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THE INFLUENCE OF COOLING AND LUBRICATION LIQUID QUANTITY ON THE ISOTROPY OF A MACHINE COMPONENT SURFACE DURING MACHINING

WPŁYW WARUNKÓW CHŁODZENIA I SMAROWANIA PODCZAS OBRÓBKI ELEMENTÓW MASZYN NA STOPIEŃ IZOTROPOWOŚCI ICH POWIERZCHNI

Key words:

cooling and lubrication, surface geometric structure, surface isotropy

Słowa kluczowe:

chłodzenie i smarowanie, struktura geometryczna powierzchni, izotropowość powierzchni

Abstract

This paper presents an initial verification of the influence of a cooling-lubrication liquid or its lack on the geometric surface structure of machine components undergoing the process of machining. It has been proposed to use the degree of isotropy of the finish surfaces, apart from commonly used

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roughness parameters, for the evaluation of changes in the quality of components machined in different cooling and lubrication conditions. In this study, the usefulness of the degree of isotropy for a description of the surface geometric structure characteristics has been verified.

INTRODUCTION

Functional qualities of kinematic pairs such as wear resistance, motion resistance, and fatigue life are largely affected by features of the surface layer created during the manufacturing process. Therefore, it is important to define the influence of the technological process conditions and parameters on these features. The surface geometric structure (SGS) shaped in a manufacturing process depends on the type of machining, which is affected by the tool shape, the kinematics of the workpiece, the relative motion of the tool, and the machining environment.

Therefore, it is necessary to look for a solution to reduce the impact of negative effects or even entirely eliminate them. In machining, which is prevalent in the machine industry **[L. 1]**, it is the cooling-lubrication liquid that poses the biggest threat to the environment. Most scientific research concerning machining, that is, dry machining, machining with the minimum quantity of cooling and lubrication liquid, and machining with the conventional application of machining liquids, is focused on the tool blade wear and determination of machining conditions to provide the highest accuracy **[L. 2, 3]**. However, researchers do not take much interest in research on the elimination or reduction of the quantity of cooling-lubrication liquid, so that the functional qualities of a machined component, determined mainly by the texture of the finish surface, will possibly be the best.

The main goal of this research is to perform an initial verification of the influence of the quantity of cooling-lubrication liquid or its lack on the machined surface texture. Another goal of the research is to verify the advisability of the application of a surface topography in metrology for the evaluation of stereometric characteristics of its degree of isotropy.

MACHINING CONDITIONS AND SGS

During machining, the surface of a workpiece is affected by cooling--lubrication liquids and their potential contamination. They also have an influence on the wear of machining tools, the shape-dimension accuracy of the machined surfaces, as well as on the formation of chips and the phenomena occurring within the machining zone **[L. 2, 3]**.

Although cooling-lubrication liquids provide many benefits, they are more and more frequently viewed as an undesired factor during machining and, therefore, need to be reduced or eliminated. This is due to two factors, one of which is economic. It is estimated that the application of machining liquids accounts for nearly 16.8% of the total manufacturing costs. Another factor is of an ecological nature connected with the introduction of more restrictive environment protection rules as well as health and safety rules **[L. 4, 5]**.

One way to reduce cooling-lubrication liquid quantity is MQL – Minimum Quantity Lubrication. This method involves providing the smallest quantity of machining liquid in a given time, usually less than 50 $ml \cdot h^{-1}$, to be supplied as close to the area of the tool and workpiece contact as possible. This method is being increasingly used in industry, due to the development of tool materials and their coatings, improving strength of the blade in difficult machining conditions as well as new structural solutions introduced to machine tools, devices and tooling **[L. 4, 6, 7, 8]**.

Another solution used for the reduction of cooling-lubrication liquid quantity is dry machining – the total elimination of liquid. Application of this method is growing, due to better functional qualities of new materials for tools and coatings used in the machining process as well as new structural solutions of machine tools **[L. 9, 10]**. The idea of this method is that the generated heat is accumulated in the tool, workpiece, and metal chips. Some portion of the heat is carried away directly to the environment and the remaining part is removed from the machining zone as quickly as possible. It is possible due to the application of a properly designed tool **[L. 11]**, which partly takes over the functions of a cooling-lubrication liquid. In dry machining, the functions of a cooling-lubrication liquid are also taken over by the machining tool. The structure of the machining tool, especially an arrangement of the working space, should prevent the workpiece from being affected by heat accumulated in the chips **[L. 12]**.

In conventional cooling methods with the use of emulsion (wet machining), the generated heat and a cooling-lubricating liquid are being removed.

