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Application of Roller Burnishing Process for Final Machining Of Cilindrical Surface

Kundan Kumar. D, Dr. K. Eswara Prasad
Reaserch Scholar, JNTU Hyderabad, Hyderabad, India
Prof. Dr. K. Eswara Prasad, Dept. of Mechanical Engineering, JNTUCEH, JNTU Hyderabad, Hyderabad

Abstract: *Final machining of 34CrMo4 steel with roller burnishing tools is shown in this paper. Roller burnishing process is clean and environmentally friendly machining process which can replace other finishing processes with pollution effects. Experimental tests on specimens prepared for final machining process estimates the rate of roughness decrease, and diameter increase. Roughness data measured before and after roller burnishing process have been compared. Roughness ratio (before/after process) and decrease factor for surface quality improvement can be up to 10.*
Presented smoothing process can be performed on standard machine tools without additional reconfiguration tasks. Process is very versatile for any workshop and can be conducted without coolant.
Keywords: *Machining, Roller burnishing, Surface roughness*

I. Introduction

A cylindrical surface exposed to the high exploitation loadings has to be machined with acceptable surface quality. In the last decades, selection of the process to satisfy these demands is additionally determined with short cycles and low-pollution priorities. Toward this idea, processes with rolling instead of sliding effects and low friction coefficient ensure low energy consumption as well as low heat generation in process.

Roller burnishing is an economical and feasible mechanical treatment for the quality improvement of rotating components, not only in sense of surface roughness but in compressive residual stresses as well.

Surface geometry machined with traditional processes consists of scallops which can be removed only with additional finishing operation. From the exploitation point of view, the smaller the surface roughness is (e.g. bellow 0,1 mm [1]), the friction losses are minimized.

When the scalloped surface is exposed to extremely high local pressures, the surface peaks are exposed to the rapid wear as well.

In traditional machining processes that are producing scalloped surface with plastic deformation, tool is sliding over the contact area between the tool and work piece what requires a lot of lubrication and a lot of friction energy. Additionally to lubricants that circulate through the cooling system and over machine tool, some quantity of lubricants remain on chips after the process is finished and is also potential waste material and a risk for pollution.

Nowadays, about 50% of the energy supplied is lost in the friction of elements in relative motion [2]. Roughness values less than 0.1 mm are required for good aesthetic appearance, easy mould release, good corrosion resistance, and high fatigue strength.

Many reports of surface integrity referee that an improvement in wear resistance can be very easy achieved by burnishing, but very few actual studies analyzed environmental implications and versatility.

Roller burnishing is a fine machining process that is used to improve certain physical and mechanical properties, such as surface roughness, corrosion resistance, friction coefficient, wear, and fatigue resistance. The principle of the burnishing process, shown in Fig. 1, is based on the rolling movement of a tool (a ball or a roller) over the work piece's surface. With application of roller burnishing process, plastic deformation of machining surface and allocation of material starts from peaks to valleys. Roller burnishing is a material micro-displacement process which (Fig. 1) in comparison with other finishing processes, like grinding process, also lowers the surface roughness height but the burnishing process can be achieved by applying a highly polished and hard roll on to a metallic surface under pressure. Microscopic "peaks" on the machined surface are during roller burnishing process exposed to cold flow into the "valleys," creating a plateau-like profile in which sharpness is reduced or eliminated in the contact plane.

Simultanliously with plastic deformation, residual compressive stresses are induced in the surface layer. The increase in the burnishing force will increase the plastic deformation, as well as the penetration of the roller into machining surface. This will lead to an increase in the internal compressive residual stress, which causes a considerable increase in the surface hardness. The increase of surface hardness and strength mainly serves to improve wear resistance and fatigue resistance under dynamic loadings.

Burnishing process results with no chips, no sliding wear (rolling of tool is present) and no wasted coolants.

Burnishing is a method to smooth-out the rough surface, therefore the diameter also changes as a result. The inner diameter expands and the outer diameter compresses. In order to finish within the dimensional tolerance, it is necessary to calculate the pre-machining dimension considering this diameter change. Since the variation of the diameter depends on the material, the hardness, and the burnishing value, conducting tests with several samples and determining the best beginning dimension is recommended.

Dimension of the cylindrical surface is changed for hundreds of the millimeter, and even 10 times smaller roughness can be achieved. Roughness of the pre-machined surface has to be within the range Ra = 0,8 to 3,2 □ m.

