

Reducing Labor Intensity in the Development of New Universal Cutting Fluids for Machining

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The process of developing new universal cutting fluids is labor-intensive due to the requirement of conducting experiments to determine the impact of numerous additives on tool life during different technological operations. Therefore, finding the best cutting fluid, the use of which will result in the longest tool life, is a long and laborious process. To reduce labor intensity while creating new cutting fluids accelerated methods are applied first, such as the method of determining the tribometric properties of a new fluid. Subsequently wear tests are carried out, using only those cutting fluids which show the best tribological behavior.

The aim of this study is to reduce labor intensity in developing new universal cutting fluids. For this purpose, a new accelerated method has been developed, which helps to determine the capability of the fluid to counteract the adhesion between the chips and the cutting tool. Furthermore, a new sequence of cutting fluid tests has been proposed which significantly reduces the amount of wear tests, resulting in considerable reduction of the overall labor intensity in the development of new cutting fluids.

Keywords: Adhesion, Cutting fluid, Machining, Wear

1 Introduction

Application of new cutting fluids is one of the principal methods aimed at improving machining effectiveness. Klocke and Eisenblatter [1] concluded that cutting fluids (CF) help to achieve specified results in terms of tool life, surface finish and accuracy-to-size. Jayal and Balaji [2] presented that, in turning operations, using CF increases the tool life of PVD coated tools in comparison with MQL and dry cutting. However, the process of developing new cutting fluids is time-consuming and laborious due to the requirement of testing a large number of different additives that may increase the tool life during cutting.

The determination of tool life by using different cutting fluids during various technological operations (such as milling and turning) is the most reliable yet most time-consuming way to determine the best cutting fluid. Different authors used tool life tests in their studies. Khan et al. [3] determined the growth of average auxiliary flank wear as a function of time under dry and wet conditions and using vegetable oil for MQL in turning. Thepsonthi et al. [4] investigated the application of minimal cutting fluid in high-speed milling. In addition, Axinte and De Chiffre [5] provide tool life tests for turning, milling and drilling for evaluating the performance of cutting fluids when machining aerospace materials. However, De Chiffre and Belluco [6] proved that tool life tests are the most expensive.

To reduce the labor intensity of cutting fluid development accelerated methods first were used in this investigation such as the method of determining the tribometric properties of a new fluid. Vengudusamy et al. [7] tested mineral and synthetic oils on different types of tribometers for comparison of frictional properties. Adhvaryu et al. [8] studied tribological properties of thermally and chemically modified vegetable oils as environmentally friendly lubricants by using equipment for measuring ball-on-disk friction. Deng et al. [9] used slide wear tests

on the ball-on-disk tribometer to determine friction and wear behaviors of the carbide tools embedded with solid lubricants. Piekoszewski et al. [10] used modified four-ball testers to test lubricants under conditions of extreme pressure.

After determining the tribometric properties of all the cutting fluids, the CF are discarded which possess the lowest tribometric characteristics. The final wear tests are carried out only with the fluids which have high tribological properties. For example, Fig. 1 shows the results of determining tribometric properties in 11 different fluids (No.1, No.2, ..., No.11) using the Reichert wear test.

The used equipment was the Reichert Friction & Wear tester RM 2 from Anton PaarProveTec GmbH. It is usually assumed that cutting fluids with better tribological properties will ensure greater tool life. The same principle was used by Sato et al. [11] who investigated the effect of water-based lubricants on wear of coated material, and Persson and Gåhlin [12] used Reichert friction and wear tests for tribological performance of DLC coatings in combination with water-based lubricants. Fig. 1 shows that six cutting fluids can be discarded since they possess significantly worse tribological properties, while wear tests continue with the five remaining best fluids (No.1, No.2, No.3, No.4, No.5). After that, the best cutting fluid with maximum resistance is selected from the five remaining ones. Its resistance is compared with the resistance of the conventional cutting fluids which are already used in industry. If tool life with the new cutting fluid proves to be longer than the one with conventional fluids, the new cutting fluid is recommended for industrial use. In case the new cutting fluid shows less resistance compared to the cutting fluids used in industry, the development of new cutting fluids will proceed until a new fluid is created which ensures better tool life compared with the fluids that are already industrially used. Thus, the use of two methods leads to a reduction of the overall labor intensity in creating new cutting fluids.