On the basis of the analysis of publications, it can be said that lower values of roughness can be achieved for the minimum quantity of cooling and lubrication in the form of oil with air or oil with water mixtures than for dry machining or with the conventional use of emulsion **[L. 13, 14, 15, 16]**. In dry machining and the one with conventional cooling and lubrication, the surface roughness increases as a result of higher temperatures and stresses affecting the blade.

Because cooperation of the friction pair is accompanied by the interaction of their surfaces, the formed structure has a significant impact on functional qualities and tribological characteristics. Therefore, the choice of an appropriate method and tools for the assessment of the surface stereometric features is very important. Metrological measurement of the surface topography should reflect the real shape of the structure in the best possible way, which in turn will enable the appropriate assessment of the functional qualities of the friction pair elements.

This research proposes, apart from roughness parameters that are commonly used for the structure shape characteristics, the degree of isotropy for the evaluation of the influence of a cooling-lubricating liquid quantity (or its lack) on the surface geometric structure. There are several ways to be used for the definition of a surface geometric structure isotropy. The most simple measure of isotropy in a two dimensional system is the ratio of selected values of the profile roughness parameters measured for two typical, mutually completing directions.

The most advanced methods involve using mathematical functions for SGS description whose advantage is that they can be calculated from three-dimensional measures of the surface autocorrelation function. Additionally, the description of SGS, based on its mathematical functions, especially the surface autocorrelation function or spectral power density, is a procedure that is not burdened with error of subjective, model based, choice of parameters **[L. 17, 18]**.

Thus, the surface autocorrelation function has been accepted for a description of the surface texture, that is, for the determination of isotropic density.

THE IMPACT OF COOLING AND LUBRICATION CONDITIONS ON SGS – EXPERIMENTAL TESTS

Assessment of the impact – or its lack – of a cooling-lubrication liquid on SGS was performed for grinding as the main finish machining for the following arguments:

- Machining without machining liquids – dry machining (S),
- Minimum quantity liquid machining with oil mist for 50 $ml \cdot h^{-1}$ (MQL), and
- Machining with conventional cooling-lubrication with 5% emulsion for 4 $l \cdot min^{-1}$ (E).

The machined material was 102Cr6 steel with 30±2 HRC hardness. The machining was performed with a grinding wheel made of electrocorundum 99A with dimensions Ø 350 x 50 and with the following parameters: peripheral velocity of the abrasive wheel v_s = 26 $m \cdot s^{-1}$; the plate feed velocity v_{ft} = 13.4 $m \cdot min^{-1}$; depth of grinding a_p = 0.04 mm. Before grinding, the specimens underwent initial machining with an end milling cutter with a diameter equal to = 22 mm, for machining velocity v_c = 1.2 m/s, and longitudinal feed f = 1 mm/rev. After milling, the mean value of the roughness parameter was approximately 2 μm. Quantities describing the obtained SGS were the control initial values. These values were matched with roughness parameters Ra and Rq and the surface structure the degree of isotropy (Iz).

Verification of the impact of minimum liquid lubrication on SGS was performed by means of a dispenser presented in **Figure 1**.

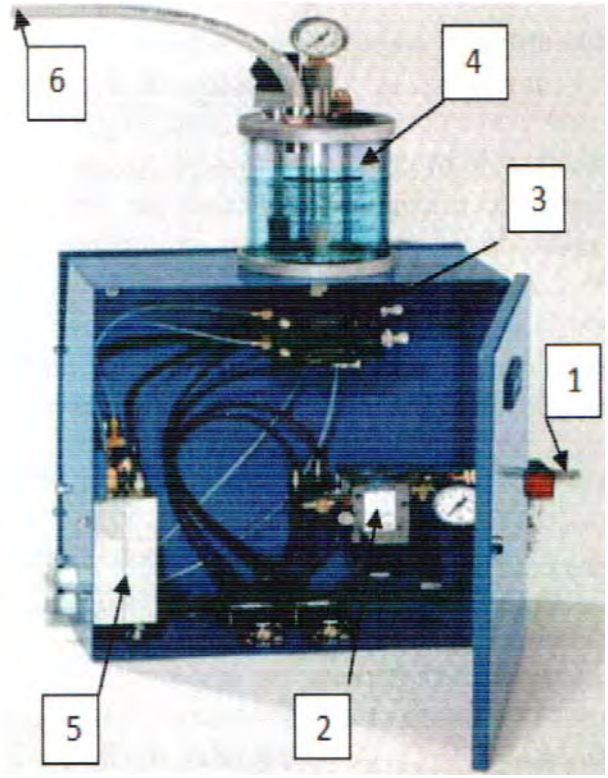

Fig. 1. Dispenser for minimum cooling and lubrication Minibooster II (described in text)
Rys. 1. Dozownik minimalnego chłodzenia i smarowania Minibooster II (opis w tekście)

