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A Review on Ball Burnishing Process

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Abstract- Burnishing is a very simple and effective method for improvement in surface finish and can be carried out using existing machines, such as lathe. On account of its high productivity, it also saves more on production costs than other conventional processes such as super finishing, honing and grinding. Moreover, the burnished surface has a high wear resistance and better fatigue life.

A literature survey being specifically focused on Ball burnishing process is done .It gives a thorough idea about various workpiece materials, various cutting tools and machine tools, process parameters ,lubricants, variable measured and methodology used as well as the prominent levels of each, being observed in the researches till today.

Index Terms- Superfinishing, Burnishing, Materials, Process Parameters

I. Introduction

To ensure reliable performance and prolonged service life of modern machinery, its components require to be manufactured not only with high dimensional and geometrical accuracy but also with high surface finish. The surface finish has a vital role in influencing functional characteristics like wear resistance, fatigue strength, corrosion resistance and power loss due to friction. Unfortunately, normal machining methods like turning, milling or even classical grinding can't meet this stringent requirement.

Table 1.1 illustrates gradual improvement of surface roughness produced by various processes ranging from precision turning to super finishing including lapping and honing.

A. Burnishing

The burnishing process consists of pressing hardened steel rolls or balls into the surface of the workpiece and imparting a feed motion to the same. Ball burnishing of a cylindrical surface is illustrated in Fig.1.1

During burnishing considerable residual compressive stress is induced in the surface of the workpiece and thereby fatigue strength and wear resistance of the surface layer increase. This process will smooth and harden the surface, creating a finish which will last longer than one that hasn't been burnished.

B. Classification of Burnishing Processes

Burnishing process can be typically classified into two categories as:

1. Based on deformation element
   a. Ball burnishing
      i. Flexible
      ii. Rigid
   b. Roller burnishing
2. Based on the motion of the tool, on the surface
   a. Normal or ordinary
   b. Impact
   c. Vibratory

C. Ball Burnishing

In the process the deformation element is hard ball. Alumina carbide ceramic, cemented carbide, silicon nitride ceramic, silicon carbide ceramic, bearing steel is the material used for ball. As ball acts as tool in deformation the surfaces layer, for the given normal force it gives high specific pressure, more fatigue strength, micro hardness & depth of work hardening layer as compared to roller burnishing. As there is a point & rolling friction between the ball & the work piece, the deformation zone is located adjacent to the ball on the work piece.Fig.1.1 represents scheme of ball burnishing process. Burnishing tools are also now widely applied in nonautomotive applications for a variety of benefits; to produce better and longer lasting seal surfaces; to improve wear life; to reduce friction and noise levels in running parts; and to enhance cosmetic appearance. Examples include valves, pistons of hydraulic or pneumatic cylinders, lawn and garden equipment components, shafts for pumps, shafts running in bushings, bearing bores, and plumbing fixtures [27].

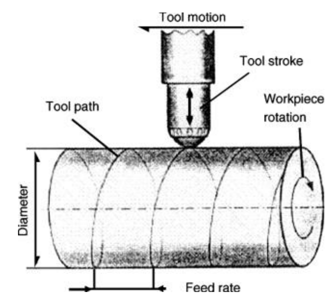


Fig.1.1. Scheme of ball burnishing [9]

II. Workpiece materials their properties and application

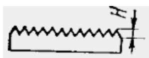
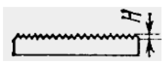
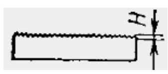
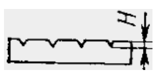
A. Aluminium and its alloys :

Properties –

U M Shirsat and B B Ahuja (2004) **[1]** used aluminium because Pure aluminium can't be heat treated properly however some of the aluminium alloys can be heat treated to improve their mechanical properties up to certain extent. Aluminium material can't be machined properly on conventional and even CNC machines due to poor machinability.

