INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume 4, Issue 3)
Available online at: www.ijariit.com

Analysis on effect of ball burnishing processes on aluminum 6061

Anvesh
anveshsuvarna@gmail.com
Shri Madhwa Vadiraja Institute of Technology and Management, Udupi, Karnataka

Sagar Hegde
sagarhegde1995@gmail.com
Shri Madhwa Vadiraja Institute of Technology and Management, Udupi, Karnataka

Pavana Kumara
pavansmvitm@gmail.com
Shri Madhwa Vadiraja Institute of Technology and Management, Udupi, Karnataka

Shreyas M Shetty
tshreyasm@gmail.com
Shri Madhwa Vadiraja Institute of Technology and Management, Udupi, Karnataka

ABSTRACT

In today's time, the manufacturing of machines and other components with the highly finished surface are becoming more and more important. Drastic attention is being given on the quality of the surface. Surface finishing is mandatory characteristic of any produced machine. The operation, which can easily improve the surface roughness of machinery parts, is called as Burnishing operation and it is getting evolved day by day. It basically involves plastic deformation of the material. It is a cold working process, without any removal of metal from the work piece, and process get computes. Peaks get changed into the valley, at last, a highly polished mirror like surface is obtained. In case of sliding surfaces, it enhances the life of material this paper explain the analysis of the effect of ball burnishing process. Surface finishing has a prolonged effect on every material. It is applied to implement a successful hard ball burnishing process. The consequence of burnishing parameters along with surface integrity needs to be evaluated before actual functioning. In this paper, an attempt is made to compare the results of ball burnishing (in abrasive paste conditions). The parameters taken into consideration are burnishing speed, burnishing feed, burnishing force, ball material and number of passes. Mathematical models have been developed in terms of surface roughness and surface hardness for ball burnishing process.

Keywords: *Burnishing, Ball burnishing, Surface roughness, Surface hardness, F, N, S, f.*

1. INTRODUCTION

A surface machined by conventional machining processes such as milling and turning consists of inherent irregularities produced by the cutter, or a finer structure due to tear in of the material during machining. There are many finishing processes used to produces surfaces with high-quality textures. These processes can be classified into chip removal process, such as grinding and chip fewer processes such as burnishing. Burnishing is a cold working process and chip less machining process carried out to improve surface roughness, surface hardness, fatigue, and compressive strength and corrosion resistance.

The Burnishing process smoothed out peaks and valleys on the surface. This is very simple and an effective method for improvement in surface finish, it can be carried out using carried existing machines, such as a lathe. The functional performance of a machined component such as fatigue strength, load-bearing capacity, friction etc. depends to a large extent on the surface as topography, hardness, nature of stress and strain induced on the surface region. During recent years, considerable attention has been paid to the post machining metal finishing operations such as burnishing which improves the surface characteristics plastic deformation of the surface layer by producing compressive residual stress on the surface. During burnishing the micro irregularities start to deform plastically Initially at the crests are subjected to plastic deformation, the valleys between the micro-irregularities start to move in the direction of the newly formed surface, i.e. towards the surface in contact with the tool. The grain structure is then condensed, producing a hard surface with superior load carrying and wear-resistant characteristics.

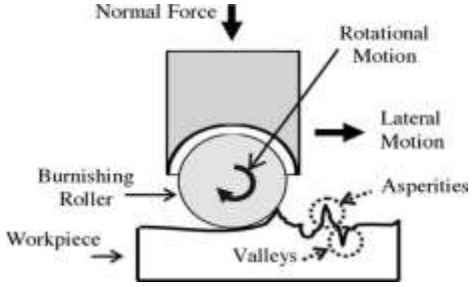

Fig1: Schematic representation of roller burnishing process

There are several forms of burnishing process, the most common are

- Ball burnishing and
- Roller burnishing.

Ball burnishing: In this method, machined surfaces are burnished by a ball burnishing tool. The experimental work is carried out on a lathe machine or milling machine.

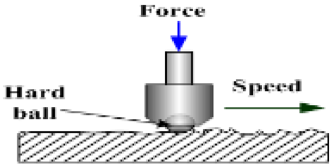

Fig2: Ball burnishing process

Roller Burnishing: Roller burnishing is a cold working process which produces a fine surface finish by the planetary rotation of hardened roils over a bored or turned metal surface. Roller burnishing involves cold working the surface of the work piece to improve surface structure. Since all machined surfaces consist of a series of peaks and valleys of irregular height and spacing, the plastic deformation created by roller burnishing is a displacement of the material in the peaks which cold flows under pressure into the valleys. The result is a mirror-like finish with a tough, work hardened, wear and corrosion resistant surface.

