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Al_2O_3 SEALING ELEMENTS LAPPING

Justyna Molenda

Gdynia Maritime University
Faculty of Marine Engineering
Morska Street 81-87, 81-225 Gdynia, Poland
tel.: +48 58 6901549, fax: +48 58 6901399
e-mail: jmolenda@am.gdynia.pl

Adam Barylski

Gdansk University of Technology
Faculty of Mechanical Engineering
G. Narutowicza Street 11/12, 80-233 Gdansk, Poland
tel.: +48 58 3471982, fax: +48 58 3471450
e-mail:abarylsk@pg.gda.pl

Abstract

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.

Aluminium oxide is one of the hardest materials known. Its high hardness promotes a series of applications in mechanical engineering, such as bearings and seals. During research Al_2O_3 *sealing elements were lapping. The main goal was to check the results of machining for different process parameters. The experiments were conduct during flat lapping with use of ABRALAP 380 lapping machine. The lapping machine executory system consists of three conditioning rings. The process results were surface roughness* R_a *and material removal rate.*

Keywords: *lapping, ceramic materials,* Al_2O_3*, lapped surface roughness*

1. Introduction

The engineering materials can be generally classified as metals, polymers, semiconductors, and ceramics. Ceramics are known as solid compounds that are formed by the application of heat, and sometimes heat and pressure, comprising at least one metal and non-metallic elemental solid or a non-metal, a combination of at least two non-metallic elemental solids, or a combination of at least two non-metallic elemental solids and a non-metal.

Ceramic materials have become increasingly important in today’s world of materials even though they are difficult and expensive to machine due to their high hardness and brittle nature. The successful application of ceramics depends largely on their special properties (mechanical, chemical, optical, and magnetic) that require their use in almost every production line: health, energy, transportation, agriculture, information/communication, civil construction, automotive industry, and defence [5, 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 piezoelectrical 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 kinds of ceramics are technical porcelain, steatite, cordierite, and mullite-ceramic.
3. Nonoxide 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 f nonoxide 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 [5, 8].

2. Ceramic materials machining

Because of their hardness and brittle nature, ceramics cannot be successfully machined with the type of cutting tools used for metals; the tools need to have a higher hardness than the ceramic being machined and must be of a configuration that does not cause surface fracture and subsurface damage of the part. Ceramic materials can be detached by mechanical, thermal, or chemical action. Mechanical approaches are used most frequently and they can be divided into three big categories:

– mounted-abrasive machining,
– free-abrasive machining,
– impact machining.

The first refers to small abrasive particles (e.g., Al_2O_3, SiC, Si_3N_4, diamond) bonded or immersed in a softer matrix (rubber, organic resin, glass, or a crystalline ceramic composition softer than the abrasive grains). The second category consists of the use of loose abrasives and is typically used for achieving the final surface finish and dimensional accuracy. Impact machining is generally performed by accelerating loose abrasive particles to high velocity such that they cause local impact damage when they hit the part to be machined. Examples of impact abrasive machining include sandblasting, water-jet machining, and ultrasonic machining [5, 8].

Modern-day products are characterised by high-precision components. Ceramic materials have been widely adapted as functional materials as well as structural materials in various industrial fields and their application to precision parts also increased. However, the high dimensional accuracy and good surface quality required for precision parts are not necessarily obtained by the conventional forming and sintering process of ceramic powders. Thus, finishing processes of the ceramics after forming and sintering are an important perspective to be considered to meet the goals like parallelism, tolerances, flatness, and smooth surface. These processes are high-precision abrasive processes used to generate surfaces of desired characteristics such as geometry, form, tolerances, surface integrity, and roughness characteristics. Abrasive finishing processes are used in a wide range of material applications and industries. Grinding, lapping, and polishing have a leading importance in this perspective [5, 8].

To obtain closer tolerances, ceramic materials demand a very highly sophisticated equipment and skilled labour, which will obviously lead to high manufacturing costs. Surface and subsurface damage (after grinding process) is one of the problems that is seriously affecting the performance of ceramic components. Hence, to obtain all necessary machining qualities without much investment, design engineers have suggested the lapping process, used especially after grinding.

The relative speed in lapping are much lower than in grinding. Consequently, the concentration of energy in the contact area is much lower.

Polishing usually is used after lapping. Lapping tends to decrease the original surface roughness but its main purpose is to remove material and modify the shape, whereas polishing implies better finish with little attention for form accuracy [5, 8].