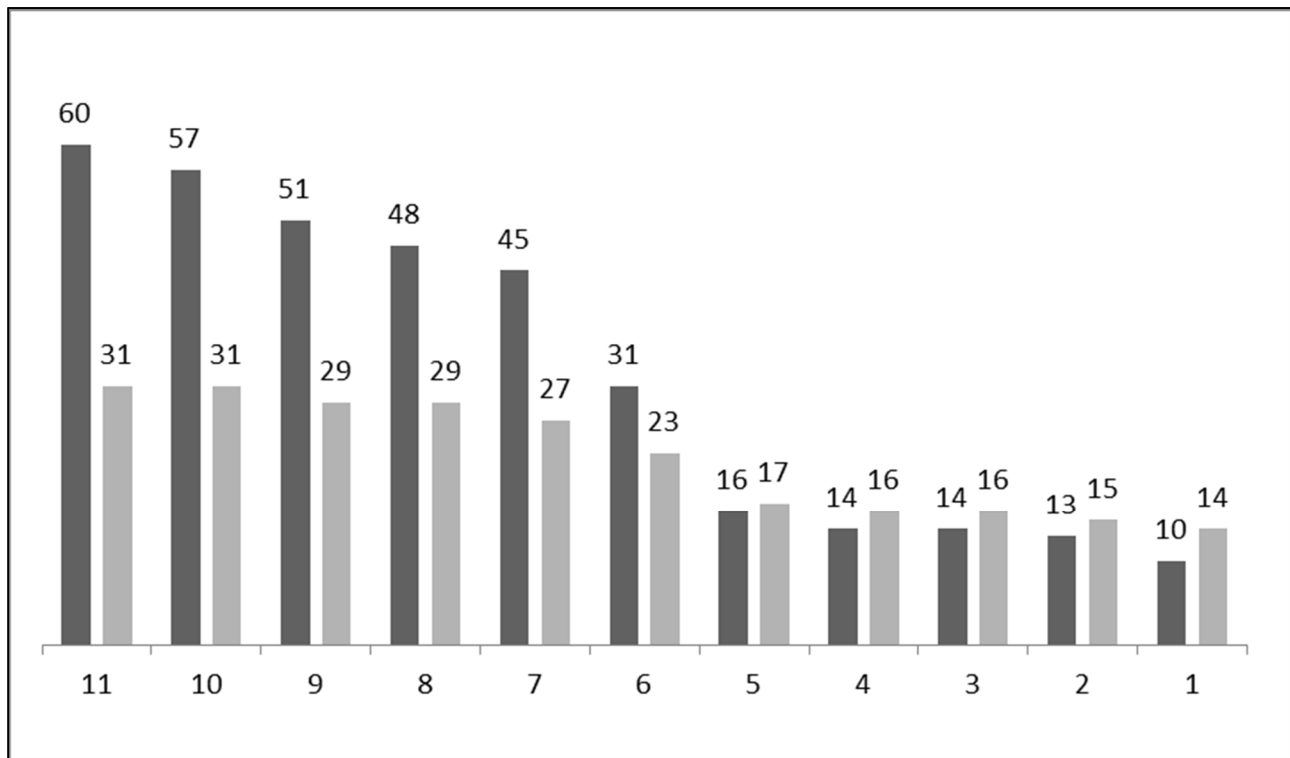


Fig. 1 Determining the tribometric properties of various cutting fluids using Reichert wear test; ■ - mass loss, mg; ■ - wear scar area, mm²

The purpose of this article is to show how to reduce the overall labor intensity in developing new cutting fluids for machining, based on working out accelerated methods and on the rational sequence of different methods use.

2 Experimental procedures

2.1 Method for determining the ability of a cutting fluid to counteract the adhesion between chips and cutting tool by Dugin et al. [13]

The tests for determining the ability of a cutting fluid to counteract the adhesion between chips and cutting tool were conducted during free rectangular cutting on a universal milling machine. The cutter was mounted fixedly on a vertical milling head. The PRAMET TOOLS cutter, type CTCPN 2514 M16 was used with the insert TPUN 160308 of hard alloy N10 (K15 -30), S30 (P 20-35) and S26 (P 15-30) (Fig. 2). A similar scheme of orthogonal cutting has been described by Dugin et al. [14] for determining the tribological properties of the cutting fluid and by Popov et al. [15] for studying the influence of lubricant and coolant fluid on the cutting force in small-increment planning. In order to save testing time austenitic stainless steel was used, which has a very strong adhesion effect on cutting; this was proved by Naveset et al. [16] in evaluating the effect of applying cutting fluid on tool wear during turning operation of AISI 316 austenitic stainless steel. The work piece made of stainless steel 20Cr13 (253 HB) was fastened in the vice. Cutting was carried out with a cutting thickness of 0.1 mm, a width of 6 mm and at cutting speeds of 0.3 m/min - 0.9 m/min. Diffusion wear is not typical at such low cutting speeds since they do not

cause high temperatures, which was noted by Armarego [17], Trent and Met [18] and later confirmed by Loladze [19]. Low cutting speeds usually result in adhesive wear, which was demonstrated by Loladze [19]. Wear occurred on the front face of the cutting tool (Fig. 3, a).