The surface of the material is during the process smoothed out and become hardened because of the plastic deformation process happening on the surface. The machined surface left with a residual compressive stresses distribution [3].

Oppositely to burnishing, sharp peaks on the contact surface has been left on ground surface.

Work piece surface integrity is in burnishing process ensured due to the compression effect of this surface and its associated cold working.

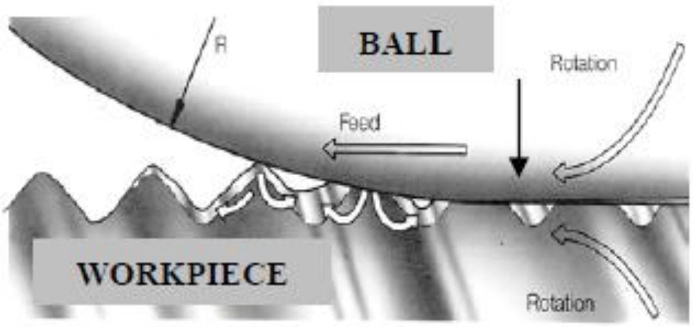
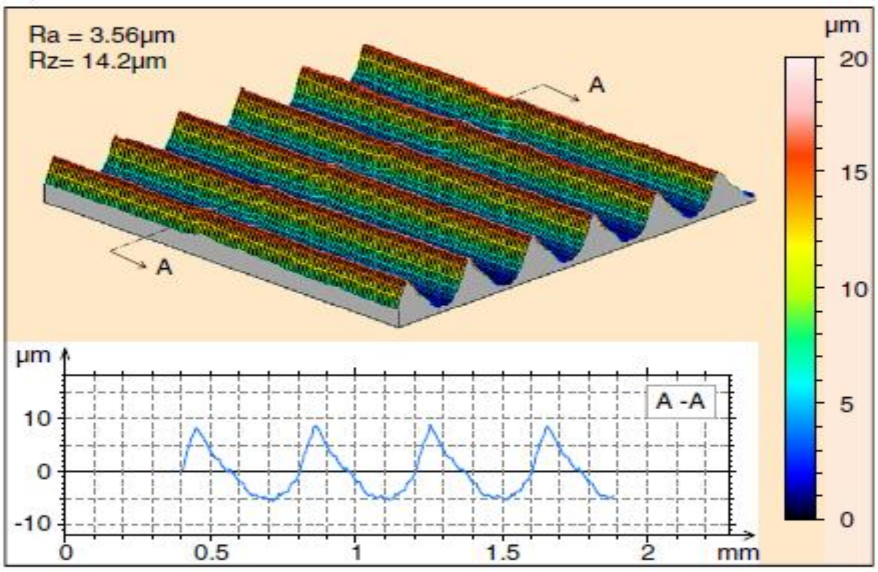


Fig.1. Scheme of roller burnishing process [4]

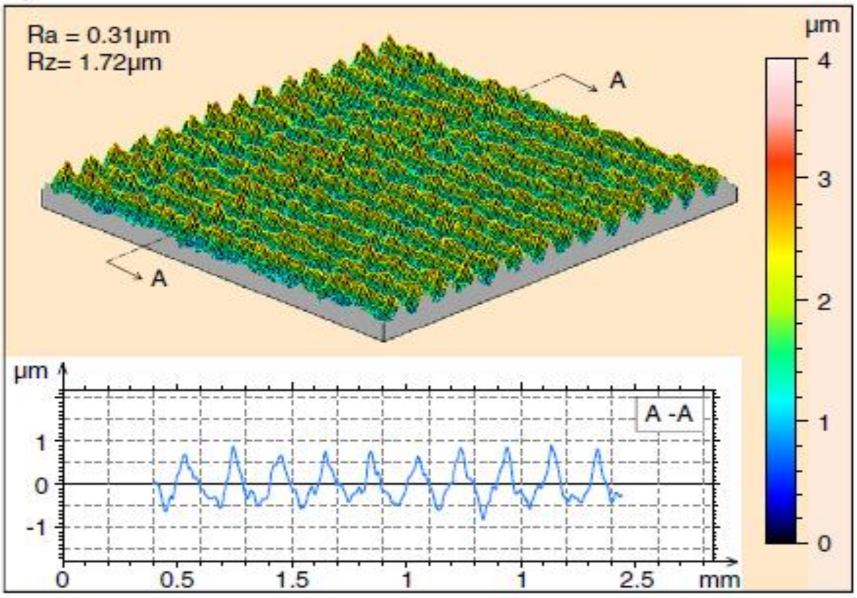
Residual stresses are probably the most important aspect in assessing integrity because of their direct influence on performance in service, compressive residual stresses generally improve component performance and exploatation life because they reduce service (working) tensile stresses and inhibit crack nucleation and propagation.