M.H. El-Axir,and A.M. Abodiena (2008) **[6]** used Aluminum alloy 2014 as an experimental work material. This material was selected because of its importance in industry.In the study of M.M. El-Khabeery & M.H. El-Axir(2001) **[16]**,

Table 1.1. Comparison of Finishing Processes

Process	Diagram of resulting surface	Height of micro irregularity (µm)
Precision Turning		1.25-12.50
Grinding		0.90-5.00
Honing		0.13-1.25
Lapping		0.08-0.25
Super finishing		0.01-0.25

workpieces of 6061 aluminum alloy were used. This material was chosen because of its importance in industry and its susceptibility to degradation when burnished, through surface and subsurface damage. Aluminum alloys are particularly well suited for parts and structures requiring high strength-to-weight ratio.

Applications-

Aluminum alloys are probably the best known materials used extensively in aircraft and truck wheels, M.M. El-Khabeery & M.H. El-Axir(2001) **[16].**

N.S.M. El-Tayeb (2007)**[20]** selected Aluminium 6061 because of its wide range of applications in the industry such as aircraft fittings, truck wheels, brake disc, hinge pins, couplings, brake pistons and hydraulic pistons. The strength and good mechanical properties make the AA 7075 aluminum alloy appropriate for the use in aerospace industry, Ugur Esme (2010) **[15].**

B. Steel and its alloys:

Properties-

The hardness of PDS5 tool steel is about HRC33 (HS46). One specific advantage of this material is that after machining, the mold can be directly used without further heat treatment due to its special pre-treatment, Fang-Jung Shiou and Chien-Hua Chen (2003) **[4]** .L.N. Lo´pez de Lacalle et.al (2005) **[7]** used Tempered steel :This is a versatile through- hardening 5% Cr mould and die steel, with good wear resistance, polishability, and toughness. Mean hardness is 52 HRC.

A.A. Ibrahim et.al.(2009) **[9]** In his work, mild steel was used as a workpiece material. This material was selected because of its importance in industry and its susceptibility to degradation when burnished, through surface and subsurface damage.

Applications-

Fang-Jung Shiou and Chien-Hua Chen (2003) **[4]** used PDS5 tool steel in their study (equivalent to AISI P20), adequate for the mold of large plastic injection products in the field of automobile and domestic appliances. L.N. Lo´pez de Lacalle et.al (2005) **[7]** used Heat treated steel :The first application was on a pre-hardened steel (AISI P20) at 290–335 HB (31– 37 HRC,980–1130 MPa). This steel is used for the construction of injection moulds.Feng Lei Li et.al(2012) **[11]** used AA 7075 and AISI 5140 for validation . They are always used to produce some important components under the working conditions of alternate loading, and burnishing can increase the fatigue strength of them significantly.

M.H. El-Axir (2000) **[17]** used Steel-37 (0.20% C; 0.30% Si; 0.80% Mg; 0.05% P; 0.05% S) of hardness 220 *H*v. It was selected because of its importance in industry and its susceptibility to degradation when burnished, through surface and subsurface damage.“En-8” material, which is commonly used in shafts, press-rods and actuators. Consequently, it can be visualized that work-hardening phenomenon ob-served present in En-8, whereas for soft materials like Aluminium, material flow is reported due to plastic deformation, which is due to the soft and ductile nature of the material, C.S. Jawalar &R.S.Walia (2009) **[18].** AISI 4140 was chosen as a workpiece material by Y. Tian & Y. C. Shin (2007) **[19]**due to its wide applications.Burnishing experiments are conducted on turned mild steel work piece, which is ductile and available commercially in the form of round bars, M.Rao J. N. ,C. K. Reddy & P. V. R. Rao (2011) **[27].**

C. Polymers:

K.O. Low and K.J.Wong(2011) **[12]**used polymers in their study as polyoxymethylene (POM) and polyurethane (PUR).The two polymers were selected as each come from the two different groups of polymers, thermoplastic and thermosets. The POM is a semi- crystalline thermoplastic supplied by TNG Sdn. Bhd, Malaysia, while the PUR is a rigid thermosetting polymer supplied by RS Components Sdn. Bhd, Malaysia. The polymers were received as solid rods.