Minimum cooling and lubrication dispenser Minibooster II of Accu-Lube Manufacturing GmgH produces an oil mist from a mixture of air and plant oil LB8000 of Accu-Lube with kinematic viscosity 37 $mm^2 \cdot s^{-1}$ in 40°C. In order to produce the oil mist, a feed valve (1) was connected to the source of compressed air (0.6 MPa). The supplied air flows through a frequency generator (2), and its task is to generate impulses of air with a frequency defined by the required properties of the oil mist. The air impulses flow to the oil pump (3), which, depending on the set cylinder feed, takes a given quantity of oil from the oil tank (4) and carries it, according to the set frequency of air impulses, to mixing chamber – minibooster (5). The air supplied to the mixing chamber causes atomization of the oil and the generation of an oil mist that is directed to the oil tank. Oil mist accumulated in the tank then flows through a hose (6) to nozzles that dose the mist to the machining zone.

Figure 2 presents the topography of the machined surfaces in particular conditions of grinding. The images were obtained through scanning on a measuring machine Talyscan 150 of Taylor Hobson, using TalyMap Expert. An area of 3 x 3 mm surface was measured for a sampling step equal to 0.05 mm.

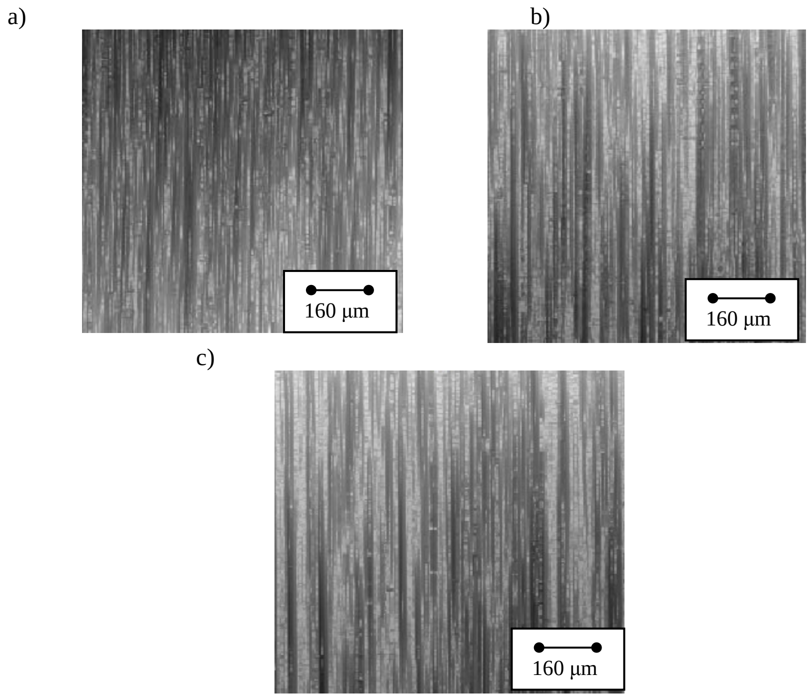

Fig. 2. Images of SGS depending on the method of cooling and lubrication during the machining process: a) MQL b) E – involving emulsion c) S – dry

Rys. 2. Obrazy SGP w zależności od sposobu chłodzenia i smarowania w czasie obróbki: a) MQL, b) E – z udziałem emulsji, c) S – na sucho

Images of the obtained structures do not make it possible to carry out a detailed qualitative analysis. It seems that, due to the shape of characteristic elements of the structure, they are the same or very similar, and they were created in the same conditions. However, after a quantitative analysis, it is possible to differentiate the machined structures.

Table 1 presents dry machining results averaged from six repetitions (S), with conventional cooling and lubrication and using emulsion (E) as well as minimum quantity liquid with oil mist (MQL).

Table 1. Presentation of averaged tests results for machining conditions different in terms of cooling-lubrication liquid quantity or its total lack

Tabela 1. Zestawienie uśrednionych rezultatów badań dla różnych warunków obróbki związanych z ilością lub brakiem cieczy chłodząco-smarującej

Method of cooling and lubrication	Roughness parameter Ra, µm	Roughness parameter Rq, µm	The degree of isotropy Iz, %
S	1.72	2.04	11.8
E	1.37	1.73	9.27
MQL	1.16	1.64	8.01

Figure 3 graphically presents the results of the tests.