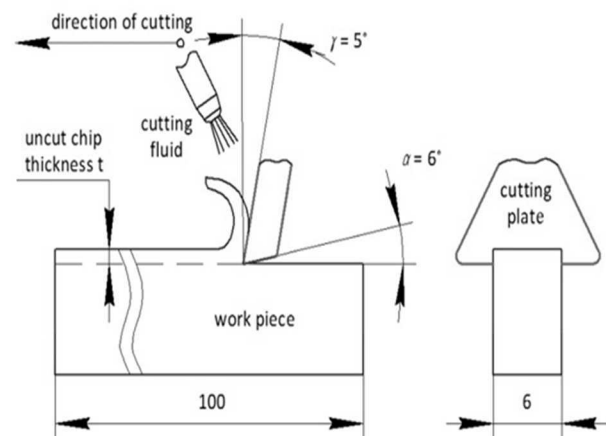
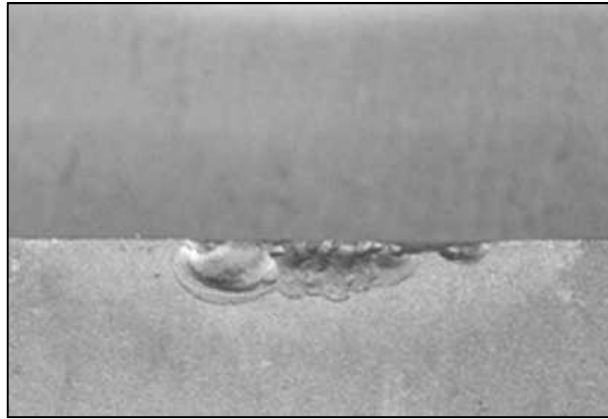


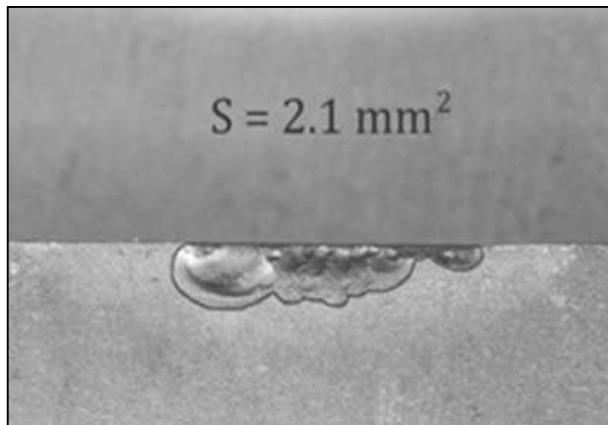
Fig. 2 Chipping scheme

The ability of cutting fluids to counteract the adhesion between the chips and the cutting tool was characterized by the wear area at the front surface of the cutting tool after the same number of cutting passes. 100 passes were performed under the same conditions, followed by determination of the wear area of the front surface S . In order to carry out this determination the front surface was photographed; the wear area was delineated as S (Fig. 3, b) and calculated using the special computer program. After the same number of passes, the use of different cutting

fluids significantly affected the wear area of the front surface S . Thus, Fig. 4 shows the pictures of the front surface of the cutting tool after using the three different cutting fluids. The fluid after the use of which the wear area of the front surface of the tool is smaller (Fig. 4, a) possesses a greater ability to resist adhesion between the chips and the cutting tool. To determine the average size of the wear area of the front surface S each experiment was repeated 5 times.