D. Titanium:

S. Thamizhmnaii et.al(2008) **[23]** used Titanium alloy Ti-6Al-4V . It was cut from square block and machined to 45 x 45 x 120 mm in size. The initial surface hardness was 272 HV.

E. Brass :

Commercially pure aluminium (99.85% Al) and brass (high speed machining brass, AS 1573- 385 and JIS H3250 C3604 standards), were used throughout the experiments. The aluminium and brass workpieces were received as bars with a diameter of 32 mm. These bars were cut to appropriate lengths then annealed in an electric furnace at 400°C for alumininum, and 580°C for brass for 1 h. After annealing, the workpieces were turned to proper diameters according to the experimental tests required. The surface hardness of the metals after annealing and turning was as follows: *HK*it=35.48 kg/mm2 for aluminium;

Table 2.1. Materials, Their Different Alloys and Studies Appeared in Literature

Materials	Alloys	References
Aluminium	Cast Al-Cu alloy Al 7075 T6 AA2014 AA 7178 AA 7075 Al Alloy 6061-T6 Al 6061	U M Shirsat and B B Ahuja (2004) [1] ,A.M. Hassan and A.M.S. Momani (2000) [2] A.M. Hassan and A.M.Maqableh(2000)[3] ,H. Basak and H. H. Goktas (2009) [5] ,. El-Axir,and A.M. Abodiena (2008) [6] ,Aysun Sagbas (2011) [10] ,Feng Lei Li et.al(2012) [11] , Ugur Esme (2010) [15] , M.M. El-Khabeery & M.H. El- Axir(2001) [16] ,N.S.M. El-Tayeb (2007)[20] S. Thamizhmanii, B. Saparudin &S.Hasan(2007)[21] J.N. M. Rao, A.C.K.Reddy and P.V. R.Rao (2010) [25]
Steel	Plastic Injection Molding Steel Heat treated and Tempered steel Hardened Steel Mild Steel AISI 5140 Steel-37 Steel En24 X5CrNiMo17-12-2 O1 Alloy Steel En-8	Fang-Jung Shiou and Chien-Hua Chen (2003) [4] , Lo´pez de Lacalle et.al (2005) [7] ,L. Luca, S. N.-Ventzel and I. Marinescu(2005) [8] , A.A. Ibrahim et.al.(2009) [9] ,Feng Lei Li et.al(2012) [11] ,Wit Grzesik and Krzysztof Zak(2012) [13],Dabeer P.S. and Purohit G.K.(2010) [14] , M.H. El-Axir(2000) [17] , Y. Tian & Y. C. Shin (2007) [19],Binu C. Yeldose, B. Ramamoorthy(2008) [22] ,Tomasz Dyl(2011) [24] ,K.S. Rababa and M.M. Al-mahasne(2011) [26],M.Rao J. N. ,C. K. Reddy & P. V. R. Rao (2011) [27],C.S. Jawalar &R.S.Walia (2009) [18]
Polymers	Polyoxymethylene (POM) and Polyurethene(PUR)	K.O. Low and K.J.Wong(2011) [12]
Brass	Heat-treated brass AS 1573-385	A.M. Hassan and A.M.Maqableh(2000) [3], A.M. Hassan and A.M.S. Momani (2000) [2] ,S. Thamizhmanii, B. Saparudin &S.Hasan(2007) [21]
Titanium	Ti6Al4V	S. Thamizhmnaii et.al(2008) [23]
Nickel	MP35 N	Yinggang Tian & Yung C. Shin (2007) [19]
Copper	--	S. Thamizhmanii, B. Saparudin &S.Hasan(2007) [21]

