The selection of optimal cutting inserts made of ceramics or cemented carbide for dry face milling of cast iron and milling using various cutting fluids.

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The use of cutting fluids, in most cases, has a positive influence on the performance of machining operations and the tool life of cutting tools. Using cutting fluids is also necessary for the reduction of the negative effects of finely dispersed chips and graphite dust produced during the machining of cast iron on the environment and human health. The Department of Machining and Assembly of the Technical University of Liberec has been faced with the problem of the reduction of tool life during the milling of cast iron with cutting fluids. During the experiments, the negative influence of cutting fluids on tool life during the milling of cast iron was reduced by the selection of combinations of different cutting materials and types of cutting fluids.

Keywords: Machining, Cutting fluid, Cutting inserts, Wear

1 Introduction

One of the best ways to reduce tool costs during metal machining and increase the performance of machining is the using of cutting fluids [1-3]. However the use of cutting fluids does not guarantee tool life maximisation and best perfomance. Under certain cutting conditions, the use of cutting fluids reduces tool life, and hence reduces the machining performance [4]. The reduction of tool life during machining with cutting fluids could be explained by cutting conditions, specifically by the types of machining operation, processed materials and by the materials of cutting tools [5-8]. The easiest way to eliminate the negative effect of cutting fluids on the tool life - is dry cutting [9-11]. At the same time the machining of cast iron is impossible without cutting fluids. Using cutting fluids reduces the negative effect of finely dispersed chips and graphite dust, produced during the machining of cast iron, on the environment, parts of equipment and human health. It is a problem faced by engineering companies around the world. The Department of Machining and Assembly of the Technical University of Liberec reduces the negative influence of cutting fluids on the tool life during the milling of cast iron by the selection of combinations of different cutting materials and types of cutting fluids. Measurements of cutting parameters were carried out at the Department of Machining and Assembly of the Technical University of Liberec (KOM TUL) and the following research steps were proposed:

- Determine the optimal ceramic cutting inserts offered by global manufacturers for face milling of gray cast iron (1 insert from KENNAMETAL INC (USA), 1 from NTK CUTTING TOOLS (Japan), 1 from SANDVIK COROMANT (Sweden)
- Determine the optimal cemented carbide cutting inserts offered by global manufacturers for face milling of gray cast iron (3 from SANDVIK COROMANT (Sweden), 1 from SECO TOOLS (Sweden).
- Determine the optimal cutting fluid for face milling of gray cast iron – three fluids from global manufacturers.

2 Testing method for milling at the KOM TUL laboratory

Type FNG 32 milling machines were used for the conventional milling experiments at the laboratories of the Department of Machining and Assembly. The following cutting parameters were used for conventional face milling: cutting speed v_c = 600 m/min, feed per tooth f_z = 0.2 mm and depth of cut a_p = 1 mm.

The following cutting inserts were selected for testing: Kennametal SNGA 120408 KY3500 (ceramic), NTK SNGF 120412 SX6 (ceramic), Sandvik R365-150536E 6190 (ceramic), Sandvik R365-1505ZNE-PL 4230, Sandvik R365-1505ZNE-KL 1020, Sandvik R365-1505ZNE-KL K20D, Seco SNKN 1204EN-M10 MK1500.

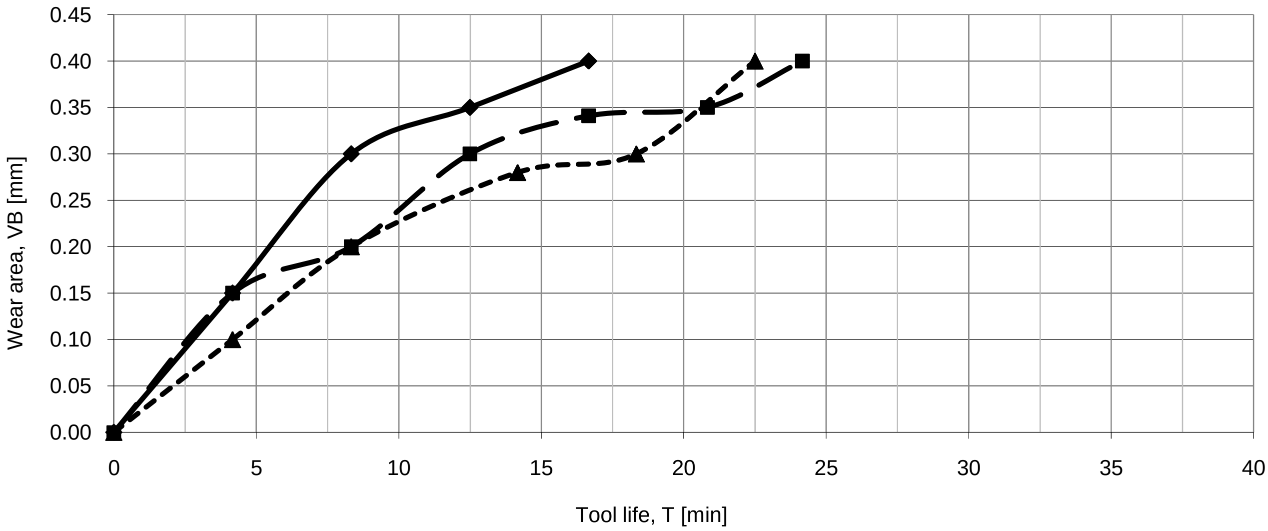
The following cutting fluids were selected for testing: cutting fluid no.1 (mineral oil-based cutting fluid), cutting fluid no.2 (semi-synthetic emulsifying oil), cutting fluid no.3 (emulsifying petroleum oils).

