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The surface texture analysis after sliding burnishing with cylindrical elements

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ABSTRACT

It is widely recognized that the chipless finishing process – burnishing can be used efficaciously to reduce the surface height and increase of the surface hardness of a workpiece. Low surface roughness and good fatigue behaviors of some engineering components are becoming now more important. Main applications are automotive crankshaft, inner and outer bearings races, bogies axles, etc.

Burnishing is a cold – working process in which plastic deformation causes roughness peaks flow towards the valleys, creating a new topography. The aspect of the final surface becomes a combinations of the previously treatment and the effect of burnishing. The main aim of the sliding burnishing is focused on the roughness reduction.

The technology of sliding burnishing with cylindrical elements of diamond composite can be easily used for various types of materials. Application of the new diamond sinter with ceramic bonding phase in the form of Ti_3SiC_2 as the tool material for sliding burnishing will allow to eliminate existing defect of the applied composites. Application of a cylindrical element instead of spherical elements has several advantages. A cylindrical element is easier to manufacture and easier to grind, which reduces the costs during wear of the contact zone tool – workpiece; one can easily change its position by rotation of the tool or change its height in relation to the workpiece. When rotation of the tool is not possible, one we can easily grind it – as the results its life will be extended several dozen times.

1. Introduction

Low surface roughness and good fatigue behaviours in some engineering components are becoming ever more in demand. The burnishing process is an attractive finishing technique which can raise the strength of the surface of a work-pieces as well as reduce its surface height. The increase of surface strength mainly serves in terms of improved fatigue behaviour of work-pieces under dynamic load. In addition, this process transforms tensile residual stresses, present in the surface zone after turning, into compressive residual stresses [1–3]. The ball burnishing is a cold-working process that do not involve material removal, and that produce work hardening of the part surface up to a certain extent. Under certain condition, this process provides a manufacturing alternative to grinding, precision turning and honing operations. The burnishing process is applied to cylindrical work-piece of both, external and internal surfaces, using tools similar to roller bearings. Main applications are automotive crankshafts, inner and outer bearings races, boogies axles, etc. In these cases burnishing process is performed on the same lathes where work-pieces were machined. Many researchers have studied experimentally this process with regard to the effect of burnishing feed, speed and force [1–4]. The residual stresses in the workpiece before and after the burnishing process were also investigated [1,5,6]. The results show that compressive residual stresses in the surface, which are advantageous in improving the functional life of components, can be obtained after the burnishing process. It was found that the number of burnishing tool passes is another important parameter for the surface roughness and hardness of burnishing components [3–5]. The ball diameter of the burnishing tool [7] and the use of different lubricant [8] in this process were studied too.

However, most of these experimental studies were carried on with the use of cemented carbide as the tool material (except Mr. F. Klocke who used ceramic). Little work has been done on the work-pieces with a polycrystalline diamond (PCD) tool. The burnishing tools used were always ball or roller.

2. Experimental work

2.1. Materials of specimens

The $42CrMo_4$ steel was used as the sample material of 32 HRC, its chemical composition is shown in Table 1. The specimens were hardened in temperature 840 °C, reheated 1 h, soaked 30 min, oil cooled, tempered in temperatures 640 °C, reheated 1 h, soaked 1 h and air-cooling. The specimens were machined to be shape of a

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Nomenclature

Sa	arithmetical mean height
St	peak–peak height
Sz	maximum height of scale limited surface
Ssk	surface skewness of the scale limited surface
Sku	kurtosis of the scale limited surface
Sdq	root mean square gradient of the scale limited surface
Ssc	mean summit curvature
Sdr	developed interfacial area ratio of the scale limited surface
Str	texture aspect ratio
Sal	auto-correlation length
Sbi	surface bearing index
Sci	core fluid retention index
Svk	reduced valley depth
Sk	core roughness depth
Spk	reduced summit height

Table 1
Chemical composition of the specimens (wt%).