*HK*it=106.27 kg/mm2 for brass, A.M. Hassan and A.M.S. Momani (2000) **[2].**

F. Nickel :
Y. Tian & Y. C. Shin (2007) **[19],** for his study MP35N was selected as one of the Workpiece materials because of its unique hardening mechanism and excellent properties, such as high strength, excellent ductility and good corrosion resistance.
G. Copper :
S. Thamizhmanii, B. Saparudin &S.Hasan(2007) **[21]** used three types of non ferrous work pieces namely Aluminum, Brass and Copper were used. These three materials are commercially available as square bars. The initial size of all the materials was 45 mm square and 100 mm long.

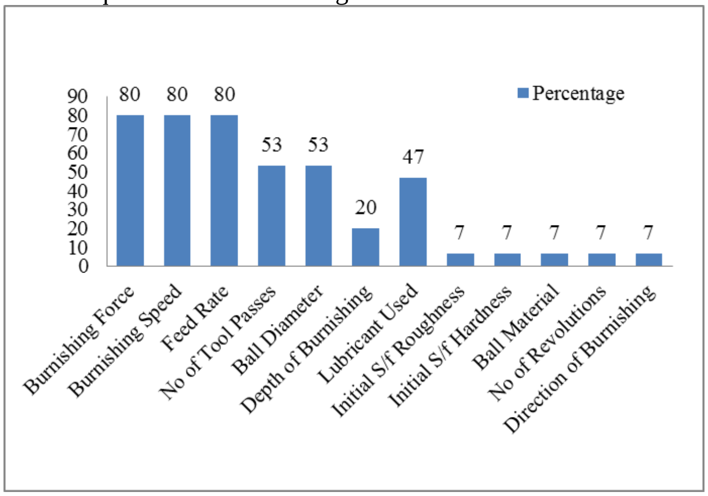


Figure 3.1: Parameter Percentage Importance According to the Authors Who are Studied (Ball Burnishing)

III. ANALYSIS OF PROCESS PARAMETERS

Work on the burnishing process has been carried out by various authors on Conventional Lathe [1-3, 17-18, 20, 27], CNC Lathe [6, 10, 11, 15, 19] and CNC Milling [4, 7, 21, 23]. Table summarizes the Parameters that different authors considered in the Ball Burnishing Process. Fig.3.1 represents the percentage importance of the ball burnishing parameters according to the authors which are studied in the literature.

Parameters like Burnishing force, Speed and Feed were considered the most i.e.80%, secondly the no of tool passes and ball diameter (53%),then Lubricant used (47%),the lesser was Depth of Burnishing and Initial s/f roughness, initial s/f hardness ,Ball material, No of revolutions and Direction of Burnishing were the least considered (7%), by the authors.

IV. LUBRICANTS AND THEIR PERFORMANCE

This section focuses on different lubricants appeared in the literature along with their results being seen on surface finish. At different values of force, speed and feed, kerosene gave best surface finish as compared to SAE-30 oil,5% and 10% graphite in SAE-30 oil by weight[1].In order to study the effect of lubricants on the ball burnishing process, different types of commercial lubricants were used by A.M. Hassan and A.M.Maqableh(2000) [3].

Lubrication, in this case using the machining coolant. In the burnishing process, coolant forms an elasto-hydrodynamic film between the ball and the workpiece's surface, avoiding the adhesive contact of materials on the ceramic ball and removing frictional heat [7].Since dry burnishing conditions produced poor surface finish, it was decided to apply a suitable lubricant during all tests which was emulation-type Soluble oil mixed with water [9].Continuous lubrication (kinematic viscosity of 1.4m²/s at 40 ºC) was supplied from external reservoir to the balls during all burnishing operations [12]. Super finishing passes were done using the ceramic honing stone 99A320N10V and cooling medium containing 85% kerosene and 15% machine oil. Burnishing was performed under static ball–workpiece interaction using special burnishing tool equipped with bearingizing ball and controlled spring-based pressure system to generate force [13].