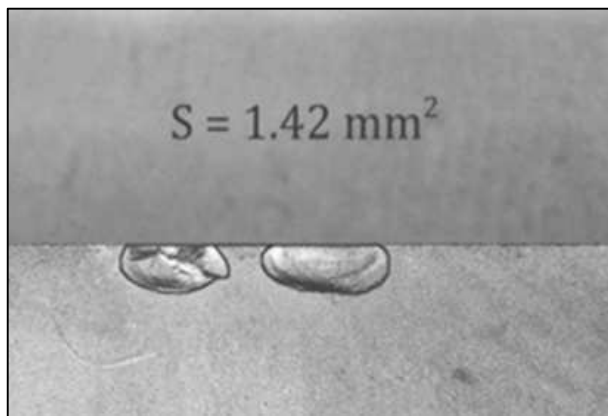


a)

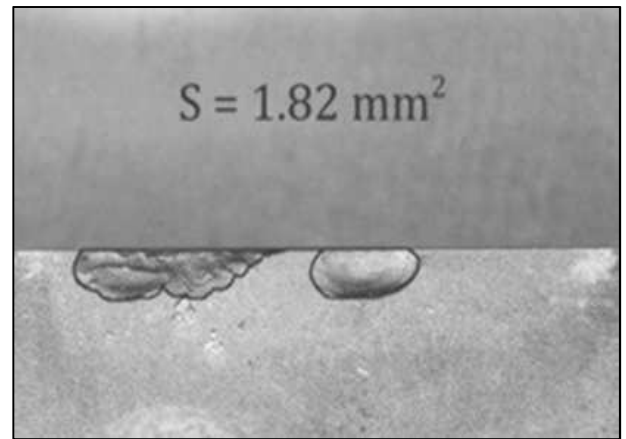


b)

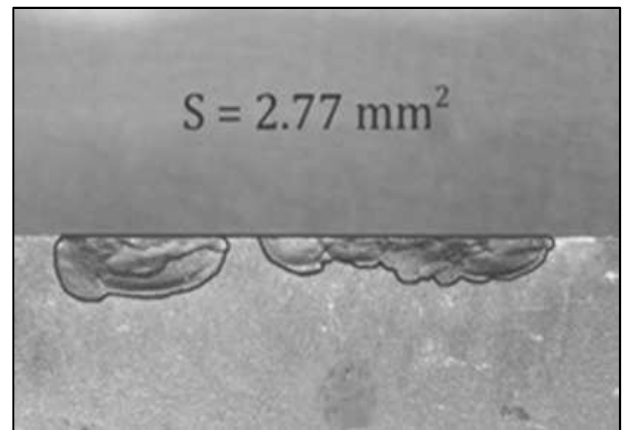
Fig. 3 The wear of the front surface of the tool (a) and delineation of the wear area of the front surface S of the tool (b)



a)



b)



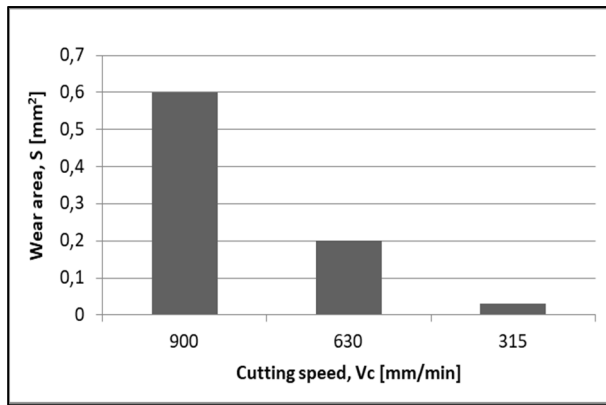
c)

Fig. 4 The wear area of the front surface S of the cutting tool after using three different cutting fluids, after the same number of cutting passes (100 passes) and at the same cutting width (6 mm)

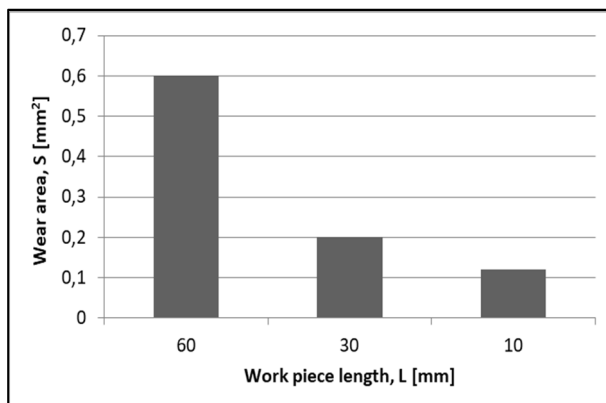
In order to speed up the tests to determine the ability of cutting fluid to counteract the adhesion between chips and cutting tool examinations were carried out on the effect of the cutting speed, the length of the work piece and the grade of cutting alloy on the wear area of the front surface S of the tool after 100 cutting passes. Only one cutting fluid was used during these experiments.