C	Mn	Si	P	S	Cr	Ni	Cu	Mo
0.4	0.7	0.24	0.01	0.02	0.97	0.08	0.17	0.17

shaft, with diameter ∅ 28 mm and length 150 mm. Using the aloxite disc type 99A60L5VBE at 2250 rpm and 200 rpm for workpiece the medium quality surface roughness texture was achieved. Initial surface roughness was Sa = 0.63 μm.

2.2. Cylindrical PCD burnishing tools

The spherical surfaced burnishing tools were always employed in the past [1,4–7]. From previous research we know how hard and difficult is to fabricate and align the spherical surfaced burnishing tool (especially for the PCD material which has very high hardness). The special cylindrical surface PCD tool was introduced in our research work. It has some advantages compared with the spherical surface. Firstly, the cylinder surface tool is easier to be fabricated and easier to grind, which will decrease the fabrication cost and time. Secondly, its machining height can be adjusted. When some part of the cylindrical surface burnishing tool is worn, we can change the position of burnishing tool so that there is no need to reface the tool frequently as is the case for the spherical surfaced burnishing tool. As a results, the life of our cylindrical PCD tool can be prolonged many times. The time for tool reface and tool change will decrease as well. Thirdly, the burnishing radius can be changed easily by rotating the tool rod, allowing the research relating to burnishing radius to be carried out more easily than with the spherical surfaced burnishing tool [9].

Table 2
Selected properties of diamond composites with 30 wt% of Ti_3SiC_2 as the bonding phase.

Hardness HV1 (GPa)	Apparent density (g/cm^3)	Young modulus (GPa)	Compressive radian strength (MPa)
37.2 ± 5.32	3.58	487.7	253.98

The PCD compacts are usually produced through high pressure–high temperature (HP–HT) sintering. The HP–HT technique always introduces strong structural stresses in compacts, which might result even in their self-fragmentation. The structural stress might be relived only by bonding phase as diamond crystallites undergo any plastic deformation at low temperatures where these stresses are at maximum. A titanium silicon carbide Ti_3SiC_2 was reported to have interesting properties between ceramics and metal. Specifically, Ti_3SiC_2 combines high stiffness characteristics for ceramic materials with some ductile behaviour characteristics for metal. Composites were prepared in the Institute of Advanced Manufacturing Technology in Cracow, from diamond powders of 3–6 μm and 2–4 μm Ti_3SiC_2 average crystallites size. They were sintered using a high pressure apparatus of Bridgman type at 8.0 ± 0.2 GPa and at temperature of 1800 ± 50 °C [10]. Samples were heated in an internal graphite heater of an inside diameter of 4 mm, 6 mm and 8 mm. Selected mechanical properties and characteristics parameters of the prepared compacts are presented in Table 2.

2.3. Experimental procedure

To evaluate the effects of burnishing parameters on some performance characteristics (surface roughness, micro-hardness, the improvement ratio of surface roughness and the improvement ratio of micro-hardness) and to identify the performance characteristics under the optimal burnishing parameters, a specially designed experimental procedure is required. Classical experimental design methods are complex and difficult to use. Additionally, large number of experiments has to be carried out when number of burnishing parameters increases [11,12]. Design of experiments was done using full factorial, statically (3^n) design (Hartley design). The burnishing process parameters considered for this study were burnishing force, diameter of the cylindrical tool and feed. The chosen intervals for the burnishing parameters variations are: burnishing force from 150 N to 250 N; burnishing feed from 0.068 mm/r

Table 3
Experimental design matrix.

Expt. no.	Coded values			Actual values		
	x_1	x_2	x_3	x_1	x_2	x_3
				Force [N]	Feed [mm/r]	Diam. [mm]
1	+	+	+	250	0.102	8
2	+	–	–	250	0.068	4
3	–	+	–	150	0.102	4
4	–	–	+	150	0.068	8
5	+	0	0	250	0.085	6
6	–	0	0	150	0.085	6
7	0	+	0	200	0.102	6
8	0	–	0	200	0.068	6
9	0	0	+	200	0.085	8
10	0	0	–	200	0.085	4
11	0	0	0	200	0.085	6