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BEARING CAPACITY OF THE SURFACE AFTER MACHINING WITH MINIMUM COOLING AND LUBRICATION

NOŚNOŚĆ POWIERZCHNI PO OBRÓBCE Z MINIMALNYM CHŁODZENIEM I SMAROWANIEM

Key words: bearing capacity, cooling and lubrication, condition of the geometrical surface structure.

Abstract The paper discusses the problem of surface bearing capacity and the parameters that characterize it in the context of the assessment of functional features. The result of the tests that are concerning the verification of the influence of minimal cooling and lubrication during processing on the constituted geometric surface structure described by the load capacity parameters are presented. On the basis of the obtained results, it was found that the minimum cooling and lubrication does not have a negative impact on the functional features, and they are even more advantageous than with the conventional processing fluid.

Słowa kluczowe: nośność powierzchni, chłodzenie i smarowanie, stan struktury geometrycznej powierzchni.

Streszczenie W pracy omówiono zagadnienie nośności powierzchni i parametry, które ją charakteryzują w kontekście oceny cech użytkowych. Przedstawiono wyniki badań dotyczących weryfikacji wpływu minimalnego chłodzenia i smarowania podczas obróbki na konstytuowaną strukturę geometryczną powierzchni opisaną parametrami nośności. Na podstawie uzyskanych wyników stwierdzono, że minimalne chłodzenie i smarowanie nie ma negatywnego wpływu na cechy użytkowe, a nawet są one korzystniejsze niż przy konwencjonalnym doprowadzeniu cieczy obróbkowej.

INTRODUCTION

The surface layer of cooperating machine elements, which is the result of operations and technological process procedures, determines the functional features of kinematic pair elements, e.g., wear resistance, movement resistance, and fatigue strength [**L. 10, 11, 13, 16, 17, 24**].

This is due to the fact that the negative impact of external factors leads to changes in the surface layer, which consequently leads to wear and damage. For this reason, it is important to determine the impact of conditions and parameters of the technological process on the surface layer condition. The condition of the surface layer and the related properties are mostly determined by the stereometric surface structure features, which is more often referred as the geometrical surface structure. Due to this fact, the description of the relationship between the surface layer condition and the course of the wear process, the values describing the geometric surface structure, e.g., surface roughness and surface directivity, are assumed [**L. 4, 8, 9, 19, 21**].

In this paper, characteristics of the surface bearing capacity were adopted to assess the condition of the geometrical surface structure. The bearing capacity curves next to the amplitude parameters, distance parameters, or hybrid roughness are important supplement for assessment the geometrical surface structure features. The bearing capacity parameters were determined for surfaces treated with grinding in various cooling and lubrication conditions, which was a set of independent variables.

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THE SURFACE BEARING CAPACITY AND ITS TRIBOLOGICAL FEATURES

Among the determined bearing capacity characteristics of the geometrical surface structure for the assessment of surface properties, the material ratio curve profile is most often accepted, which is the bearing capacity curve (the distribution of the relative length of the bearing capacity). It is due to the fact that, from its course, one might obtain some information about the shape of the profile, even about its largest valleys. This curve, also referred as the Abbott-Firestone diagram and denoted by AFC, describes the distribution of the material in the profile [**L. 1, 23**]. Based on the course of this curve, conclusions are drawn by regarding the tribological features of the considered elements.

It is possible to interpret the properties of a profile by paying special attention to the usability functions of the geometric surface structure [**L. 1, 22**].

Basic parameters that we receive from the bearing capacity curve of the profile that simultaniously characterize this curve are the following [**L. 1, 3, 23**]:

- *Rk* – roughness core profile, μm,
- *Rpk* – reduced peak height, μm,
- *Rvk* – reduced valley depth, μm,
- Mr_1 – bearing share peaks, %,
- Mr_2 – bearing share valleys, %.

A graphical interpretation of these parameters is shown in **Figure 1**.

