. T. et al. [4] concentrated on the present optimization procedure to enhance the AZ31B Mg alloy's surface hardness and roughness. The machining conditions were finalized using the archive-based microgenetic algorithm (AMGA) in order to produce the best possible output. The result demonstrates that by increasing surface hardness and decreasing surface roughness, an approximate solution can be provided. The AMGA and RSM models are crucial for process modeling and optimization. The Group Method of Data Handling Mathematical Models Used Parameters was examined by El-Khabeery et al. [14]. The outcome demonstrates that the minimum burnishing speed and high penetration depth improve surface roughness; if we apply the high speed and increased penetration depth, we increase surface roughness. For better surface finish, three to four passes were found to be necessary; for residual stress, the depth of penetration and number of passes increased residual stress; and for residual stress to be reduced, we increased burnishing speed. For obtaining a good surface quality, speed should not be exceeded 1 20m/min. Rotella et al. [16] used a physics-based model of Ti6Al4V to begin simulating the flow stress behaviour. Software for finite element analysis examines the metallurgical and physical deformation of material strength. Kanovic and others [17]. Regression analysis (RA), support vector regression (SVR), and artificial neural networks (ANN) are investigated and employed in based studies. In terms of application in real-world industries, the results demonstrate that the RA model exhibits the maximum error at a low surface roughness value but accepts a higher roughness value based on the mean percentage error, indicating that the use of ANN and SVR was sufficient for modeling the ball burnishing process and predicting the roughness of the treated surface. Kurkute, V et al. [18] investigated the microhardness by using the RSM (Response Surface Methodology) method with material AL63400, for used CCD (central composite design) matrix and to analyse by ANOVA (Analysis of variance) and Quadratic analysis to calculate the coefficient of correlation. The parameters are speed, feed, and force, and the result is obtained that the microhardness was force are the most important parameters. Felhő, C et al. [26] studied the CAD-modelling and FEM are the methods used in the theoretical data of process. Diamond burnishing and other plastic deformation processes were not supported by the previous model. In order to ascertain the depth of penetration, Hertz's theory for feasible contact of elastic substances is applied. To validate the used modeling approaches, real-world cutting tests were carried out, wherein surface roughness values were measured during diamond burnishing operations with different feed per revolution values. The real data closely approximates theoretical roughness values, according to a comparison of the two applicable modeling approaches with actual roughness data. Kiran A. Patel et al. [40] used the Taguchi optimization method for better surface roughness of aluminum alloy 6061, dry roller burnishing process was used. The result shows that the spindle speed and burnishing depth are the most important parameters for decreasing the surface roughness. Marek Kowalik et al. [46] experimented on the C4 carbon Steel using the Bracking movement of roller burnishing to increase the depth and fatigue life using Finite element analysis (MSc. MARC program). Results show that improvement in fatigue life. L Kamgaing Souop et al. [35] Using 2024-T351 aluminum alloy drilled pieces, two 2D and three 3D plane strain finite element simulations are used to make a numerical comparison of helical burnishing. Additionally, the impact of process operating factors is investigated. O Bataineh et al [13] modified these two factors in relation to how they affected the hardness and surface roughness of 6061-T6 aluminum rods after roller burnishing them. In order to obtain statistically sound results, data from meticulously planned factorial experiments were evaluated using the analysis of variance (ANOVA) method. The preferred statistical program for carrying out real calculations and data analysis was Mintab®. Results showed that both surface hardness and roughness were improved. Hardness improved by 14.5 percent on average, while surface roughness was reduced by an average of 87.6 percent. TT Nguyen et al [71] investigated to determine the optimal MQL system parameters for reducing the maximum profile peak height of roughness (MAR) and raising Vickers hardness (VH) during the roller burnishing process. These parameters included nozzle diameter (D), impingement angle (I), flow rate (Q), and air pressure (P). It was suggested to use an ideal artificial neural network (ANN) model to illustrate the connections between improving inputs and refining responses. To generate a set of feasible solutions, an efficient evolutionary technique known as multi-objective glowworm swarm optimization (MOGSO) was used. The best optimal solution was found by applying the VIKOR approach. The outcomes demonstrated that the created ANN models' 4–10–2 architecture correctly predicted the response values and defined the burnishing performances.

