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SURFACE QUALITY CONTROL OF AL_2O_3 SPECIMENS AFTER LAPPING

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Abstract

The finishing processes are an important perspective to be considered today to meet the goals like parallelism, tolerances, flatness and smooth surface of workpieces. These processes are high-precision abrasive processes. A leading importance in this perspective has the lapping process. It leads to a surface with low roughness and high precision.

This paper reports the results of surface analysis of sealing elements made of oxide ceramic Al_2O_3. Because of elements, application as sealing parts in water valves, high surface quality and flatness is required. To meet those requirements grinding and lapping were execute. The first was realized by elements manufacturer, the second – during experiments. Research was carried out on a plate-lapping machine ABRALAP 380 with a grooved cast-iron lapping plate and three conditioning rings. As abrasive material boron carbide was use. Surface quality was investigated firstly after grinding and then, after lapping. A Hommeltester T8000-R60 profilometer with a resolution of 0.01 μm was used. The surface roughness parameters R_a and R_k were studied in the light of varying lapping parameters, like grains size, lapping pressure, velocity and time. According to literature, those are the most extensively used parameters for describing the surface roughness after finishing processes. Additionally the Abbot Firestone curves were analysed.

Keywords: *lapping, surface quality, ceramic machining*

1. Introduction

The engineering materials can be generally classified as metals, polymers, semiconductors and ceramics. The term ceramics is applied to a range of inorganic materials of widely varying uses. Ceramics in recent years have been sought in many applications due to their improved properties like low density, high fracture toughness, high hardness and wear resistance, good high temperature strength and others. On the negative side, they are far less ductile than metals and tend to fracture immediately when any attempt is made to deform them by mechanical work. This is why machining of ceramic materials is a big challenge and quite expensive affair. Primarily they are finished by abrasive machining processes such as grinding, lapping and polishing.

Lapping is used for achieving ultra-high finishes and close tolerances between mating pieces. It has been found very useful in the manufacture of optical mirrors and lenses, ceramics, hard disk drive, semiconductor wafers, valve seats, ball bearings, and many more parts. Lapping process on ceramics usually produces the surface finish as about 1-0.01 μm of R_a. The topographical structure resulting from lapping is very advantageous in sliding joints, because of the high ability of lubricant retention, as well as in non-sliding joints because of the high load-carrying ability. It is used in a wide range of applications and industries. Typical examples of the processed components are pump parts, transmission equipment, cutting tools, hydraulic and pneumatic, aerospace parts, inspections equipment, stamping and forging [1, 3, 4, 6-8].

In accordance with their chemical composition, the technical ceramic materials can be classified into several important groups:

1. Oxide ceramics: the materials in this group consist 90% of single phase and single component metal oxides. These materials are no or low glass phase. Aluminium oxide (Al_2O_3), magnesium oxide (MgO), zirconium oxide (ZrO), aluminium titanate (AT), and piezoelectric ceramic (PZT) belong to this category. The main oxide materials are alumina (in spark plugs, substrates and wear applications), zirconia (in oxygen sensors, wear applications and thermal barrier coatings), titanates and ferrites.
2. Silicate ceramics: these materials combine the basic electrical, mechanical and thermal properties of technical ceramics. Amongst these kind of ceramics are technical porcelain, steatite, cordierite and mullite-ceramic.
3. Non-oxide ceramics: ceramic materials such as compounds of silicon and aluminium with nitrogen or carbon fit in this category. Generally, they have covalent bonding that provides them with very good mechanical properties. Carbide ceramics and nitride ceramics are examples of non-oxide ceramic materials. Carbides (mainly silicon carbide SiC ad boron carbide BC) are used in wear applications whereas nitrides (primarily silicon nitride Si_3N_4 and Sialon) are used in wear applications and cutting tools [6, 7].

2. Ceramics lapping

The lapping process leads to a surface with low roughness and high precision. The topographical structure resulting from lapping is very advantageous in sliding joints, because of the high ability of lubricant retention, as well as in non-sliding joints because of the high load-carrying ability [1, 2, 4, 6].