3. 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 [1-3, 5, 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 is 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).

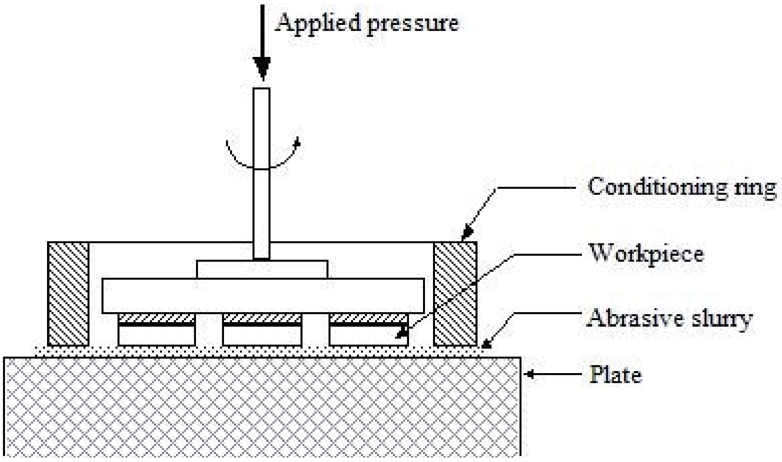

Fig. 1. Schematic diagram of lapping process [3]

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 elastically and plastically deformed 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 [3-5, 7].

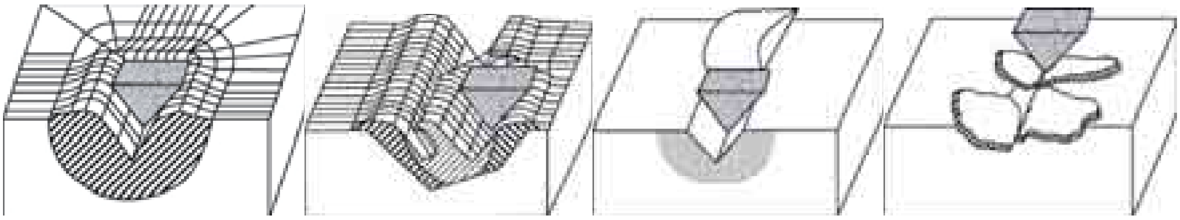

Fig. 2. Different interactions between abrasive and workpiece surface during lapping [4]

Microploughing 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. But if more and more polishing grains get to the same area, the material is again and again pushed to the sides, until it breaks out. This phenomena is called microfatigue. During the microcutting 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. Microcracking 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 microcutting and microploughing mainly appear at ductile materials (e.g. steel) [4, 5, 7, 8].

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 [1-3, 6, 8].

4. Test procedure

Aluminium oxide is one of the hardest materials known. Its high hardness promotes a series of applications in mechanical engineering, such as bearings and seals. 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 material removal rate (MRR) and surface characteristic are studied in the light of varying lapping parameters, like grains size, lapping pressure, and time. Each workpiece was weighed before and after lapping using a precision weighing scale precise to within 1×10^{-4} g to determine the material removal rate in gram per minute. In addition, the initial thickness of each sample was determined with a digital micrometer precise to within 1×10^{-3} mm. The difference between the initial thickness and final thickness was used to obtain the material removal rate in mm per minute. Equation (1) was used to calculate the MRR [1]:

$$\mathrm{MRR} = \frac{\Delta \mathrm{W}}{\Delta \mathrm{T}} = \frac{W_1 - W_2}{T_2 - T_1}\, or \,\frac{\Delta H}{\Delta T} = \frac{H_1 - H_2}{T_2 - T_1}, \tag{1}$$

where:
W_1 – initial weight of sample,
W_2 – final weight of sample,
T_1 – time at onset of lapping,
T_2 – time at the end of lapping,
H_1 – initial thickness of sample,
H_2 – final thickness of sample.

A Hommeltester T8000-R60 profilometer with a resolution of 0.01 μm was used to determine the surface roughness before and after lapping. The radius of the stylus used was 2 μm.