It was found that by increasing the cutting speed from 0.3 m/min to 0.9 m/min (Fig. 5, a), by increasing the length of the work piece from 10 mm to 60 mm (Fig. 5, b), and by using the cutting alloy intended for turning of structural steels (P) instead of the hard alloy intended for turning of stainless steels (K) (Fig. 5, c), and by reducing the strength of the hard alloy from P20 - P35 to P15 - P30 (Fig. 5, c), the wear area of the front surface S of the tool increases after 100 cutting passages.

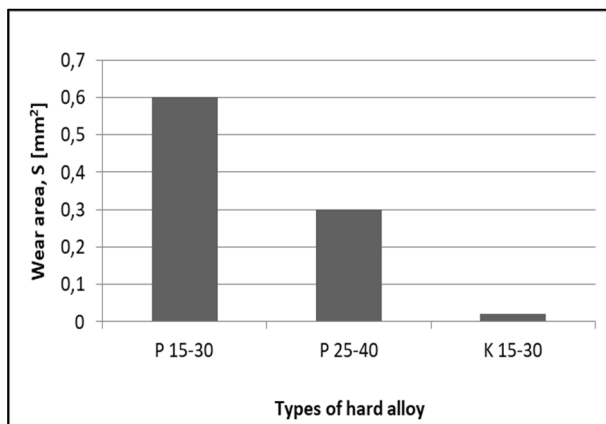
Thus, to increase sensitivity and to reduce labor intensity of subsequent experiments to determine the ability of cutting fluids to counteract the adhesion between chips and cutting tool it is recommended to use a cutting speed of 0.9 m/min, a work piece length of 60 mm and the cutting alloy P15 - P30.



a)



b)



c)

Fig. 5 Effect of cutting speed V_c (a), work piece length L (b) and hard alloy grade (c) on the wear area of the front surface S of the tool after 100 cutting passes

2.2 Cutting test and materials

In order to determine tool life when using different cutting fluids the experiments were carried out by milling on the milling machine FNG 32 with manual control and by turning on the CNC lathe CHEVALIER FCL- 2140.

The cutter used for milling was a 63-diameter cutter by the company NAREX. Milling of the structural steel 16MnCr5 (138 HB) was performed with the cutting inserts SNUN 120412 of hard alloy S30 (P20 - P35) by the company Pramet Tools s. r. o., at a cutting speed of $V_c = 85 \text{ m/min}$, feed $f_z = 0.1 \text{ mm/tooth}$ and depth of cut $a_p = 1 \text{ mm}$. Milling of the stainless steel X6CrNiMoTi17- 12-2 (189 HB) was performed with the cutting inserts SNUN 120412 of hard alloy with the coating 8230 (M20 - M40) by the company Pramet Tools s. r. o., at the cutting speed $V_c = 47.5 \text{ m/min}$, feed $f_z = 0.1 \text{ mm/tooth}$ and depth of cut $a_p = 1 \text{ mm}$. The experiments were carried out with one insert fixed to the milling cutter.

The tool used for turning was CTAPR 20x20 K16 KT 834 by the company Pramet Tools s. r. o.. Turning of the structural steel 16MnCr5 (138 HB) was performed using cutting inserts TPUN 160304 of hard alloy S26 (P15 - P30) by the company Pramet Tools s. r. o. at a cutting speed of $V_c = 245 \text{ m/min}$, feed $f = 0.1 \text{ mm/rev}$ and depth of cut $a_p = 0.5 \text{ mm}$. Turning of the stainless steel X5CrNiTi18-10 (259 HB) was performed with cutting inserts TPUN 160304 of hard alloy with the coating 8230 (M20 - M40) by the company Pramet Tools s. r. o. at a cutting speed of $V_c = 160 \text{ m/min}$, feed $f = 0.1 \text{ mm/rev}$ and depth of cut $a_p = 0.5 \text{ mm}$. To determine the average resistance value each experiment was repeated 5 times for milling and turning.

In all experiments, 11 cutting fluids were used which had the same concentration of 5%. These cutting fluids were made by the following manufacturers: Blaser Swissslube AG, Cimcool Industrial Products B.V., Houghton plc, Paramo a.s. The cutting fluid concentration was controlled by the refractometer Optech Brix RLC / ATC, characterized by concentration measurement at a range of 0-18% and accuracy of 0.1%. The desired value for each fluid was calculated by the refractometer K with the following formula: $K = 5/\ln$, with 5 being the required concentration of 5%, and \ln being the refraction index whose value was provided by the cutting fluid manufacturer.