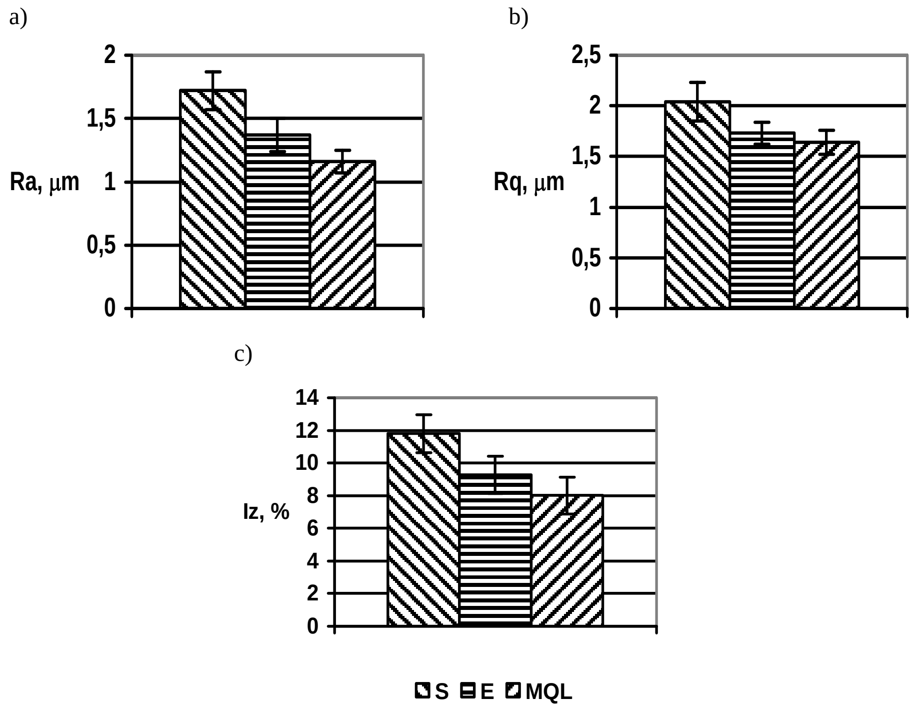

Fig. 3. The influence of cooling and lubrication on the SGS described by: a) Ra parameter, b) Rq parameter, c) the degree of isotropy Iz

Rys. 3. Wpływ sposobu chłodzenia i smarowania na SGP opisaną: a) parametrem Ra, b) parametrem Rq, c) stopniem izotropowości Iz

The presented test results show that the method of cooling and lubrication affects the obtained geometric structure. The lowest values of parameters describing the machined surface structure have been found for MQL machining. The highest values of respective parameters are observed for dry machining. For conventional machining with emulsion, the parameters assume medium values. This character of value changes has been observed for all the evaluated parameters describing SGS. The charts also show that the values of studied quantities for liquid or mist are similar to each other and for dry machining the values are significantly higher.

The tests have also shown that it is advisable to use the degree of isotropy for a description of features of a surface texture. Due to that fact that the degree of isotropy characterizes the surface topographic shaping, it can also be a better indicator of the surface functional qualities than roughness parameters in terms of the operation process – its control and optimization. The value of the degree of isotropy is mainly affected by the lay but also by all micro- or even nano-irregularities occurring on SGS.

CONCLUSIONS

The presented tests results prove that the method of cooling and lubrication does have an influence on the finish surface texture, hence on its functional qualities.

The experimental tests have proved that it is advisable to use the degree of isotropy for a description of the surface texture characteristics.

Because the experimental tests were supposed to verify the influence of cooling-lubrication liquid quantity on the transformation of technological surface layer (TSL), it would be advisable to perform complex experimental tests concerning the usability of SGS for a description of TSL transformation. In these tests, the set of arguments should include all the factors that contribute to the creation of a technological surface layer.

A set of arguments should also be completed with other parameters of the surface texture that could be used for a more complex characterization of the finish surface layer.

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Streszczenie

W artykule przedstawiono wstępną weryfikację wpływu ilości lub braku cieczy chłodząco-smarującej na konstytuowaną podczas obróbki strukturę geometryczną powierzchni. Do oceny zmian cech w ukształtowaniu struktur obrabianych elementów przy różnych warunkach chłodzenia i smarowania oprócz powszechnie stosowanych parametrów chropowatości przyjęto stopień izotropowości uzyskanych powierzchni. Przeprowadzona analiza zweryfikowała przydatność zastosowania ich stopnia izotropowości do opisu cech struktury geometrycznej powierzchni.