2.1.6 Out of Roundness:

The departure of a cylindrical or circular object from a flawlessly round shape is known as out-of-roundness. It is a measurement of the object's deviation from a perfect circle in cross-section. Out-of-roundness is frequently measured mathematically as the maximum radial distance (MRO) or total indicator reading (TIR) between the measured surface and a best-fit circle. Out-of-roundness may be calculated using the following formula-9:

$$Out-of-roundness = Max(R_{max} - R_{min})\ldots 9$$

where, R_{max}= “maximum radius of the measures surface”, R_{min}= “minimum radius of the measured surface”.

The out-of-roundness of the cylindrical object is quantified by this formula, which basically calculates the biggest radius difference across its surface. When exact cylindrical components are needed for best performance in many industries, including manufacturing and engineering, accurate out-of-roundness assessment is essential.

Prasad, K. R., et al. [20] have examined the workpiece's dimensional precision. The outcome demonstrates that as the tool and workpiece come into more contact and compress the workpiece's surface, the feed drops and roundness decreases. Barahate, V. et al. [9used a roller burnishing technique on al6061-T6 material to examine the surface texture, microhardness, and out-of-roundness. Burnishing speed, feed rate, depth of cut, and number of passes were the factors. The result shows that the surface roughness is decreased when feed is decreased. feed is the most important parameter. out of roundness El-Taweel et al. [10] studied the roller burnishing process to reduce the roundness error by using electrochemical smoothing and roller burnishing are used. Electrochemical smoothing–roller burnishing (ECS–RB) is a combined super finishing technology characterized by a combination of the ECS and RB actions to use to control the functional surfaces. Results show that the compact process had found the roundness error was achieved at 2.32 µm.

2.2. Comparison of Factors Affecting Surface Integrity through Roller Burnishing

An after-processing method called roller burnishing greatly enhances the surface integrity of machined parts. The many elements affecting surface quality and integrity following roller burnishing are compared technically in this table. The effects of feed rate, burnishing force, and cooling techniques on surface roughness, microhardness, residual stresses, and out-of-roundness are investigated. The table-1 also emphasizes the part modeling methods play in process optimization for intended results.

Table 1 Comparison of Factors Affecting Surface Integrity through Roller Burnishing

Factor	Effect on Surface Integrity	Optimization for Improvement
Surface Roughness	Decreases significantly	Lower feed rates, higher burnishing force
Microhardness	Increases due to plastic deformation	Higher burnishing force, optimal speed
Residual Stresses	Introduces compressive residual stresses	Higher burnishing force, optimal speed
Cooling Techniques	Minimizes thermal softening	Cryogenic cooling for maximizing hardening
Modeling Technique	Finite Element Analysis (FEA) predicts process effects	Enables optimization of parameters before experimentation
Out of Roundness	May improve slightly due to material redistribution	Limited impact, dedicated correction methods needed

3 Result and discussion:

The review of research works related to the influence of the roller burnishing procedure on diverse surface properties demonstrates a thorough comprehension of the impacts of various parameters, cooling methods, and modeling approaches. The summarized results and discussions for each aspect are as follows:

3.1 Surface Roughness:

Numerous studies investigated the influence of burnishing parameters on surface roughness. Researchers like H. Luo et al., Z. Pu et al., M. Nemat et al., and others focused on various materials, burnishing speeds, feeds, depths of penetration, and number of passes. The consensus is that decreasing feed or optimizing parameters leads to improved surface finish. The surface roughness was found to decrease with reduced feed and optimized burnishing conditions. The speed was identified as a significant parameter affecting surface roughness; higher speeds often led to increased roughness. Variations in parameters and material properties directly impacted surface roughness.