3 Experimental results and analysis

The studies found that cutting fluid No.1 (CF1) possesses the best ability to resist adhesion between chips and cutting tool (Fig. 6). It also exhibits the best tribometric characteristics (Fig. 1). Cutting fluids No. 2, No. 3, No. 4 and No. 5, which showed good results in the Reichert testing (Fig. 1), have substantially poorer ability to counteract the adhesion between chips and cutting tool in comparison with CF1 (Fig. 6). It has been established that the use of CF1 helped reduce the wear area of the front surface by 21 times in comparison with the cutting fluid No. 7 (Fig. 6). This significant difference in the wear areas of the front surface S using different cutting fluids is indicative of the high sensitivity of the new method.

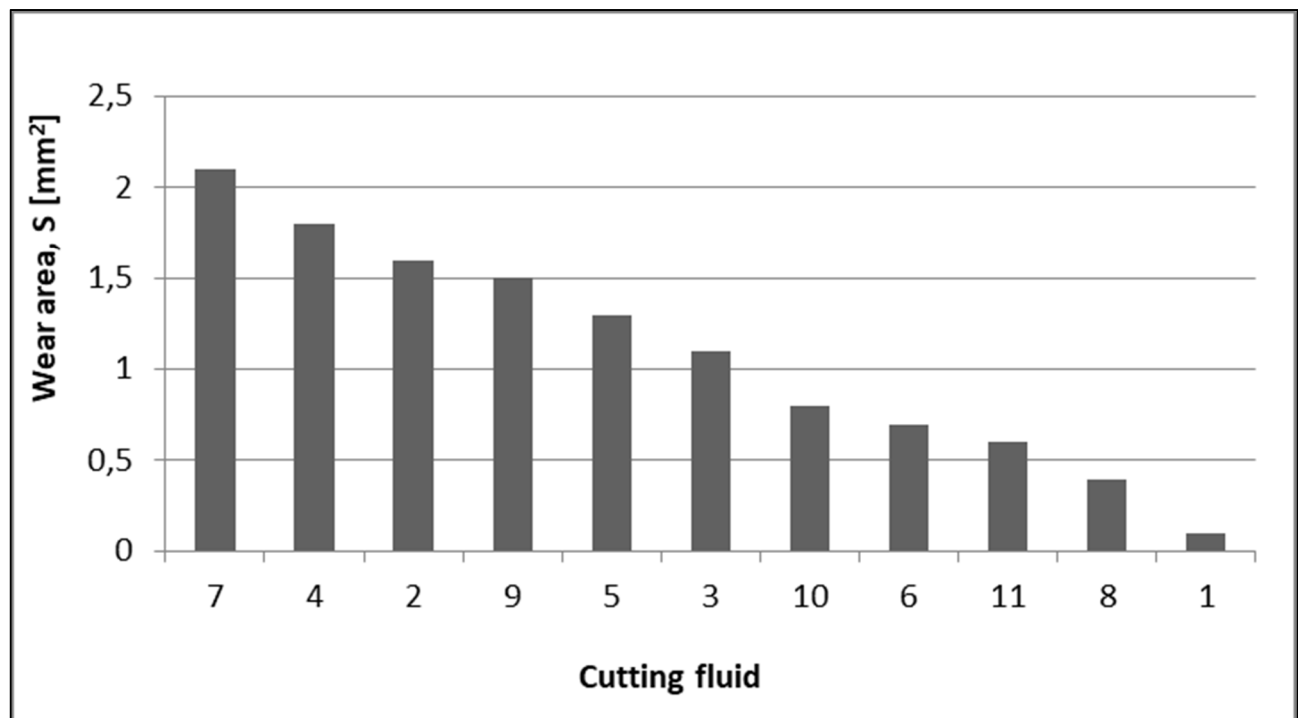
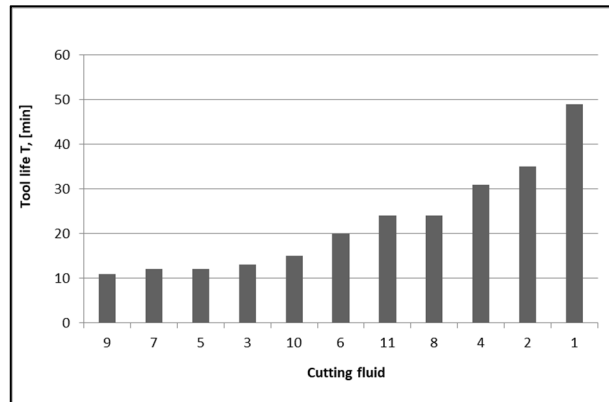
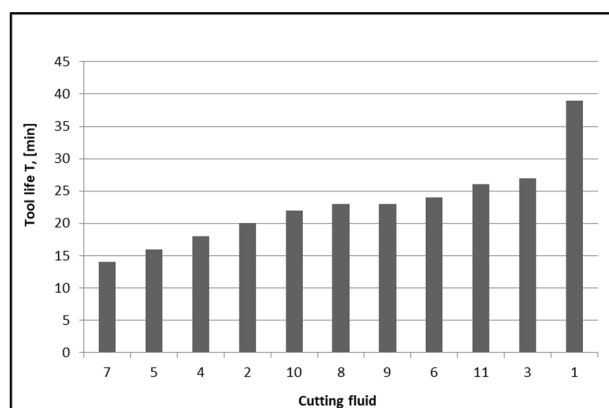