Equipment used included a Narex 2460.12 face milling machine with a diameter of 63 mm and a Sandvik T/U-Max R365 080Q27-S15M face milling machine with a diameter of 80 mm. The milling machines were always fitted with only a single cutting insert. Inserts from the Sandvik Company were fitted into the Sandvik milling machine (Ø 80 mm), inserts from the Kennametal, NTK and Seco companies were fitted into the Narex milling machine (Ø 63 mm).

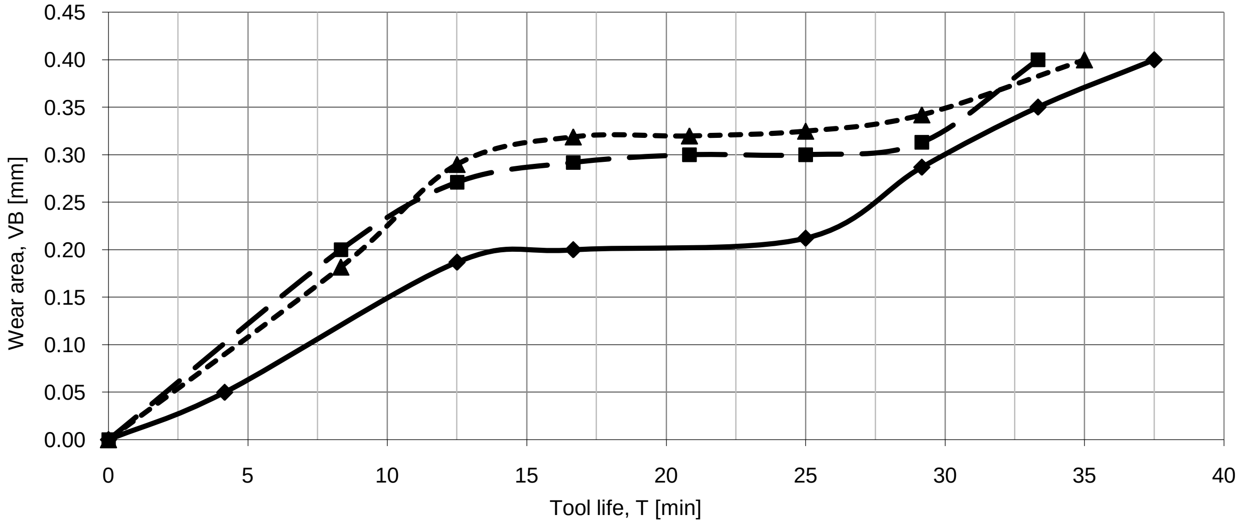
All milling tests were carried out on casts from Unibar 250 material (EN-GJL-250, gray cast iron with lamellar graphite) with a hardness of 170-230 HB. During tool life tests, a key parameter monitored was the width of wear on the ridge of the cutting insert, VB_{kr} = 0.4 mm [12,13]. The width of wear on the insert ridge was measured using a Brinell magnifying glass. All tool life experiments were carried out under constant cutting conditions and repeated three times. Cutting fluid was always diluted to a concentration of 8 % and checked with a Brix refractometer.

3 Assessment of the ceramic cutting inserts

Ceramic cutting inserts from three global manufacturers were tested: KENNAMETAL, NTK and SANDVIK. Fig. 1 shows wear over time of the KENNAMETAL KY3500 insert for both dry cutting and cutting with cooling (cutting fluid no.1). The graph clearly shows that the application of cutting fluid at the cutting site increases the tool life of the KENNAMETAL KY3500 insert by an average of 70%. When dry cutting, critical wear is reached after an average of 21 min., with cooling it is reached after 36 min. of cutting. The greatest tool life and best performance was attained during milling with cooling.



a) dry cutting



b) with cooling

Fig. 1 *Wear over time of KENNAMETAL KY3500 insert*

a) dry cutting; b) with cooling

Testing for both dry cutting and milling using cutting fluid no.1 showed that the application of cutting fluid at the cutting site only marginally influenced the tool life of the NTK SX6 insert. Critical wear was reached after an average of 37.5 min. for both dry cutting and milling with cooling.

Testing of the KENNAMETAL KY3500 insert and the NTK SX6 insert for both dry cutting and milling using cutting fluid no.1 showed that the application of cutting fluid at the cutting site had positive effects on insert tool life. The NTK SX6 insert was found to have the greatest tool life and best performance. This insert was found to be nearly as durable when milling without a coolant as with one. The KENNAMETAL KY3500 insert was nearly as durable as the NTK SX6 insert when a cutting fluid was applied at the cutting site.