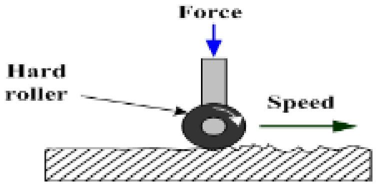

Fig3: Roller burnishing process

Need for Burnishing: Most of the finishing techniques which are in use such as precision finishing techniques like lapping, honing, super finishing, ultrasonic impact grinding and Non-precision finishing techniques such as polishing, buffing, power brushing, tumbling, vibratory finishing, shot and sandblasting only increase the surface finish of the components when it is carried out. But in the burnishing is a single operation. Both the surface finish and hardness will increase which is not possible in any other finishing techniques. Hence, this technique became popular among researchers to continue work. So, in this work, it was decided to study about burnishing effect on EN24 components.

Mechanics of Burnishing: To understand burnishing, let us consider the simple case of a hardened ball on a flat plate. If the ball is pressed directly into the plate, stresses develop in both objects around the area where they contact. As this normal force increases, both the ball and the plate's surface deform. The deformation caused by the hardened ball is different depending upon the magnitude of the force pressing against it. If the force on it is small, when the force is released both the plate's surface will return to their original, undeformed shape. In this case, the stresses in the plate are always than the yield strength of the material, so the deformation is purely elastic. Since it was given that the flat plate is softer than the ball, the plate's surface will always deform more. If a larger force is used, there will also be plastic deformation and plate's surface will be permanently altered. A bowl-shaped indentation will be left behind, surrounded by a ring of raised material that was displaced by the ball.

If the external force on the ball drags it across the plate, the force on the ball can be decomposed into two component forces: one normal to the plate's surface, pressing it in, and the other tangential, dragging it along. As the tangential component is increased, the ball will start to slide along the plate. At the same time, the normal force will deform both objects, just as with static situation. If the normal force is low, the ball will rub against the plate but not permanently alter its surface. The rubbing action will create friction and heat, but it will not leave a mark on the plate. However, as the normal force increases eventually the stresses in the plate's surface will exceed its yield strength. When this happens the ball will plow through the surface and create a trough behind it. The plowing action of the ball is burnishing.

Fig4: Burnishing between two plates

Burnishing also occurs on surfaces that conform to each other, such as between two flat plates, but it happens on a microscopic scale. Even the smoothest of surfaces will have imperfections that extend above the general from of a surface are called asperities, and they can plow material on another surface just like the ball dragging along the plate. The combined effect of many of these asperities produces the smeared texture that is associated with burnishing.

The typical range of surface finish obtained by various surface finish methods:

The following shows the various surface finish methods and their surface finish ranges.

Table I Typical Range of Surface Finish, RA, µM

Process	Average applications
Grinding	0.1 to 1.6
Lapping	0.05 to 0.4
Honing	0.1 to 0.8
Buffing	0.05 to 0.5
Super finishing	0.05 to0.2
Burnishing	0.2 to 0.8

In this chapter, the topics discussed are a selection of process parameters, burnishing tool and machine used to conduct experiment etc., the work piece material, lubricants etc., and specifications regarding the method of burnishing, the design of the experiments.

Selections of process parameters: It is required to choose the parameters, also called as input variables or controlled variables. The very nature of the design dictated the type of the input variables. As these are to monitored continuously and should be able to maintain at exactly at the desired upper and lower levels through the experimental runs a judicious selection of these parameters is important. From literature survey it can be seen that the burnishing process can be controlled by different parameters such as burnishing speed, burnishing feed, burnishing force, and Number of passes etc. as we developed roller burnishing tools to suit for working in lathe machine we have taken the parameters in accordance with controllable factors in lathe machine, as we can control the burnishing speed i.e. spindle speed, also we can set the value of burnishing feed and no of tool passes which is easy to change during need of experiments we have taken three factors in our experiments. Also, the spring which we have used in tools can measure the force which we had applied on at the work piece during machining so we take the burnishing force as one of the factors in consideration. So, totally as per requirement of work and the sources available we have taken four factors into account such as

- Burnishing speed (RPM)
- Burnishing feed (mm/ rev)
- Burnishing force (Kgf) and
- A number of passes.