Percentage R_a improvement was determined using [1]:

$$\Delta \mathrm{R_a} = \frac{(\text{Average initial } \mathrm{R_a} - \text{Average final } \mathrm{R_a}) \times 100}{\text{Average initial } \mathrm{R_a}}. \tag{2}$$

The experiments were carried out on a one-plate lapping machine ABRALAP 380 with a grooved cast-iron lapping plate and three conditioning rings (Fig. 3). The machine kinematics allows for direct adjusting wheel velocity in range up to 64 rev/min. It is also equipped with a four-channel tachometer built with optical reflectance sensors SCOO-1002P, and a programmable tachometer 7760 Trumeter Company, which enables to read the value of rings and plate rotational speed. Experiments were carried out with an angular speed of the lapping plate set at 64 RPM.

Fig. 3. One-plate lapping machine ABRALAP 380

Workpieces were commercially available valve sealing elements placed in the conditioning rings with use of workholdings (Fig. 4). Samples were lapped during 15 and 20 minutes.

Fig. 4. Samples location in the conditioning ring

ABRALAP 380 is also equipped with liquid slurry dispensing system, enabling constant supplying of fresh abrasive grains into the work zone. The supply of the slurry was maintained at $19 \cdot 10^{-8}$ m^3/s. It was composed of boron carbide grains mixed with kerosene and machine oil. There were three abrasive grains sizes used: F400/17, F800/6.5, and F1200/3.

Abrasive concentration, which is defined as:

$$m = \frac{\text{Mass of the abrasive}}{\text{Mass of the lapping liquid}}, \tag{3}$$

was m = 0.25.

The lapping pressure was provided by dead weights. During experiments two values were executed: 0.025 and 0.04 MPa.

5. Test results

Figures 5-9. presents some results obtained during the tests. There are presented dependencies of MRR, in mg/min and µm/min, and surface roughness parameter R_a on abrasive grains size, lapping time, and lapping pressure.