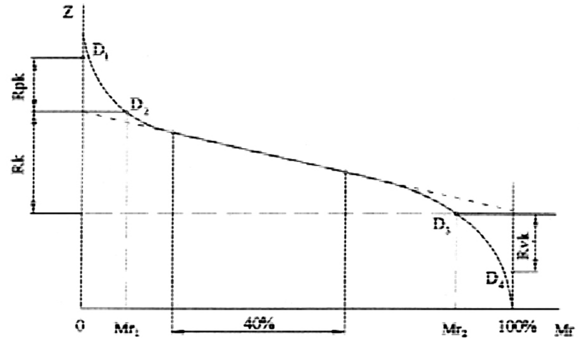

Fig. 1. A typical graph of the bearing capacity curve [L. 25]

Rys. 1. Typowy wykres krzywej nośności powierzchni [**L. 25**]

From the bearing capacity curve, we can determine the parameters which, in turn, describe the functional surface retention over cooperation. The group of these parameters contain the following basic parameters: *Rk, Rpk,* and *Rvk* [**L. 28**].

The *Rk* parameter is the depth of the roughness core profile, and it means a part of the profile excluding distinctive peaks and deep valleys.

Reduced peak height *Rpk* is the average height, protruding above the roughness core profile. Therefore, this parameter is of average height of the upper part of the surface profile. It determines the preservation of geometrical surface structure while elements are lapping. Low values of the *Rpk* parameter indicate the high wear resistance of the geometrical surface structure. Whereas, the *Rvk* parameter called "reduced valley depth" is the average depth of these valleys occurring beneath the roughness core profile. Therefore, it is the average depth of the lowest surface profile part. Based on this parameter value, the ability to keep the lubricating film medium by geometrical surface structure can be deduced. Surfaces that require proper lubrication should have high *Rvk* values.

MACHINING CONDITIONS AND THE SHAPED GEOMETRIC SURFACE STRUCTURE

The shape of the tool, the kinematics of relative movements of the tool, the workpiece, and the environment in which the processing takes place are determined by the geometric surface structure shaped in the technological process, which depends on the type of processing.

The harmful effects of many technological processes on the environment imply that the maximum or total elimination of these effects is desired. In the case of machining, which is the dominant operation in engineering industry [**L. 5, 7**], the cooling agent is a commonly used factor with the greatest ecological significance. Most scientific research concerning dry or minimal cooling lubrication with the conventional use of machining fluids in working conditions focuses on tool nose wear and determine the advantageous processing conditions with respect to the precision of workmanship [**L. 6, 7, 15**]. However, only a few are scientific works over the effects of the elimination or limiting quantity of cooling agent in terms of received functional features are mainly determined by the geometric surface structure. During the machining processes, the most cooling agents and their potential foulants impact the geometric surface structure shape. They also have an influence on the following factors: the durability of the cutting tools noses, the dimension and form accuracy of machining surfaces of the object, and the effect on the shaping process and phenomena occurring in the cutting zone [**L. 7, 26**].

In recent years, despite many process advantages resulting from use cooling agents, they are more and more often considered as an undesirable factor in the cutting process. This is based not only on economic reasons (it is estimated that processing fluids constitute 16.8% of total manufacturing costs), but also due to ecological aspects and the need to adapt to increasingly stringent regulations related to environmental protection, health, and safety. The storage and utilization of used cutting fluids are also potential threats to the natural environment [**L. 6, 12**].

One of the ways to reduce the amount of cooling agent in the cutting process is machining with the minimum quantity lubrication (MQL). The essence of it consists of supplying the lowest possible quantity of machining fluid (usually less than 50 ml·h^{-1}) as close as possible to the point of contact of the tool nose with processed material. This method is increasingly used in industrial practice, which is fostered by the development of tool materials and their coatings, increasing the strength of the cutting edge in difficult cutting conditions and new construction solutions of machine tools and equipment [**L. 2, 6, 15**].

OWN TESTS

The purpose and research methodology

The aim of the conducted tests was to assess the impact of cooling and lubrication conditions during the processing on the surface structure features determined by the parameters of its bearing capacity in the aspect of tribological features. The evaluation of the impact of the lack or absence of cooling and lubrication conditions on the geometric surface structure was made on the basis of the surface structure analysis after grinding as the dominant finishing processing with the following basic independent variables:

- Processing with conventional cooling and 5% emulsion lubrication at an expense of 4 l·min^{-1} (E),
- Processing with minimal cooling and oil mist lubrication on the ARTEsol ULTRA EP (MQL) fluid base,
- Processing with minimal cooling and oil mist lubrication based on ARTEsol ULTRA EP (MQL) with the addition 50 g of copper (MQL + Cu).