Fig. 6 Wear area of the front surface S of the cutting tool using different cutting fluids

As a result of these studies, it was found that when milling structural steel X16MnCr5 (Fig. 7, a) and stainless steel X6CrNiMoTi17-12-2 (Fig. 7, b), maximum tool life was achieved using CF1 (Fig. 7).



a)

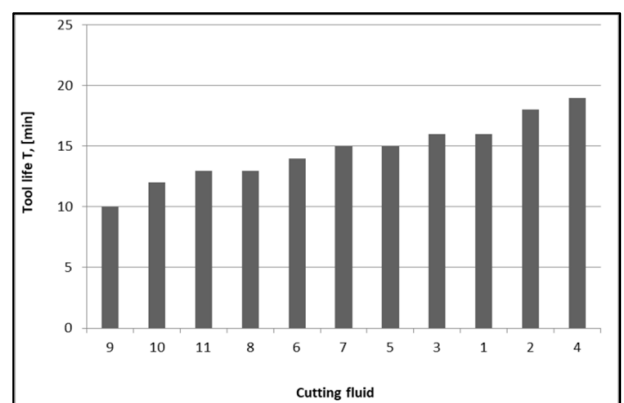


b)

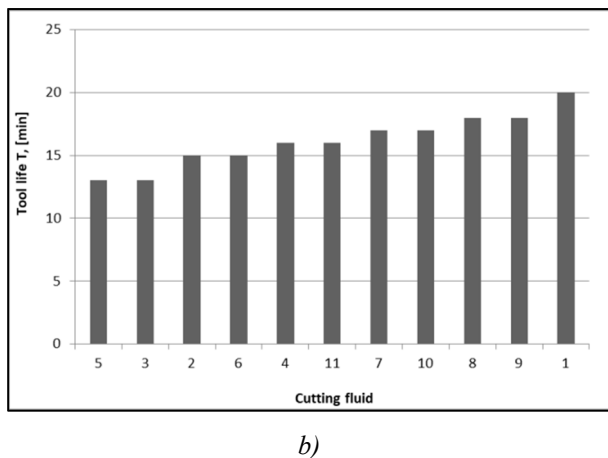
Fig. 7 Effect of cutting fluid on tool life when milling structural steel (a) and stainless steel (b)

While turning structural steel 16MnCr5, maximum tool life was achieved using cutting fluids No. 2 and No.4 (Fig. 8, a). CF1 showed the third result, but the difference between CF4 with the best resistance and CF1 was merely 16% (Fig. 8, a). While turning stainless steel X5CrNiTi18-10, the longest tool life was achieved using CF1 (Fig. 8,b).