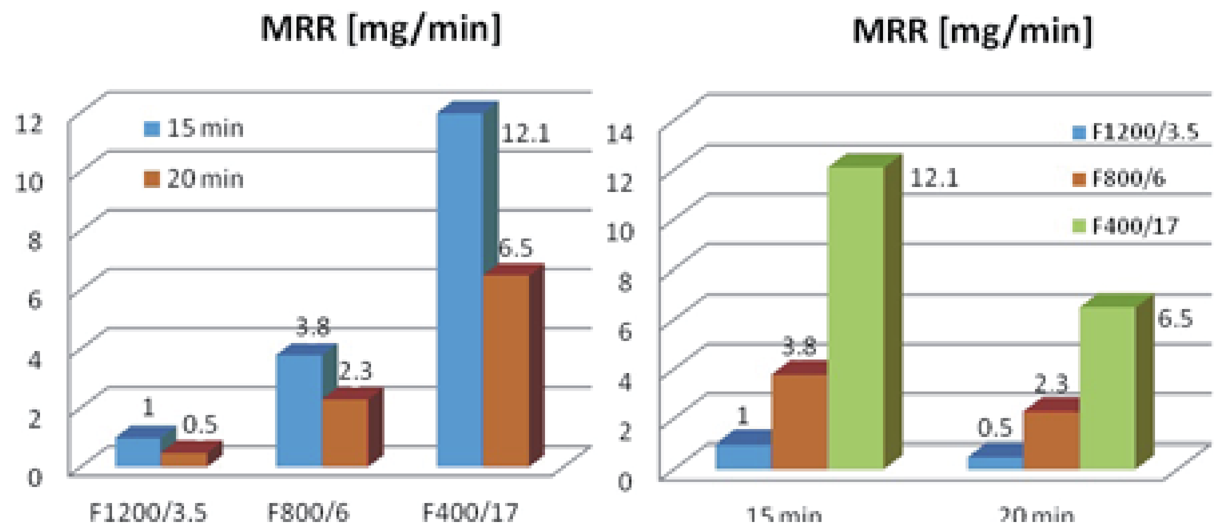

Fig. 5. Test results of MRR in mg/min depending on grains size and lapping time

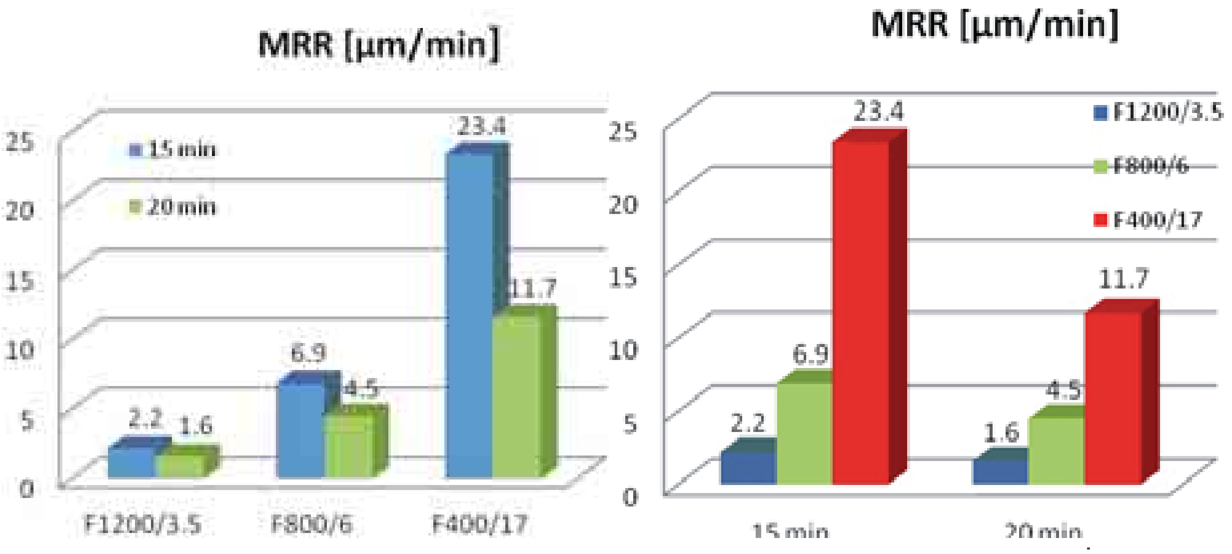

Fig. 6. Test results of MRR in µm/min depending on grains size and lapping time

It can be seen that MRR per minute is in all cases lower for longer (20 min) lapping time. In fact, the total material removal rate is bigger for 20 minutes lapping than for 15. Only after dividing it by machining time, which is bigger for 20 minutes, it get smaller.

Figure 7 shows that MRR strongly depends on abrasive grains size. To get high quality surface, lapping process should be divided for rough and finishing step. For each step other grains size ought to be used. The smaller grains utilised, the better surface roughness after lapping.

During the experiments the dependence of MRR on lapping pressure was investigated. According to obtained data (Fig. 8 and 9) there is no such strong relationship as before. It is not consistent with expectations based on earlier studies. All parameters were chosen after available materials analysis. The highest pressure value was 1 MPa, the lowest 0,01 MPa. Thus, the values chosen were in range.