Amongst the lubricants, use of diesel effects in maximum hardness followed by kerosene and soluble oil.

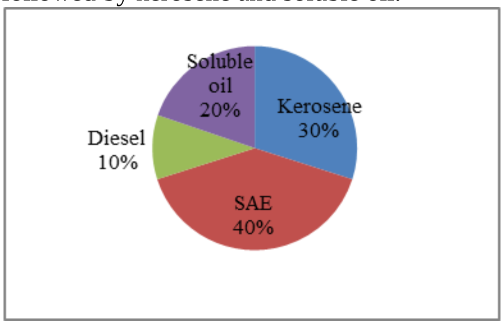


Fig 4.1. Lubricants and Their Performance

Hence in micro-hardness of En-8 Burnishing, number of passes contributes maximum (56.1%) followed by lubricant 22.9%, speed (18.37%) and feed has the least contribution [18]. For lubricated tribo-tests, a light viscosity lubricant (SAE 20W/40) was used. SEM examination of the worn surface reveals that interposing lubricant during tribo-test acts as a cooler and polishing agent, resulting in smoother surface compared to the burnished surface [20].

It is required that the lubricant has considerable effect on roller burnishing process. There will be higher reduction in surface roughness with increased burnishing force, in the presence of lubricant than in dry condition. A light oil such as kerosene oil produces better surface finish values than heavy oils such as SAE 40 engine oil on aluminium work piece [25]. Fig 4.1 shows the percentage usage of different lubricants by the researchers.

V. MEASURED VARIABLES AND RESULTS OBTAINED

The following section explores about various measured variables and summarizes few results from literature which gives an idea about the nature of measured variable.

A. Surface Roughness

Roughness is due to the inherent kinematic differences of the cutting process. Various parameters of surface roughness i. e. Ra, Rz, Rmax are measured by using Surface Roughness Tester, Centre line average (C. L. A.) or Ra value is the arithmetic average roughness height. Maximum reduction in surface roughness is observed in first five passes on mild steel by Roller Burnishing operation [27].

B. Surface Microhardness

The microhardness of the surface considerably decreases with increasing burnishing speed within the range used in this work. It is believed that the deforming action of the roller decreases with an increase in burnishing speed. Microhardness increases with an increase in the number of passes and/or depth of penetration. The highest surface microhardness was obtained with the combination of a high number of passes and high depth of penetration used in this work [16].The surface hardness of mild steel specimens increases with increase in the burnishing force up to 42 kgf. Further increase of burnishing force results in the decrease of surface hardness on mild steel specimens. The maximum surface hardness obtained is 70 HRB [27].

C. Surface out-of-roundness

Surface roundness plays an important role on the required tolerance and fit especially during part assembly. A roundness error is considered as one of the important geometrical errors for cylindrical components because it has negative effects on accuracy and other important factors such as wears in rotating elements. Also, it is well known that only plastic deformation takes place in the surface during the burnishing process, which, in turn, causes variation in the produced roundness [9].

- Therefore, surface roundness before and after burnishing was measured using ROUNDTEST RA-112-122. For better results the arithmetic average of three readings has been calculated [9].
- Surface roundness (maximum deviation) before and after internal burnishing was measured using coordinate measuring machine CMM. Similarly for better results the arithmetic average of three readings has been calculated [6].

D. Friction and Wear characteristics

The friction characteristics are assessed in terms of coefficient of friction of the polymers sliding against stainless steel. The coefficient of friction initially decreased with increasing burnishing force, attaining up to 32.9% and 28.8% reduction for POM and PUR respectively at burnishing force of 124 N, and then it increased [12].
Tribo-tests were performed using disc-on-ring and cross cylinder techniques to investigate the effect of burnishing parameters on friction and wear resistance under dry and lubricated contact conditions[20].