In order to verify the impact of the quantity of cutting fluid on the bearing capacity surface parameters (*Rk*, *Rpk*, and *Rvk*), machining with conventional cooling and lubrication and with the minimal flow capacity of cutting fluid was accepted as the basic processing variants. Additionally, in the case of machining with minimal cooling and lubrication, the tests were extended by adding 50 g of copper to the fluid base. Due to the characteristics of copper, this way of cooling and lubrication is also often used in production processes in which the minimum flow capacity of cutting fluid is used. Copper, in general, counteracts the abrasion of friction pair elements, reduces friction, presents high resistance to pressure, and protects the surface from corrosion. Thus, copper can have a significant impact on the formed geometric surface structure and the profile bearing capacity curves, which, in turn, determine the tribological characteristics. The addition of copper can also affect the tribological features of the shaped surface through adhesion forces and diffusion.

Grinding was carried out by an abrasive disk made of fused alumina 99A with dimensions of 350 × 50 mm, and the workpiece material was 102Cr6 steel. The abrasive disk condition was adjusted to a constant parameter, i.e. after each processing, its initial cutting properties were restored by truing the grinding wheel. The other machining parameters were as follows: tangential velocity of abrasive disk v_s = 26 m·s^{-1}, rate of table feed v_{ft} = 0.22 m·s^{-1}, and grinding depth a_p = 0.04 mm.

The tests phase related to the verification effect of minimum cooling and lubrication on surface bearing capacity parameters were carried out by the use of a batchmeter shown in **Figure 2**. The bearing capacity parameters were determined with a contact profilometer MARSURF XR 20 MIT GD 120 by the stylus method. The profilometer was equipped with a measuring head with an R MFW 250 B sensor, and the measurement was made with a Gauss filter according to ISO 16610-31.

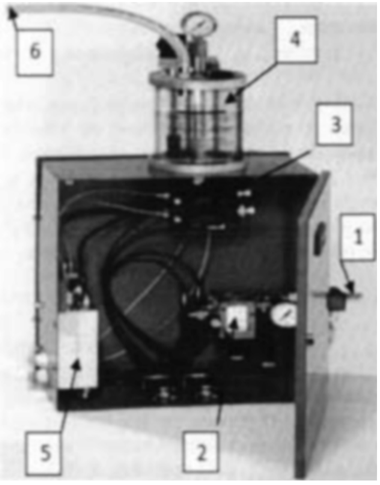

Fig. 2. A minibooster II, minimal cooling and lubrication batchmeter (description in text)

Rys. 2. Dozownik minimalnego chłodzenia i smarowania Minibooster II (opis w tekście)

The Accu-Lube Manufacturing GmgH Minibooster II minimized cooling and lubrication batchmeter generates oil mist from the air mixture and vegetable oil (Accu-Lube oil LB-8000) with a kinematic viscosity of 37 mm^2·s^{-1} at 40°C. In order to generate oil mist, the feed valve (1) was connected to the source of compressed air (0.6 MPa). Then supplied air flows through the frequency generator (2), it produces air pulses at a specific frequency resulting from the required properties of the oil mist. Generated air impulses flow to the oil pump (3), which, depending on the cylinder travel, tap an established quantity of oil from the oil storage tank (4), and transmits it according to the adopted frequency of air impulses to the mini booster-mixing chamber (5). The air piped into the mixing chamber in this way causes oil atomization and generates the oil mist, which then is directed to the oil storage tank. Then the oil mist stored in this tank flows through the hose (6) to the dose nozzles to the machining zone.

RESULTS

Table 1 presents the obtained results for the following tested cooling and lubrication conditions: a conventional use of cutting fluid- E, minimal cooling and lubrication- MQL, and minimal cooling and lubrication with the addition of copper- MQL + Cu. The presented values are the average values for six tested specimens. The spread of results was within ±2%.