Lapping is a machining process that utilises abrasives such as diamond, silicon carbide, boron carbide and aluminium oxide for stock removal and finishing. The abrasive grains in lapping are usually mixed with a liquid to form a slurry. This slurry is placed between a hard rotating wheel, called the lapping plate, and the workpiece. A schematic diagram of the process is shown (Fig. 1).

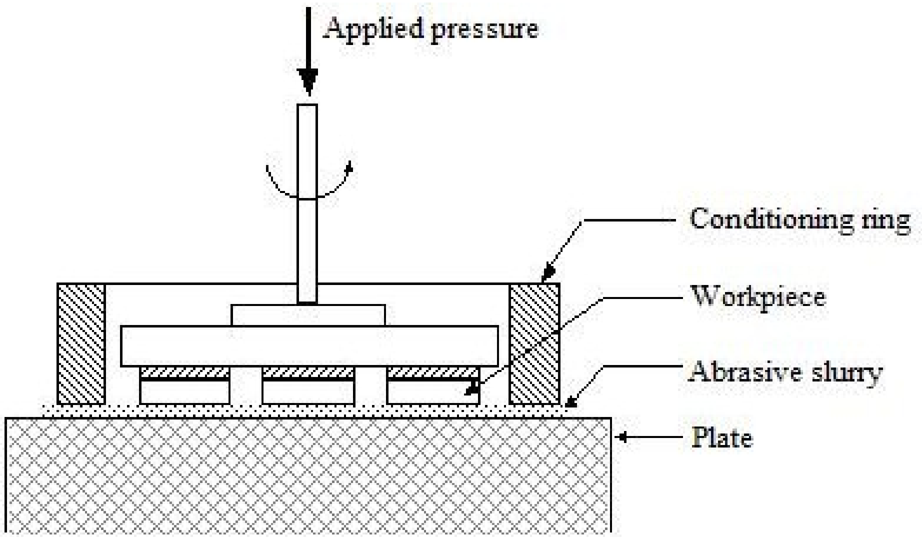

Fig. 1. Schematic diagram of lapping process [1]

The grains are the cutting tools during lapping. There are two models to explain the predominant mechanism for material removal (Fig. 2). In the first one, the grains roll in the working gap. The workpiece material is deformed elastically and plastically by the indentation of corner points until small particles break off due to material fatigue. In the second mechanism, lapping grains are embedded in the lapping plate and material is removed by chip formation. Which mechanism is dominant depends on workpiece material properties and structure [5, 7, 9, 10].

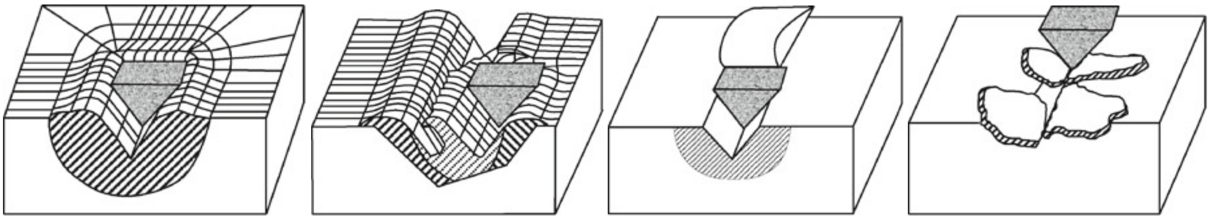

Fig. 2. Different interactions between abrasive and workpiece surface during lapping [10]

Micro ploughing shows that the polishing grain after getting in contact with the surface pushes the loosened material along, which finally agglomerates at the sides of the groove. Ideally, no material is removed with the micro ploughing. However, if more and more polishing grains get to the same area, the material is repeatedly pushed to the sides, until it breaks out. This phenomenon is called micro-fatigue. During the micro-cutting the grain gets deep into the material and due to the maximum forming ability of the material a chip is formed, which matches in the best case to the groove. Micro cracking is the result of high tensions, which are put into the material from the abrasive particles. This mechanism exists at brittle materials (e.g. ceramics), while micro cutting and micro ploughing mainly appear at ductile materials (e.g. steel) [3, 5, 7, 10].