Roller burnishing produce accurately sized (tolerances within 0.0075 mm or better, depending on material type and other variables) and finished surface (typically Ra is between 0,05 to 0,50 µm) with increased surface hardness (increase of hardness is in the range of 10 HRC) that resists wear.

Fig.2 shows the surface profile after turning (a) and burnishing process (b).



a)



b)

Fig. 2. 3D topographies and roughness profiles (a) after turning operation & (b) after burnishing operation

Other process advantages include: reduced cycle time (parts are processed in seconds), cleaner production (it is cleaner than honing or other abrasive finishing methods) and versatility (it can run on any rotating spindle).

Because the metal must be capable of cold flowing under roll pressure, workpiece hardness normally should not exceed 40 HRC [5].

A literature survey shows that work on the burnishing process has been conducted by many researchers and the process also improves the properties of the parts, e.g. hardness [6–8], surface quality [9,10,11] and increased maximum residual stress in compression.

Roller burnishing tool are very versatile and can be used on most of the machine tools already installed in the shop, like turret lathes, engine lathes, drill machines or other NC machines. Burnishing occurs as an additional phase in machining processes. In grinding, since the abrasive grains are randomly oriented and some are not sharp, there is always some amount of burnishing. This is one reason the grinding is less efficient and generates more heat than turning [12].

One of the most important advantage of this cold process is lowering or even avoid of crack initiation and the crack speed propagation during the use. The influence of roller burnishing within this objective has been analyzed by Gardin et. al. [13] on both crack initiation and propagation. The aim of the work performed is to study roller burnished notched shafts . Roller burnishing permits the fatigue strength of structures to be increased. Crack propagation speed is lowered by the introduction of compressive residual stresses. Crack propagation in round bars has been widely investigated, experimentally and numerically.

El-Axir [14] refers in his study the relationship between residual stress and both burnishing speed and force. For predicting the surface microhardness and roughness of St-37 caused by roller burnishing under lubricated conditions, authors used mathematical models. From a pre-machined roughness of about Ra = 4.5 µm, the specimen could be finished to a roughness of 0.5 µm. It is shown that the spindle speed, burnishing force, burnishing feed and number of passes have the most significant effect on both surface microhardness and surface roughness and there are many interactions between these parameters.

Burnishing process is a very low consumption power process due to the small amount of torque generated for machining. Work-piece fixturing problems are therefore considerably simplified when machine set-ups to be employed in surface finishing with this type tool.

II. Selection Of Burnishing Parameters

The main burnishing parameters are the spindle speed, burnishing force, burnishing feed and number of passes, and these parameters have the most significant effect on both surface microhardness and surface roughness.

The parameters affecting the surface finish are: burnishing force, feed rate, ball material, number of passes, workpiece material, and lubrication [15].

Burnishing tools operate at standard speeds and feeds found in the most conventional shop machines.

El-Tawel & El Axir [16] were used Taguchi technique to identify the effect of burnishing parameters, i.e., burnishing speed, burnishing feed, burnishing force and number of passes, on surface roughness, surface micro-hardness, improvement ratio of surface roughness, and improvement ratio of surface micro-hardness. The analysis of results shows that the dominant influence on cutting outputs have had burnishing force with a contribution of 39.87% for surface roughness and 42.85% for surface micro-hardness followed by burnishing feed, burnishing speed and then by number of passes.

Al-Qawabeha et al [17] refers that hardness increases with increasing of the applied force. Hardness improvements are found to be within 12 and 65 percent what depends on applied burnishing force value [17]. The principle factors which affect the results of both surface microhardness and roughness are the tool chatter that occurs when using a high spindle speed and then the impact between tool and work piece surface. The work piece over hardening and then flaking generally occurs when using a combination of high burnishing force with a high number of passes, and the great deforming action of the tool and the increase of structural homogeneity of the surface layers that occurs when using low burnishing feed.

The recommended spindle speeds that result in high surface microhardness and good surface finish are in the range from 150 to 230 rpm.