Table 1. The list of average bearing capacity parameters obtained from tests for various cooling and lubrication conditions during grinding

Tabela 1. Zestawienie średnich wartości parametrów krzywej nośności uzyskanych z badań dla różnych warunków chłodzenia i smarowania podczas szlifowania

Method of cooling and lubrication	Bearing capacity curve parameter *Rk*, µm	Bearing capacity curve parameter *Rpk*, µm	Bearing capacity curve parameter *Rvk*, µm
E	0.7304	0.3809	0.6005
MQL	0.7165	0.3701	0.6092
MQL + Cu	0.6905	0.3366	0.6171

Figure 3 shows the results obtained in graphical form.

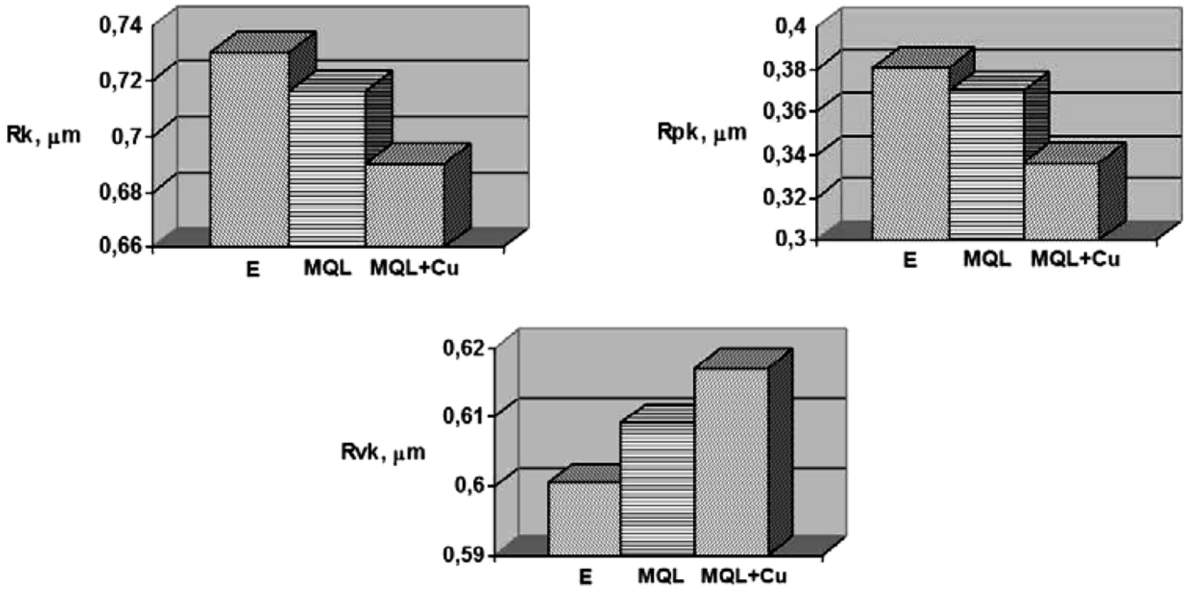

Fig. 3. Changes of the geometrical surface structure bearing capacity values due to the effect of cooling and lubrication method during grinding, for: a) *Rk*, b) *Rpk*, c) *Rvk* parameters

Rys. 3. Zmiana wartości parametrów nośności SGP ze względu na wpływ sposobu chłodzenia i smarowania podczas szlifowania dla: a) *Rk*, b) *Rpk*, c) *Rvk*

From the presented tests results, it can be observed that the method of cooling and lubrication during processing generally affects the condition of geometric surface structure. In particular, it affects the bearing capacity surface curve parameters, which were subject to experimental verification. In turn, as has been mentioned before, the condition of the geometric surface structure determines the tribological characteristics and functional features of friction pair elements. Generally, it can be concluded that machining with minimal cooling and lubrication (MQL) has a positive effect on the evaluated bearing capacity parameters due to tribological criteria [**L. 14, 18, 20, 27**]. Analysed parameters of the bearing capacity curve (*Rpk* and *Rvk*), on the basis of which one indicates the highest durability, allows one to deduce which parameters that indicate the ability to store lubricating oil have more advantageous values due to its functional characteristics. This is in particular obvious for minimal cooling and lubrication by the cutting fluid with the addition of copper (MQL + Cu). This may be caused by the fact that copper (as already has been mentioned) reduces friction between the surfaces and prevents their abrasion.