Improvements in machining tolerances have enabled researchers to expose the ductile material removal of brittle materials. Under certain controlled conditions, it is possible to machine brittle materials like ceramics using single- or multi-point diamond tools so that the material is removed by plastic flow, leasing a crack-free surface. This process is called ductile regime machining.

Abrasive processes have a large number of parameters that can be varied in order to obtain the desired process output. The lapping process is influenced by load, rotation of the lapping plate, material of the lapping plate, lapping time, type of slurry used, grain size of the abrasive, flow rate, slurry concentration, etc. Tough many years of studies, there is still a lack of a systematic understanding of the process, fine-tuning or developing processes for a new product has always been an empirical process with success dependent upon the skill of the machine operator or engineer. Thus, the operator needs to stop the process continually to measure the results to guarantee that the workpieces will reach the required tolerances.

Fundamentally, benefits and effects of the lapping process must be studied, shedding light on the scientific basis that transforms lapping from art to engineering [1, 2, 4-6].

3. Experimental setup

The experiments were carried out on a plate-lapping machine ABRALAP 380 with a grooved cast-iron lapping plate and three conditioning rings (Fig. 3). The machine kinematics allows adjusting directly the wheel velocity in range up to 65 rev/min. It is also equipped with a 4-channel tachometer built with optical reflectance sensors SCOO-1002P and a programmable tachometer 7760 Trumeter Company that enables to read the value of rings and plate rotational speed.

The workpieces were valve sealing parts (Fig. 4) made of oxide ceramic Al_2O_3 (95%), one of the most commonly used ceramic materials. It is used for machining tools, mechanical sealing elements, bearings, as abrasive material or electrical and thermal insulator [4, 6].

Elements were set in rings with used of separators, as depicted in Fig. 5.

Because of elements, application as sealing parts in water valves, high surface quality and flatness is required. Those can be received by carefully planned machining, especially finishing processes. In this case, grinding and lapping were execute. The first was realised by elements manufacturer, the second – during experiments.

Surface quality was investigated firstly after grinding and then, after lapping. A Hommeltester T8000-R60 profilometer (Fig. 6) with a resolution of 0.01 μm was used. During testing the stylus radius was 2 μm.