E. Tensile test

Tension test is probably the most fundamental type of mechanical test you can perform on material. Tensile tests are simple, relatively inexpensive, and fully standardized. By pulling on the material, As the material is being pulled, you will find its strength along with how much it will elongate. A curve will result showing how it reacted to the forces being applied. The point of failure is of much interest and is typically called UTS on the chart. The test was carried out on work piece at strain rate 1×10-3, the load-deflection curve was obtained from which the true stress-strain diagram is graphical for each alloy steel[26].

F. Residual Stress

An increase in burnishing speed within the range used in this work produces a significant decrease in the maximum compressive residual stress and may be changed gradually to tensile. This is because of the decrease in the deforming action of the roller burnishing tool with the increase in burnishing speed. It is well known that the generation of residual stress depends upon the interplay of many factors — such as in homogeneous plastic deformation induced by mechanical and thermal events associated with the process. The increase in the deformation action of the roller burnishing tool at low speed produces high plastic deformation at the burnished surface which leads to compressive residual stress [16].

Table 6.1.Summary of Ball Burnishing Process

Reference	Work Material	Machine Tool	Process Parameter	Measured Variable	Analysis Method	Remark
U M Shirsat and B B Ahuja (2004) **[1]**	Aluminium	Kirloskar Turn master T-40 Lathe	Burnishing Force, Speed, Feed Rate, Lubricant	s/f roughness and micro hardness	Mathematical model, ANOVA	-About 60-70% improved s/f finish obtained -At different values of force ,speed and feed ,Kerosene gave best s/f finish
A.M. Hassan and A.M.S. Momani (2000) **[2]**	Pure Al and Brass	Colchester master 2500 lathe	Burnishing Force, speed, Feed Rate , No of Tool Passes, Ball Diameter	s/f roughness and micro hardness, fatigue life and weight loss due to corrosion	Design of Experiment (DOE)	Shot peening and burnishing used on metallic components to improve certain properties
A.M. Hassan and A.M.Maqableh(2000) **[3]**	Brass and Cast Al-Cu alloy	Colchester master 2500 lathe	Ball Dia., Lubricant, Initial S/f Roughness , Initial S/f Hardness	s/f roughness and micro hardness and weight loss	DOE	An increase in ball diameter will cause a decrease in: (i) the final surface roughness; (ii) the total amount of the increase in hardness; (iii) the wear resistance
Fang-Jung Shiou and Chien-Hua Chen (2003) **[4]**	Plastic Injection Molding Steel	Three axis CNC Milling	Burnishing Force , Speed, Feed Rate, Ball Material	Optimal burnishing parameters	Taguchi's L18 orthogonal table, ANOVA ,full factorial	The optimal burnishing parameters for the plastic injection mold steel PDS5 were the combination of the tungsten carbide ball, the burnishing speed of 200 mm/min, the burnishing force of 300 N, and the feed of 40µm
Hudayim Basak and H. Haldun Goktas (2009) **[5]**	Al alloy (Al 7075 T6)	---	Feed Rate , No of Tool Passes, Ball Diameter, Burnishing Force	s/f roughness and micro hardness	Fuzzy logic	Best s/f roughness obtained at 300 N ,0.3 feed and 3 passes
M.H. El-Axir,and A.M. Abodiena (2008)	Al alloy 2014	A CNC lathe machine (Model, Biglia B56/1)	Speed, Feed Rate , No of Tool Passes, Depth of	Out of roundness(µm) and micro hardness (HV)	RSM with Box and Hunter method	s/f micro hardness and out of roundness better with depth of penetration range (0.025-0.045mm) and 3-4 passes