The studies found that CF1 should be used as a universal cutting fluid for milling and turning of structural and stainless steel as it possesses the best tribometric characteristics (Fig. 1) as well as the best ability to resist the adhesion between chips and cutting tool (Fig. 6). In order to propose a new test sequence of cutting fluids on the basis of the studies that were carried out it is required to analyze the results of wear tests for CF2, CF3, CF4 and CF5.



a)



b)

Fig. 8 Effect of cutting fluid on tool life when turning structural steel (a) and stainless steel (b)

In the Reichert testing, cutting fluid No. 2 has shown high tribometric properties which are close to the properties of CF1 (Fig. 1). However, CF2 demonstrates significantly poorer ability to resist adhesion between chips and cutting tool in comparison with CF1 (Fig. 6). Wear tests have revealed that CF2 showed high resistance while turning (Fig. 7, a) and milling (Fig. 8, a) of structural steel, and low resistance while turning (Fig. 7, b) and milling (Fig. 8, b) of stainless steel. Therefore, CF2 cannot be recommended as a universal cutting fluid for milling and turning of both structural and stainless steel. For the same reason, CF3, CF4 and CF5 cannot be used as universal cutting fluids. Of all the tested cutting fluids, it is reasonable to use only one as a universal cutting fluid for milling and turning of structural and stainless steel - CF1, which has the best tribometric properties (Fig. 1) and the greatest ability to resist the adhesion between chips and cutting tool (Fig. 6). Without finding a cutting fluid which will have the best tribometric properties and the best ability to counteract the adhesion between chips and cutting tool, it is impossible to create a new universal cutting fluid.

The following new test sequence is proposed based on experiments aimed at reducing labor intensity of creating new universal cutting fluids. In the beginning it is advisable to determine the tribometric properties of all new cutting fluids and to determine the ability of all new cutting fluids to resist adhesion between chips and cutting tool. It is required to find a cutting fluid which will have the best tribometric properties and the best ability to resist adhesion between chips and cutting tool. If such a fluid will not be found among the new cutting fluids, it is necessary to continue the development of new fluids by improving the cutting fluid composition. The development of new cutting fluids should continue until the fluid will be discovered which has the best tribometric characteristics and the best ability to counteract the adhesion between chips and cutting tool.

When carrying out the final and labor-intensive tests to determine the effect of cutting fluids on the tool life during different machining operations (milling, turning), it is proposed to use only those new cutting fluids which possess the best tribometric abilities and the best

ability to counteract the adhesion between chips and cutting tool. During wear tests it is useful to compare the resistance of the new CFs with the resistance of the conventional CFs which are already used in industry. If the new cutting fluids provide greater tool life than the CFs that are already industrially used, it can be assumed that the goal is achieved, and new cutting fluids can be recommended for industrial use instead of the conventional ones. In case the new cutting fluids show less resistance compared with industrially used ones, it is required to continue the development of new CFs which will have the best tribometric properties and better ability to counteract the adhesion between chips and cutting tool until the new CFs guarantee greater tool life compared to the old CFs.

The proposed new CF test sequence, which involves using the methods of determining the ability of a cutting fluid to counteract the adhesion between chips and cutting tool, significantly reduces the amount of wear tests and, as a result, significantly reduces the overall labor intensity of the development of new cutting fluids.

4 Conclusion

The author's aim of this research was not to repeat the classic experiment of cutting fluid performance testing. The new method for determining the ability of a cutting fluid to counteract the adhesion between chips and the cutting tool has been presented as the intermediate method between tribological experiments and classic cutting fluid performance testing experiments.

That is why during the research, the ability of a cutting fluid to counteract adhesion was compared at cutting speeds much lower than usually used in experiments under which adhesive wear is dominant.

A new, highly sensitive and accelerated method has been developed to determine the ability of cutting fluids to counteract the adhesion between chips and cutting tool. When investigating a universal cutting fluid for milling and turning of structural and stainless steel, it has been found that it is appropriate to recommend the cutting fluid which has the greatest tribometric properties and the best ability to resist adhesion between chips and cutting tool.

In order to reduce labor intensity while creating a new universal CF the following sequence of cutting fluid tests is proposed. In the beginning it is advisable to determine the tribometric properties of all the new cutting fluids and to determine the ability of all the new CFs to resist adhesion between chips and cutting tool. After that the cutting fluid should be determined which has the best tribometric characteristics and the best ability to counteract the adhesion between chips and cutting tool. Next, it is necessary to confirm that this cutting fluid will provide greater tool life compared with the CFs which are already used in industry. If the new CF reveals less resistance compared with the cutting fluids which are already industrially used, it is required to continue the search for a new CF that will have the best tribometric properties and better ability to counteract the adhesion between chips and cutting tool and that can ensure greater tool life than the tool life provided by the CFs already used in industry.

The proposed new cutting fluid test sequence significantly reduces the amount of wear tests and, as a result,

significantly reduces the overall labor intensity in the development of new universal cutting fluids.

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