Figure 4 also shows the surface roughness profiles obtained from tested circumstances.

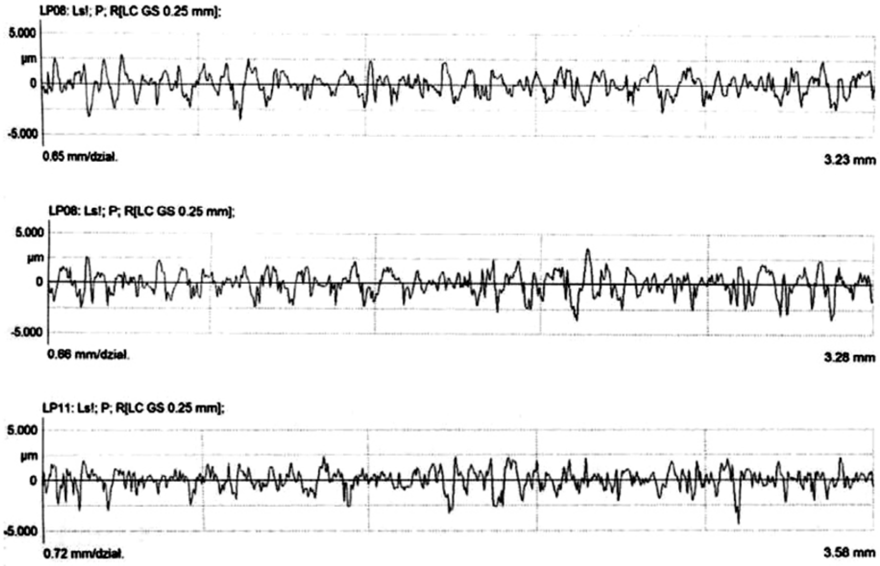

Fig. 4. Surface roughness profiles obtained for the following cooling and lubrication conditions: a) E, b) MQL, c) MQL + Cu

Rys. 4. Profile chropowatości powierzchni uzyskanych dla następujących warunków chłodzenia i smarowania: a) E, b) MQL, c) MQL+Cu

The presented profiles do not univocally differentiate received surfaces. They are very similar to each other, so it may be stated that, due to bearing capacity parameters, the potential usable features of these surfaces are similar. The minimal cooling and lubrication did not (for the tested samples and conditions) negatively affect the parameters of the bearing capacity curve, which we can use to describe the functional maintenance during surface cooperation. For this reason, the method of cooling and lubrication with the minimal flow capacity of cutting fluid presented above is considered functional. This is also a method that addresses the increased attention being paid to the ecological impact of the quantity of cooling agent on the environment and personnel when designing a technological process with ecological and tribological criteria. However, to generalize the mentioned above observation, it would be necessary to verify the effect of minimal cooling and lubrication on functional features for other processes with different technological parameters and to expand the range of resultant factors.

CONCLUSIONS

The aim of the carried out tests was to assess the impact of cooling and lubrication conditions during grinding on the surface structure features determined by the parameters of its bearing capacity in the aspect of the tribological features. The parameters characterizing the bearing capacity curve may be useful for assessing tribological features. They may be an important supplement to provide information on the geometric surface structure condition resulting from the amplitude or distance roughness profile parameters.

The presented test results have shown that the cooling and lubrication method affects the constituted surface structure and the resulting tribological characteristics and functional features. The minimal cooling and lubrication (MQL) during grinding, especially with the addition of copper, has a positive effect on the evaluated bearing capacity due to tribological criteria. Due to the ecological aspects of cooling agent use and the lack of negative impact of minimal cooling and lubrication on the functional features determined by bearing capacity parameters, designing of technological process should be considered by presented method of supplying cutting fluid to the machining zone.

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