[6]			Burnishing			
L.N. Lo´pez de Lacalle et.al (2005) **[7]**	Heat treated and Tempered steel	5-axis High Speed Milling Centre	Burnishing Force , Speed, No of tool passes, Depth of Burnishing, Lubricant	Max height (Rt),Max Roughness (Rz),Mean roughness(Ra), micro hardness, microstructure photographs	DOE	Max pressure 30 MPa leads to highest quality improvement for the materials of 35-55 HRC
L. Luca, S. N.-Ventzel and I. Marinescu(2005) **[8]**	Hardened Steel	---	Burnishing Force , Speed, Feed Rate, Ball Diameter	Final roughness	Factorial Experiment	Result showed significant influence of pressure as well as original roughness after hard turning
A.A. Ibrahim et.al.(2009) **[9]**	Mild Steel	---	Burnishing Force , Speed, Feed Rate, Ball Diameter, Lubricant	s/f finish and s/f out of roundness	Self organising fuzzy logic controller, DOE	Experimental and fuzzy results showed that an increase in burnishing speed up to 1.5 m/s leads to a decrease in the burnished out-of-roundness whereas the increase in burnishing speed more than 1.5m/sec results in an increase in out-of-roundness
Aysun Sagbas (2011) **[10]**	Al alloy 7178	Industrial type of CNC lathe	Burnishing Force , Speed, Feed Rate , No of Tool Passes	s/f roughness	Desirability function approach (DFA) with RSM, Quadratic model, ANOVA	-Significant factors on s/f roughness were Burnishing force and no of passes -RSM helps determining appropriate burnishing conditions
Feng Lei Li et.al(2012) **[11]**	AA 7075 and AISI 5140	C6132A Lathe machine	Burnishing Force , Speed, Depth of Burnishing, Lubricant	s/f roughness, microscopic topography	Analytical modelling, DOE	s/f roughness proportional to burnishing force to 2/3 and ½ power in roller and ball burnishing respectively
K.O. Low and K.J.Wong(2011) **[12]**	Polyoxymethylene (POM) and Polyurethene (PUR)	---	Burnishing Force , Speed, Feed Rate , No of Tool Passes, Ball Diameter, Lubricant	s/f roughness, wear and friction characteristics	SEM images, DOE	Lowest s/f roughness 0.44 µm and 0.46 µm achieved for POM and PUR respectively
Wit Grzesik and Krzysztof Zak(2012) **[13]**	AISI 5140	---	Burnishing Force, Feed, Ball Diameter, Lubricant	s/f roughness	Optical images ,DOE	Improvement of s/f roughness is about 40%

Dabeer P.S. and Purohit G.K.(2010) **[14]**	Aluminium	---	Burnishing Force, Speed, No of Tool Passes, Ball Diameter	s/f roughness	Mathematical model, RSM	Optimum s/f finish obtained at 425rpm speed,7 mm ball diameter,70 N force and 2 tool passes
Ugur Esme (2010) **[15]**	AA 7075	FANUC GT-250B CNC lathe	Burnishing Force , Speed, Feed Rate , No of Tool Passes	s/f roughness and micro hardness	Grey based Taguchi method, ANOVA	s/f roughness and micro hardness are greatly improved

VI. SUMMARY AND DISCUSSIONS

Table 6.1 depicts the summary of literature reviewed for the present study which focuses on following points;

1. A review on burnishing thus gives us an overview of Materials, Burnishing tools and Machine tools along with process parameter and lubricant comparison.
2. It can be seen that Aluminum and steel materials are most preferred by the authors whereas a much scope is there to work on Polymers.
3. Amongst the ball burnishing process parameters Burnishing force, speed and feed were considered the most compared to Ball material, No of revolutions and Direction of burnishing.
4. SAE-oils are mostly used as Lubricants but use of diesel effects maximum hardness followed by Kerosene and then soluble oil.
5. Surface roughness and Microhardness are the popular measured variables.
6. Mathematical modeling and design of experiment are the commonly used methodologies. In the recent years, researchers are using Taguchi Method, Response surface Methodology and Fuzzy Logic for optimizing Burnishing Process parameters.

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