Work Piece Material: Aluminium (Al 6061) was used as work piece material with 68 HRB. The chemical composition of the material is as shown in Table II. This material was selected 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 structure requiring high strength-to-weight ratio and are the probably the best-known materials used extensively in aircraft and truck wheels.

Table II Chemical composition and properties of the work piece material Al 6061

Material identification	Percentage Proportion
Fe	MAX 0.7
Si	0.4-0.8
Cu	0.15-0.4
Cr	0.04 -0.35
Mg	0.8-1.2
Mn	Max 0.15
Zn	Max 0.25
Ti	Max 0.15
Al	Balance
Other	0.05 (Max) each 0.15(Max) total

Table III Mechanical properties of the work piece

Al 6061	
Tensile Strength	70-360 MPa
Yield Stress	30-286 MPa
Hardness-Vickers	30-100Hv

Ball material: The specification of the ball, which is used in the tool is as follows,

The ball is made up of a tungsten carbide. The tungsten carbide ball used here is harder than the Al 6061 steel and causes plastic deformation hen pressed or forced against Al 6061 material.

Experimental set up on the lathe: By reviewing the literature, papers it came to know that the burnishing process can be performed either by lathe or using vertical machining centers such as milling machines. In this project, the lathe is used to perform the burnishing process because it a machine in which various operations can be carried out and also the burnishing is such a process which can be carried out successively on the easily available machines such as a lathe. As it was decided previously, the tools, which can be adjusted on the lathe machine to perform burnishing process, were developed in ball forms. It is a universal machine compare to all other machines. The burnishing tool attachments can be easily mounted on the tool post without any extra set up. The lathe which is used here is engine lathe all geared has the unique options to set the parameters as per the requirements in this work to perform the experimental runs.

Experimental Planning: Since it was decided to improve the surface hardness and surface finish of the materials, Al 6061 materials were used, which have wide application in the construction of aircraft structures, such as wings and fuselages, more commonly in homebuilt aircraft than commercial or military aircraft. 2024 alloy is somewhat stronger, but 6061 is more easily worked and remains resistant to corrosion even when the surface is abraded, which is not the case for 2024, which is usually used with a thin Alclad coating for corrosion resistance, automotive parts, such as the chassis of the Audi A8, yacht construction, including small utility boats and aluminium cans for the packaging of food and beverages.

Therefore, it requires burnishing process to fulfill the criteria of high hardness and good surface finish. Thus, a special ball burnishing tool was designed for this purpose and tested.

The Ball burnishing tool consists of Upper body, Lower body, Carbide ball holder, Carbide rod holder, spring, Carbide ball, Tension screw. The body of the tool is made up of EN12 Steel, ball and ball holders are made up of Tungsten carbide material, spring and tension screws are made of hardened steel.

The carbide rod was reduced into two pieces of 20mm each and V-shaped groove was made on top of one of the cut ends of the carbide rod, to mount the ball on it. To fabricate the body, the EN12 Steel was machined into size.

The lower body consists of spring and tension screw. Tension screw is used to obtain the required tension in the spring. The carbide rod holder was mounted on the spring on which carbide ball holder was fixed, on top of which carbide ball was mounted. These components were enclosed by the upper body.

The developed tool was used to carry out burnishing process (with abrasives) on ferrous and nonferrous metals.

The input parameter also known as factors, chosen were:

- Burnishing speed, rpm (S)
- Burnishing feed, mm/rev (f)
- Burnishing force, Kg (F)j
- Number of passes (N)

The spring stiffness was calibrated and the results were noted down.. From the calibrated result, we found that for 1mm rotation of the tool post, 2.5 kg of force was applied on the work piece. A carbide tip tool was used to turn the Al 6061 work piece, as this is the hardest material present. Whereas high speed steel was used to turn aluminium work piece as it was a softer material.

40 tests were conducted altogether on Al 6061. Then the 40 work piece of each material was divided into two batches of 20 samples. In that one batch were turned at 250RPM, 0.1 mm/rev Feed and 1 mm Depth of Cut. 20 samples were further divided into batch of 10 samples. One batch of samples were subjected to ball burnishing process using fine abrasives and another batch was subjected to ball burnishing process using medium abrasive. Another batch of 20 samples was turned at 250RPM, 0.1 mm/rev Feed and 1 mm Depth of Cut. 20 samples were further divided into batch of 10 samples. One batch of samples were subjected to ball burnishing process using fine abrasives and another batch was subjected to ball burnishing process using medium abrasive. Burnishing was conducted using the above mentioned parameters. First set of 5 samples were processed by keeping the values of Feed, Speed, and Number of passes as constants. Here the Force value was varied for each sample. Second set of 5 samples were burnished by keeping the values of Feed, Force, Speed as constants and Number of passes were varied for each samples. The process is done for the both of the turned samples.