3.2 Microhardness:

Microhardness improvement was frequently observed in the studies. H. Luo et al., Tugay et al., and others showed that roller burnishing contributed to enhanced microhardness. The hardness improvement was attributed to plastic deformation and compressive forces during the process. Depth of penetration, number of passes, and other parameters played a vital role in microhardness enhancement. The research indicated that optimized parameters led to significant increases in microhardness, which contributed to improved material properties.

3.3 Residual Stresses:

Residual stresses were a key focus in some studies. El-Khabeery et al., M.M. El-Khabeery et al., and Others examined the effects on residual stress of variables such as burnishing speed, penetration depth, and number of passes. Compressive residual stress was observed to increase with optimal parameter settings. Coolant usage, burnishing speed, and other factors played roles in altering the residual stress distribution on the workpiece's surface. Compressive residual stresses were often desirable for enhancing material strength and fatigue life.

3.4 Cooling Techniques:

Cooling techniques, such as minimum quantity lubrication, cryogenic cooling, and others, were investigated to understand their effects on surface integrity. Researchers like Arvind Ghodake et al., Rotella et al., and others explored how coolants impacted hardness, roughness, and material properties. The use of coolants led to improvements in surface characteristics, including reduced roughness and enhanced hardness. Different coolants exhibited varying effects, indicating their importance in achieving desired outcomes.

3.5 Modeling Techniques:

Response surface methodology (RSM), adaptive neuro-based fuzzy inference system (ANFIS), and other modeling techniques were used to forecast and optimize results. Modeling has been used by Stalin John et al., Nguyen et al., El-Khabeery et al., and others to improve our understanding of burnishing effects. These models helped researchers find the ideal conditions for desired outcomes by illuminating the ways in which certain factors influenced particular traits. The use of a high-stiffness burnishing tool to improve the dimensions and geometrical accuracy of apertures was studied by Tadic et al. [24]. The goal of the project was to use creative tooling solutions to increase the precision of machining processes. Through experimental analysis and data collection, the authors explored the effects of the burnishing tool's stiffness on the accuracy of openings. Their findings contribute valuable insights into the optimization of machining techniques, enhancing the quality and precision of manufactured components.

3.6 Out of Roundness:

Out of roundness, a parameter linked to dimensional accuracy was considered in some studies. A few researchers looked at the connection between out-of-roundness, contact time, and feed. Improved surface compression and tool-to-workpiece contact time resulted in decreased out-of-roundness when feed was decreased, or burnishing conditions were optimized. Overall, the reviewed research demonstrates that roller burnishing is a versatile process capable of enhancing. multiple surface characteristics. By understanding the effects of different parameters, cooling techniques, and modeling approaches, researchers and industries can optimize burnishing processes to achieve specific goals related to surface finish, hardness, residual stresses, and dimensional accuracy.

4 Conclusion:

The intricate nature of the burnishing process and its major impact on surface qualities are highlighted in the literature study's conclusion. Surface roughness, microhardness, residual stresses, cooling strategies, and out-of-roundness are all significantly influenced by a few variables, such as burnishing speed, feed rate, depth of penetration, and number of passes. While higher burnishing rates or deeper penetration can lead to improved microhardness and material characteristics, decreasing the feed rate frequently improves surface roughness. Furthermore, the selection of coolant and cooling methods is critical to preserving surface integrity. To forecast and optimize surface properties, researchers have used a variety of modeling tools, such as Response Surface Methodology (RSM), Adaptive Neuro-Fuzzy Inference Systems (ANFIS), and Artificial Neural Networks (ANN). Furthermore, regulating out-of-roundness has been recognized as a crucial factor, and techniques including lowering feed rates and applying electrochemical smoothing in conjunction with roller burnishing have been found to be effective. All things considered, the thorough investigation of burnishing parameters and their impacts emphasizes how crucial parameter optimization is to attaining required surface qualities in a range of industrial applications.

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