Fig. 3. Surface before and after roller burnishing [18]

Before performing of burnishing, surface must be pre-machined on lathe, milling or on drilling machine. Surface profile is shown in fig.3. Surface roughness of pre-machined surface should be in the range Ra = 0,8 do 3,2 μm.

The most appropriate pre-machining formula to be used to obtain the most appropriate surface for the process of roller burnishing is given as follows [18]:

Feed rate per revolution (mm/rev.) = 0.5 x cutter radius (mm)

Burnished surface roughness is increased with increase of the pre-machined surface roughness. The surface roughness can be also increased with increasing the burnishing force.

The surface hardness is based on the pre-machined surface hardness of the materials to be burnished. The surface hardness is directly proportional to applied force. i. e. an increase in force increases the surface hardness [19]. This is due to the increase of depth of roller penetration. The surface hardness increases with increase in the depth of penetration. The increases of the number of tool passes and/or burnishing force also leads to an increase in the surface hardness [20]. S. Thamizhmanii et al [19] refers that surface roughness is improved by high spindle speeds, feed rate and depth of penetration on non-ferrous metals like aluminium, copper and brass materials.

The good results for roughness and microhardness of burnished part can be obtained at the low value of the burnishing feed.

Very good results for surface microhardness appear at a high number of passes whereas for the surface finish good results appear in the range from 3 to 4 passes.

III. Experiment

Roller burnishing tests were in our experiment performed on connecting rod produced of heat treatable high strength steel 34CrMo4 previously forged and with reduced residual stresses with shot peening. Burnishing was performed on radial drilling machine with 280 rev/min and with feed 0,5 mm/rev. Mechanical properties and chemical composition of material are given in tables 1& 2.

The sketch of test sample is shown in fig. 4. Inner cylindrical surface (Ø 195 H6) was burnished. Roughness was measured on six samples and results are given in tables 3 and 4 and for dimension increase in table 5 [21].

Values in table 4 are arithmetical means of three measurements performed on each test sample. Fig. 5 shows roughness profile on test sample nr. 4.

Table 1. Mechanical properties of steel 34CrMo4

Hardness	Strength Rm, MPa	Strength Rp0,2, MPa
HV700	950	750

Table 2. Chemical composition of steel 34CrMo4

C	Si	Mn	P	S	Cr	Mo
0,30 - 0,37	max. 0,40	0,60 - 0,90	max. 0,035	max. 0,030	0,90 - 1,20	0,15 - 0,30

Roughness was measured with device type SURTRONIC with head feeding into the range 1,5-60 mm. Accuracy of head feeding was 0,2 μm/60 mm, referent profile length l_e=0,8 mm and observed length l_m=4mm (DIN 4762). Used filter had 75% filtering. It measured values of Ra, Rt and Rz (DIN 4762, DIN 4768 and ISO 4287/1).
The results of experimental measurement were given in table 4.

Table 3 Mean values of roughness data

	before burnishing	after burnishing
mean value of Ra, □ m	2,52	0,88
mean value of Rz, □ m	13,17	5,66