These experiments are conducted on Aluminium 6061 alloy with fine abrasive and medium abrasive.

The output parameters, also known as effects, chosen are:

- Surface finish.
- Micro hardness.

All the experiments were carried out using Tungsten Carbide ball of 10mm diameter. Silicon carbide paste was used as an abrasive in case of experiments with abrasives. Keeping three parameters fixed at one level, the effect of variation of the other parameter was studied.

2. EXPERIMENTATION

The experimental work is covered in this chapter. As mentioned earlier the whole work is divided into two stages.

Those are burnishing with fine abrasive and medium abrasive on Al 6061 – stage 1, stage 2.

Thus the whole experiment comprises:

Stage 1: where the experiment is carried out using ball burnishing tool.

Stage 2: where the experiment is carried out by ball burnishing tool with abrasive paste.

The experimental work involved the following steps:

- Calibration of the spring which is used in the tool for the sake of force measurement and tool specification.
- Preparation of the required no. of work pieces on which to do burnishing as decided Earlier.
- Making the system ready for the experiment.
- The actual running of experimental runs as per the input parameters.
- Relieving' the system.

Each one of these steps is in detail in the following tables.

Turning parameters

	Speed	Feed	Doc
Case 1	**500 rpm**	**0.1 mm/rev**	**1 mm**
Case 2	**250 rpm**	**0.1 mm/rev**	**1 mm**

The following table will give the details of experimental planning

Table IV

LEVELS	LVL 1	LVL 2	LVL 3	LVL 4	LVL 5
Force, Kgs (F)	**5**	**10**	**15**	**20**	**25**
NOP (N)	**1**	**2**	**3**	**4**	**5**

Table V

Case 1 turned; Abrasives : paste		
Experiment	**Variable Parameters**	**Constant parameters**
1-5	**F lvl 1-5**	**f ,S, N (0.119mm/rev, 585Rpm, 3)**
6-10	**NOP lvl 1-5**	**F, f, S (15 Kgf, 0.119mm/rev , 585Rpm)**

Case 2 turned; Abrasives: paste		
Experiment	**Variable Parameters**	**Constant parameters**
11-15	**F lvl 1-5**	**f ,S, N (0.119mm/rev, 585Rpm, 3)**
16-20	**NOP lvl 1-5**	**F, f, S (15 Kgf, 0.119mm/rev , 585Rpm)**

Table VI

EXP NO	FEED (f) 'mm/rev'	FORCE (F) 'KG'	SPEED (S) 'RPM'	Number of passes
1	0.019	5	585	3
2	0.019	15	585	3
3	0.019	25	585	3
4	0.019	35	585	3
5	0.019	45	585	3
6	0.019	15	585	1
7	0.019	15	585	2
8	0.019	15	585	3
9	0.019	15	585	4
10	0.019	15	585	5

Burnishing tool: The ball burnishing tool used in this process in a self-designed and fabricated. A burnishing tool with interchangeable adopter is designed and fabricated for the experimental tests.

Fig5: Burnishing tool

Calibration of tool Spring:

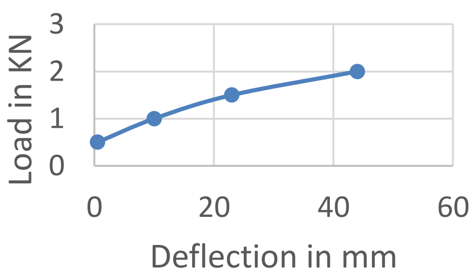

Fig6: graph between load, kg vs. deflection, mm

From the graph, it is given that,

Spring Stiffness = Load/Deflection = 0.5/34 = 0.01422KN/mm = (0.01422x1000)/9.81 = 2.998 = 3Kg/mm

Preparation of work pieces for burnishing:- The cylindrical Al 6061 rod which was not available in as required sizes, so they were cut by using hack saw cutting hand tool to required sizes with allowance for facing etc. at the faces. The Al 6061 rod size chosen was 18mm dia of 25mm lengths each. The work pieces are made to convenient size to work by between the center methods. The preparation of the work pieces involved following steps.