Fig. 3. One-side lapping machine ABRALAP 380

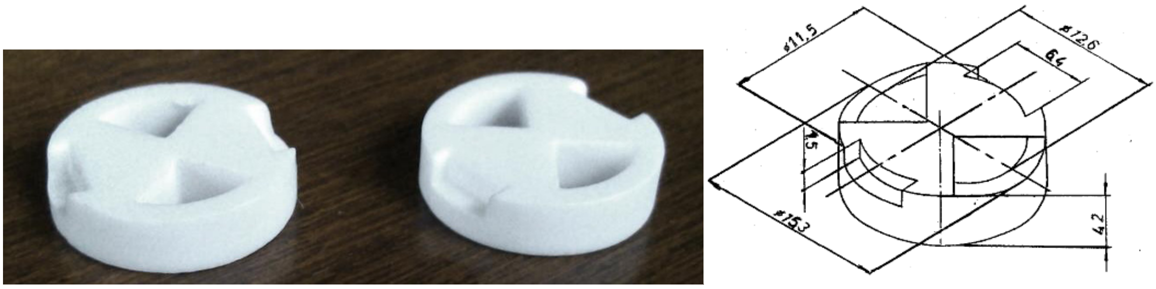

Fig. 4. Ceramic elements being lapped

Fig. 5. Sample arrangement in conditioning rings

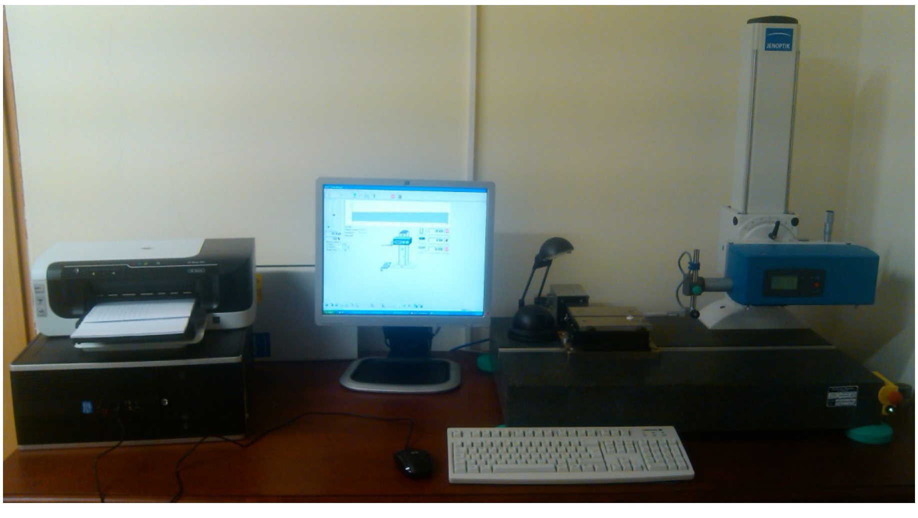

Fig. 6. Hommeltester T8000-R60 profilometer

4. Test procedure and results

Aluminium oxide is one of the hardest materials known. Researchers generally use for that material slurry composed of diamond grains mixed with liquid or paste carrier. Due to diamond price, this is expensive solution, especially when considering continuous supplying.

This paper reports the observations of Al_2O_3 lapping process results received with use of different abrasive material, cheaper than diamond – boron carbide. Specifically, the surface roughness parameters like R_a and R_k are studied in the light of varying lapping parameters, like grains size, lapping pressure, velocity and time. According to literature R_a and R_k are the most extensively used parameters for describing the surface roughness after finishing processes [1, 3, 6].

Measurements were conducted with the same settings. Since expected R_a value was between 0.1 and 2 μm, the sampling length was adjusted at 0.8 mm. During testing, there was no need to correct it.

After grinding, the elements were being lapped during 15 and 20 minutes. As mentioned, boron carbide was used as abrasive material. It was mixed with kerosene and machine oil with grain concentration equal 0.25. Three grains numbers were used: F400/17, F800/6.5, and F1200/3.

For each applied set of lapping parameters, surface quality was examined on 10 samples in three different directions. In this way, 30 values of R_a were obtained. After statistical analysis mean values were calculated. Tab. 1 presents the results.

Tab. 1. Experiments results

No.	Micrograin size	p [MPa]	v [m/min]	R_a		KR_a	
				t = 15 [min]	t = 20 [min]	t = 15 [min]	t = 20 [min]
1.	F1200	0.038	49	0.44	**0.42**	31	34
2.	F800	0.038	49	0.52	0.48	23	29
3.	F400	0.038	49	0.72	0.69	3	10
4.	F400	0.025	49	0.77	0.72	4	13
5.	F400	0.038	38	0.75	0.70	3	8
6.	F400	0.051	49	0.69	0.66	2	8
7.	F400	0.038	27	0.76	**0.74**	2	7
8.	F400	0.030	38	0.76	**0.74**	2	8
9.	F400	0.051	27	0.75	0.73	1	5

Additionally Abbot Firestone curve and R_k parameter was examined. Some results are presented in Fig. 9-11.

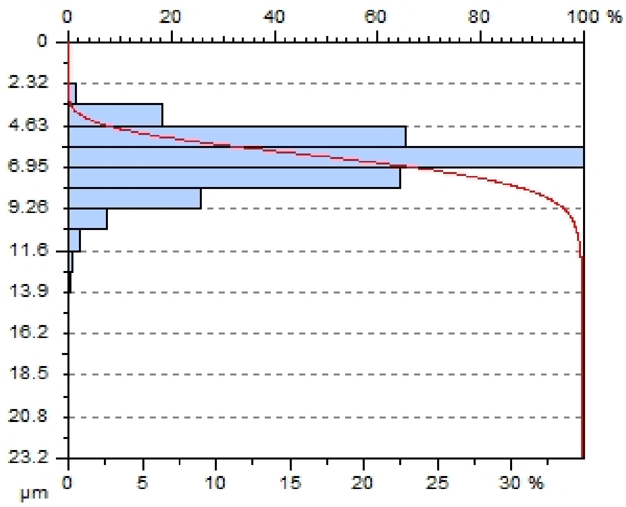

Fig. 9. Abbot Firestone curve obtained after grinding and before lapping; R_k = 2.42 µm