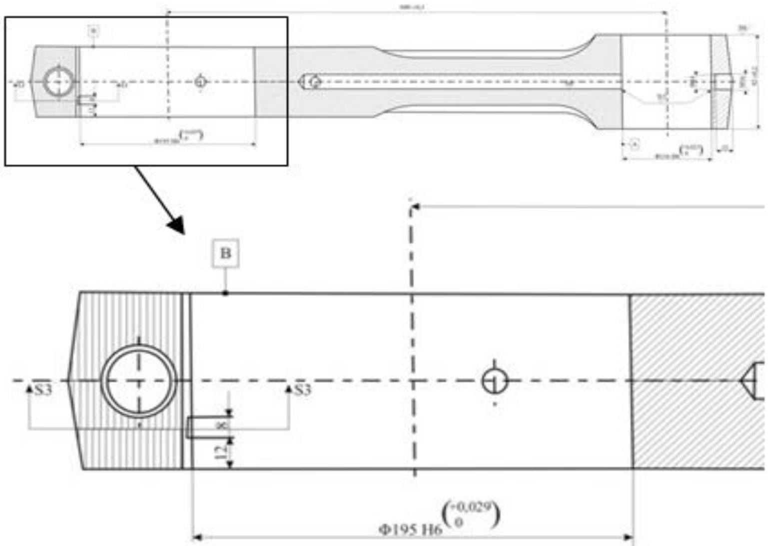


Fig. 4. Test sample

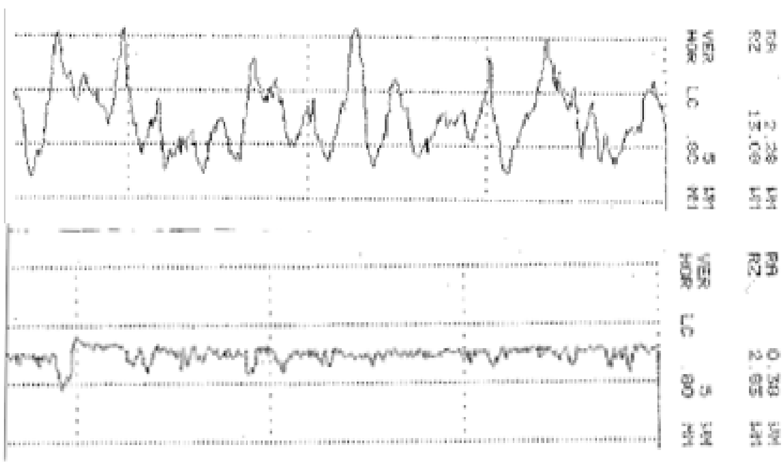


Fig. 5. Surface profile (before and after burnishing)

Table 4 Roughness measuring results

Measur. Nr.	Roughness results, μm			
	Before burn.	After burnishing	Difference	Relative difference in percentage
Ra1, μm	2,72	0,96	-1,76	35,3
Ra2, μm	2,89	1,14	-1,75	39,4
Ra3, μm	2,22	1,1	-1,12	49,5
Ra4, μm	2,28	0,38	-1,9	16,7
Ra5, μm	2,43	0,48	-1,95	19,8
Ra6, μm	2,57	1,2	-1,37	46,7
Rz1, μm	13,5	7,64	-5,86	56,6
Rz2, μm	13,31	6,33	-6,98	47,6
Rz3, μm	12,7	6,41	-6,29	50,5
Rz4, μm	13,08	2,83	-10,25	21,6
Rz5, μm	13,39	3,68	-9,71	27,5
Rz6, μm	13,05	7,05	-6	54,0

Table 5 Results of measurements for deviation from nominal size (□ □ 195 H6)

Measurment Nr	Measuramant results, mm		
	Before burnishing	After burnishing	Difference
a11, mm	0,01	0,02	-0,01
a12, mm	0,01	0,02	-0,01
a13, mm	0,005	0,015	-0,01
a14, mm	0,01	0,015	-0,005
a15, mm	0,01	0,02	-0,01
b11, mm	0,015	0,03	-0,015
b12, mm	0,02	0,03	-0,01
b13, mm	0,005	0,015	-0,01
b14, mm	0,015	0,025	-0,01
b15, mm	0,02	0,03	-0,01
c11, mm	0,015	0,035	-0,02
c12, mm	0,02	0,035	-0,015
c13, mm	0,005	0,015	-0,01
c14, mm	0,015	0,02	-0,005
c15, mm	0,025	0,03	-0,005

IV. Conclusion

This paper presents the results of the research of fine machining conditions with roller burnishing of 34CroMo4 steel. Roller burnishing process of cylindrical surface can be performed on standard performance machine tools. Surface quality improvement is evident and can be visually detect when comparison of two parts before and after burnishing is conducted. The experimental results show that all the smoothing outputs can be detected in all observed regimes. Roughness measuring data for those couples are significantly different. The following conclusions can be drawn from measurements:

1. The high efficiency of burnishing process of steel components with high hardness, was proven
2. The surface roughness of pre-machined material is determined by the contact geometry of cutting tools and work piece, and the most important influence on the burnishing roughness is identified.
3. The roller-burnishing tool employed in our experiment offers a series advantages to the process: pure rolling contact, low coolant consumption, use of the same machine as previous
4. Under the different roller burnishing parameters, the obtained surface roughness is dependant also on work piece hardness and pre-machining conditions.
5. Burnishing process has significant influence on nominal size of diameter (pre-machined diameter).
6. In the case of burnishing surface with very narrow tolerance range, pre-machined diameter hole must be stetted carefully because burnishing process can increase dimension and exceed tolerance field.

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