- The cylindrical Al 6061 is marked by chalk to cut 40+1(turning) =41 pieces.
- The EN24 Steel rods are marked to the required length by manually by keeping necessary allowance.
- The cut pieces are first made to undergo facing operation.
- The cut pieces are drilled at both ends so as to do between center methods.
- Similarly,82 pieces were made ready to conduct the experiments as per plan.

Making the system ready for the experiment:

This was done as depicted below:

- First, the prepared EN24 Steel pieces for an experimental run is to check for its correctness i.e number wise.
- Once it was cleared with work pieces next is to check with the lathe and its parameters, the lathe is first checked with its operation, the feed, speed setting must be exact.
- The burnishing tool is adulated at the tool post and tested for the application of force on the work pieces.
- The force application measurement must be exact. The giving depth of penetration is nothing but the force applied on to the work piece.
- After setting all it is helpful to check the burnishing initially on two or three of brass pieces just for checking the setup.
- If it is found ok in above step then it was concluded that the whole system i.e. work pieces, burnishing tools and Turn master- 400 lathes are ready to conduct an experiment.

Fig7: Ball burnishing operation for EN24 Steel

Fig8: Surface finish testing

Fig 9 Rockwell Hardness Machine

3. OBSERVATIONS AND RESULTS

As per the objectives set in the current work, firstly we have turned the work piece of Al 6061 by setting the moderate range of parameters and tested for its Surface Roughness and Surface Hardness and obtained the results as per the following table.

Table VII Surface roughness values for Al 6061 sample (Reference)

Ra in microns (μ)			
0º	**120º**	**240º**	Avg Ra
2.076	1.963	2.010	2.016

Table VIII Micro hardness values for Al 6061 Sample (Reference)

0º	**120º**	**240º**	**ROCKWELL HARDNESS NUMBER HRC**	**VIKERS HARDNESS NUMBER VHN**
47	46	45	46	98

From the Table VIII average microhardness value of Al6061 sample taken was 98 VHN and it was selected reference for turn the work piece.

Table IX Design matrix Micro hardness value for Al 6061 with fine abrasive

Turning Parameter Condition	W/P NO	Expt no	f 'mm/rev'	F 'KG'	S 'RPM'	N	HRC	VHN
Case 1	1	1	0.119	5	585	3	59	116
		2		15		3	59	116
		3		25		3	57	111
		4		35		3	60	117
		5		45		3	65	123
	2	6		15		1	62	119
		7		15		2	63	121
		8		15		3	62	119
		9		15		4	63	121
		10		15		5	64	122
Case 2	3	11	0.119	5	585	3	62	119
		12		15		3	61	118
		13		25		3	63	121
		14		35		3	62	119
		15		45		3	61	118
	4	16		15		1	61	118
		17		15		2	64	122
		18		15		3	63	121
		19		15		4	65	123
		20		15		5	64	122

Table X Design matrix Micro hardness value for Al 6061 with medium abrasive

Turning Parameter Condition	W/P NO	Expt no	f 'mm/rev'	F 'KG'	S 'RPM'	N	HRC	VHN
Case 1	5	1	0.119	5	585	3	62	119
		2		15		3	62	119
		3		25		3	61	118
		4		35		3	62	119
		5		45		3	62	119
	6	6		15		1	64	122
		7		15		2	64	122
		8		15		3	60	117
		9		15		4	53	107
		10		15		5	57	113
Case 2	7	11	0.119	5	585	3	63	121
		12		15		3	60	117
		13		25		3	61	118
		14		35		3	62	119
		15		45		3	64	122
	8	16		15		1	64	122
		17		15		2	64	122
		18		15		3	64	122
		19		15		4	63	121
		20		15		5	64	122

Table XI Design matrix Micro Roughness for Al 6061 with fine abrasive

Turning Parameter Case	W/P NO	EXP NO	(f) 'mm/rev'	(F) 'KG"	(S) 'RPM"	(N)	Ra microns
Case 1	1	1	0.119	5	585	3	1.20
		2		15		3	0.79
		3		25		3	0.57
		4		35		3	0.52
		5		45		3	2.12
	2	6		15		1	1.42
		7		15		2	0.79
		8		15		3	0.60
		9		15		4	0.31
		10		15		5	0.25
Case 2	3	11		5		3	0.93
		12		15		3	0.28
		13		25		3	0.423
		14		35		3	0.43
		15		45		3	0.29
	4	16		15		1	1.56
		17		15		2	1.64
		18		15		3	0.47
		19		15		4	0.30
		20		15		5	0.365