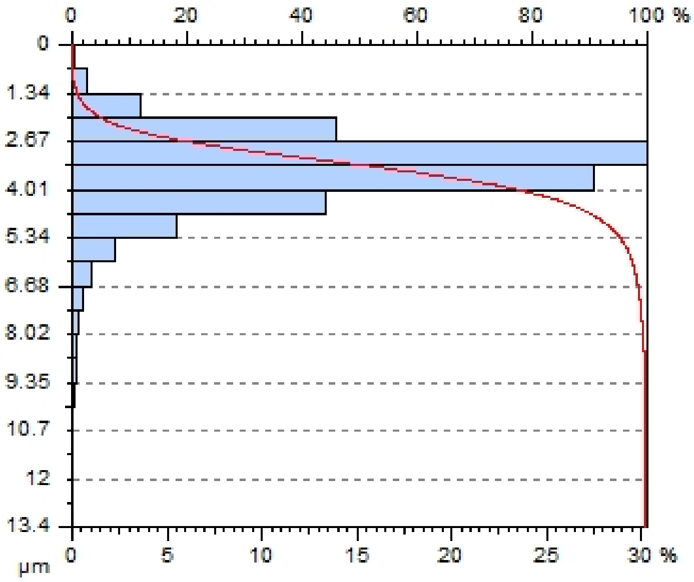

Fig. 10. Abbot Firestone curve obtained after lapping p = 0.038 MPa, v = 49 m/min, F400; R_k = 1.83 µm

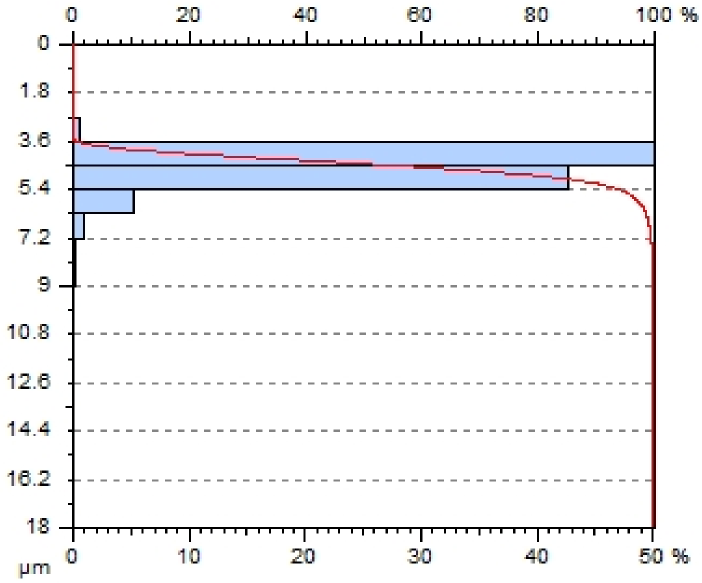

Fig. 11. Abbot Firestone curve obtained after lapping p = 0.038 MPa, v = 49 m/min, F1200; R_k = 1.15 µm

5. Conclusions

The lowest and the highest R_a values are bolded in table 1. They were obtained during lapping with smallest (F1200) and the biggest (F400) grains respectively. These results determine their applications for roughing (F400) and finishing (F1200) lapping. Worse surface quality, described by R_a parameter, can be explained by the increase of single particle load. When grain concentration and lapping pressure are constant, the number of active grains decreases with their dimension growth. As a consequence of higher load, single grain deeper penetrates the workpiece surface.

When analysing R_a values obtained for the same grain number it can be seen that surface with highest quality (value underline in table 1) was generated when p = 0.051 MPa, and v = 49 m/min. Presented Abbot Firestone curves and R_k values confirm that surface load capacity grows with surface quality improve.

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