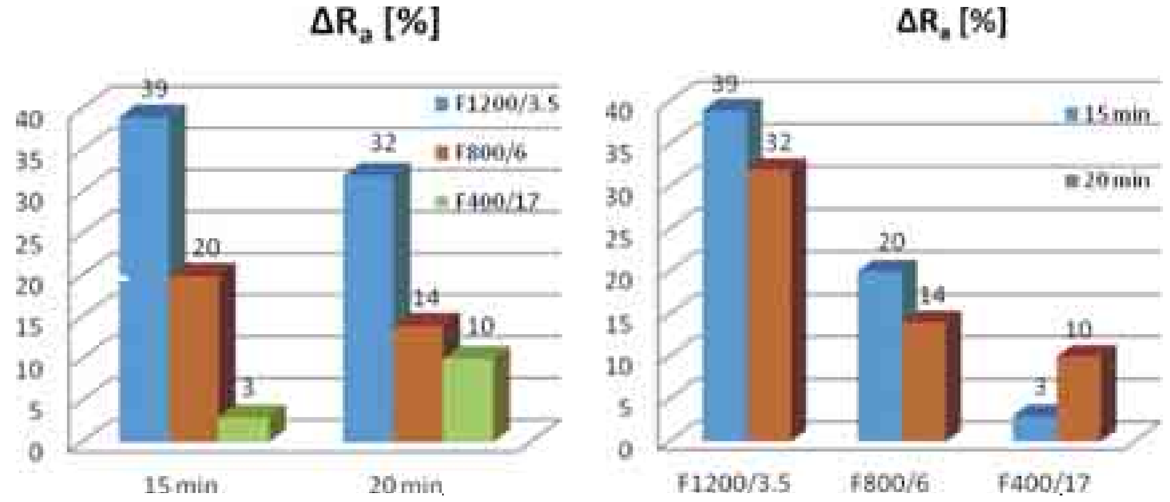

Fig. 7. Test results of R_a depending on grains size and lapping time

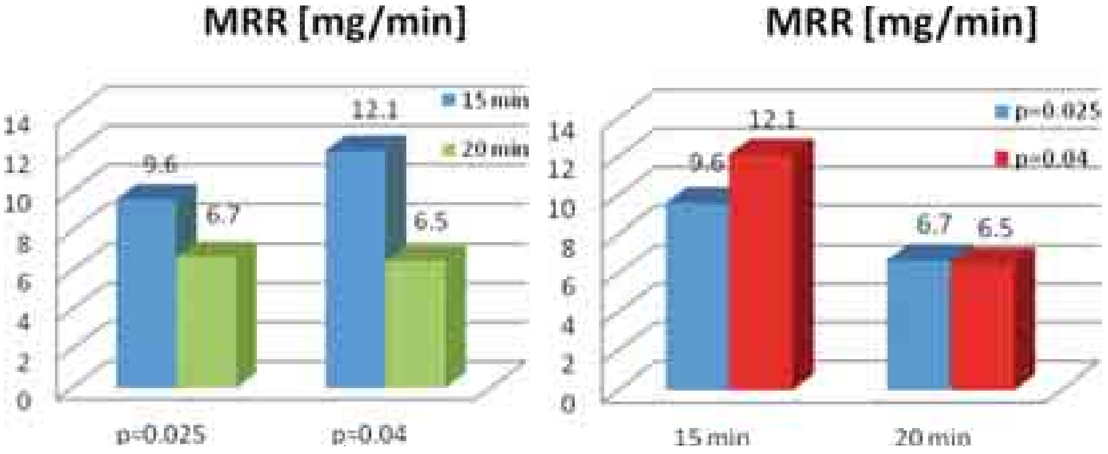

Fig. 8. Test results of MRR in mg/min depending on lapping pressure

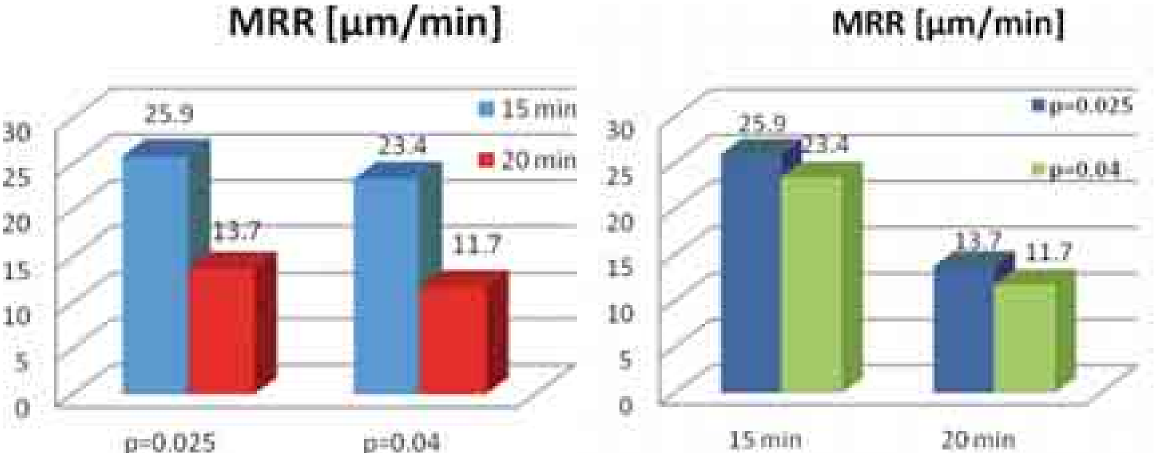

Fig. 9. Test results of MRR in µm/min depending on lapping pressure

6. Conclusions

Lapping process is commonly used for ultra-precision machining of ceramic materials. This group includes widely used aluminium oxide (Al_2O_3). Typical applications are sealing and bearings elements. Most papers authors use for Al_2O_3 lapping diamond as abrasive. Here instead authors propose boron carbide. Because of the lack of lapping process complex model there is a need to empirically find optimal parameters. The results are partially presented in this paper. It can be seen that material removal rate and surface roughness strongly depend on lapping time and abrasive grains size. Others parameters influence will be also studied and the results will be presented in future works.

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