Table XII Design matrix Micro Roughness for Al 6061 with medium abrasive

Turning Parameter Case	W/P NO	EXP NO	(f) 'mm/rev'	(F) 'KG"	(S) 'RPM"	(N)	Ra microns
Case 1	5	1	0.119	5	585	3	2.23
		2		15		3	1.16
		3		25		3	2.25
		4		35		3	3.13
		5		45		3	1.64
	6	6		15		1	3.12
		7		15		2	3.53
		8		15		3	1.25
		9		15		4	0.90
		10		15		5	0.88
Case 2	7	11		5		3	3.25
		12		15		3	3.55
		13		25		3	0.29
		14		35		3	0.26
		15		45		3	1.39
	8	16		15		1	0.48
		17		15		2	0.32
		18		15		3	0.22
		19		15		4	0.29
		20		15		5	0.21

4. CONCLUSION

- Ball burnishing is an effective method in improving both surface finish and micro hardness.
- Ball burnishing of Aluminium in fine abrasive condition for that surface finish got 0.25 microns and percentage decrease when compared to the turned work piece is 87.601% and maximum micro hardness that got 123 VHN and percentage increase in hardness is 25.51%.
- During medium abrasive condition least value of surface finish got 0.29 microns and percentage decreases are 89.584% and maximum micro hardness that got 122 VHN and percentage increase in hardness is 24.489%.

5. ACKNOWLEDGEMENT

The credit of the completion of the project work goes behind our own work, to those people who have always been with us through out and we take this opportunity to express our heart-felt gratitude to each one of them.

We wish to thank our guide **Mr. Pavan Kumar**, Assistant professor, Department of Mechanical Engineering, Shri MadhwaVadiraja Institute of Technology and Management, Bantakal for being a constant source of inspiration, encouragement and providing proper technical guidance at all stages of the project.

We are thankful to **Dr.Sudharshan** Rao K, H.O.D, Department of Mechanical Engineering, Shri MadhwaVadiraja Institute of Technology and Management, Bantakal for allowing us to carry out this project and for ensuring all the facilities required to carry out this project.

At the outset we take this opportunity to thank Prof. **Dr.Thirumaleshwar Bhat**, Principal, Shri MadhwaVadiraja Institute of Technology and Management, Bantakal for his guidance and encouragement for completion of this project.

We would like to thank **Mr Jayesh Vasavi** (Hi Tech Sales Corporation, mangalore) for providing materials which are needed for project.

We would also like to thank **Mr Stanley M Kotian** (SEATO TECHNIQUES) for helping us to build a tool of our requirement.

We specially thank **Mr Raghuram Shettigar**, Instructor and also we thank all the teaching and non-teaching staff Department of Mechanical Engineering, Shri MadhwaVadiraja Institute of Technology and Management, Bantakal for helping us in completion of the project work.

6. REFERENCES

[1] U M Shirsat and B B Ahuja,"Parametric analysis of combined turning and ball burnishing process", Indian Journal of Engineering and material sciences, Vol.11, October (2004), pp.391 -396.
[2] Adel Mahmood Hassan and Amer M.S. Momani,"Further improvements in some properties of shot peened components using the burnishing process", International Journal of Machine Tools & Manufacture Vol.40 (2000) pp.1775–1786.
[3] Adel Mahmood Hassan and Ayman Mohammad Maqableh, "The effects of initial burnishing parameters on non-ferrous components",Journal of Materials Processing Technology, Vol.102 (2000), pp.115-121.
[4] Fang-Jung Shiou and Chien-Hua Chen,"Freeform surface finish of plastic injection mold by using ball-burnishing process", Journal of Materials Processing Technology,Vol.140 (2003),pp. 248–254.
[5] M.H. El-Axir, O.M. Othman and A.M.Abodiena," "Improvements in outof-roundness and micro hardness of inner surfaces by internal ball burnishing process", Journal of materials processing technology 196 (2008) 120–128.
[6] Liviu Luca, Sorin Neagu-Ventzel and Ioan Marinescu, "Effects of working parameters on surface finish in ball-burnishing of hardened steels", Precision Engineering 29 (2005) 253–256.
[7] M.H. El-Axir, "An investigation into roller burnishing", International
Journal of Machine Tools & Manufacture 40 (2000) 1603–1617.
[8] R.L.Murthy and B.Kotiveerachari,"Burnishing of metallic surfaces-a review" Precision Engineering.