Testing of the SANDVIK 6190 insert for both dry cutting and milling using cutting fluid no.1 showed that the application of cutting fluid at the cutting site had a slightly negative effect, decreasing average tool life by 5%. When dry milling, critical wear was reached on average after 41 min., while with cooling it was 39 min. The greatest tool life and best performance was found for dry milling. The application of a cutting fluid at the cutting site had a negative effect on the tool life of the SANDVIK 6190 insert.

To compare the NKT SX6, KENNAMETAL KY3500 and SANDVIK 6190 inserts, the length of cutting L, the working length at which the insert reached critical wear (since the milling machines were different diameters) was calculated. From these measurements, it was found that NKT SX6 inserts performed 5% better than KENNAMETAL KY3500 inserts in terms of working length when milling with cooling, and 12% better than SANDVIK 6190 inserts in terms of working length for both dry milling and milling with cooling.

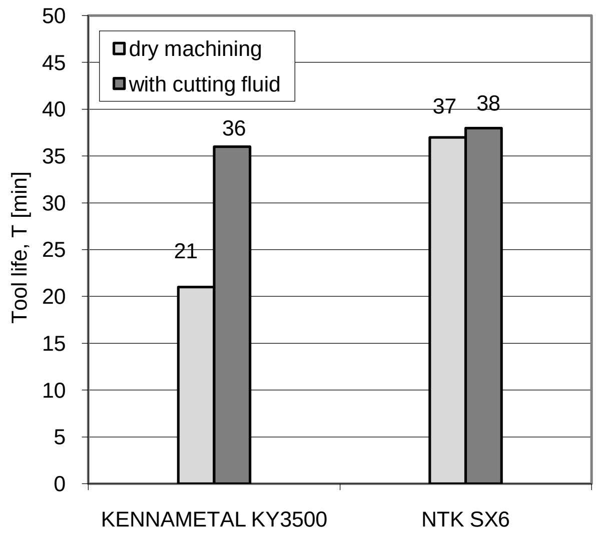


Fig. 2 *Summary graph of working length for NTK SX6, KENNAMETAL KY3500 and SANDVIK 6190 inserts*

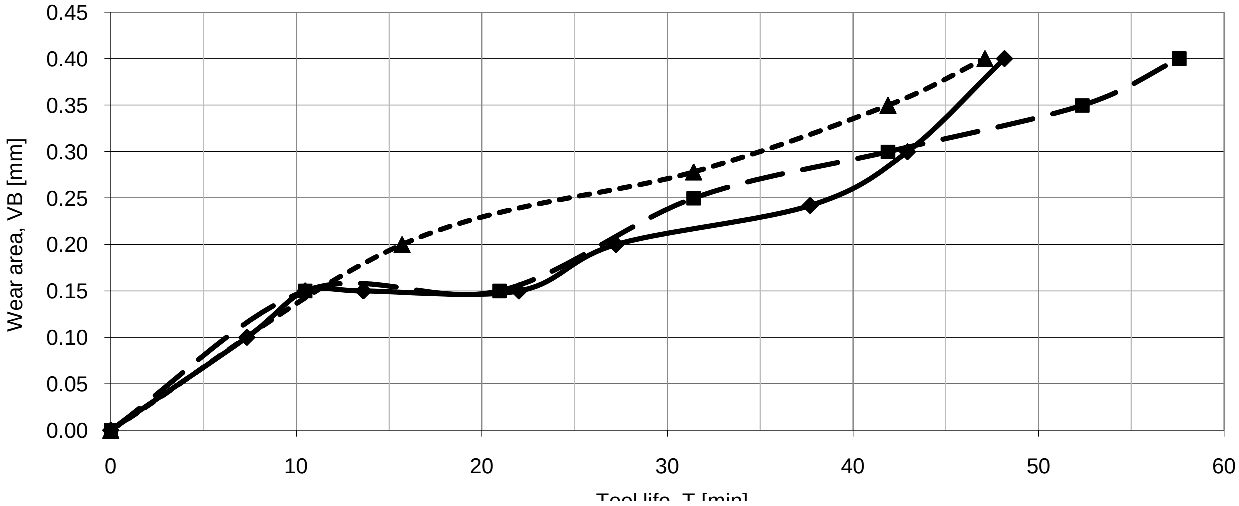
Experiments performed at KOM TUL showed that the application of cutting fluid no. 1 had minimal effect on the tool life of ceramic inserts (except for the KENNAMETAL KY3500 insert). When using the KENNAMETAL KY3500 insert, tool life increased by 40% compared to dry cutting (Fig. 2).

When comparing all ceramic inserts using cutting fluid no. 1, the best performance in terms of working length until critical wear is reached was achieved by the NTK SX6 insert, followed by the KENNAMETAL KY3500 insert (5% worse) and the SANDVIK 6190 insert, which was 14% worse.

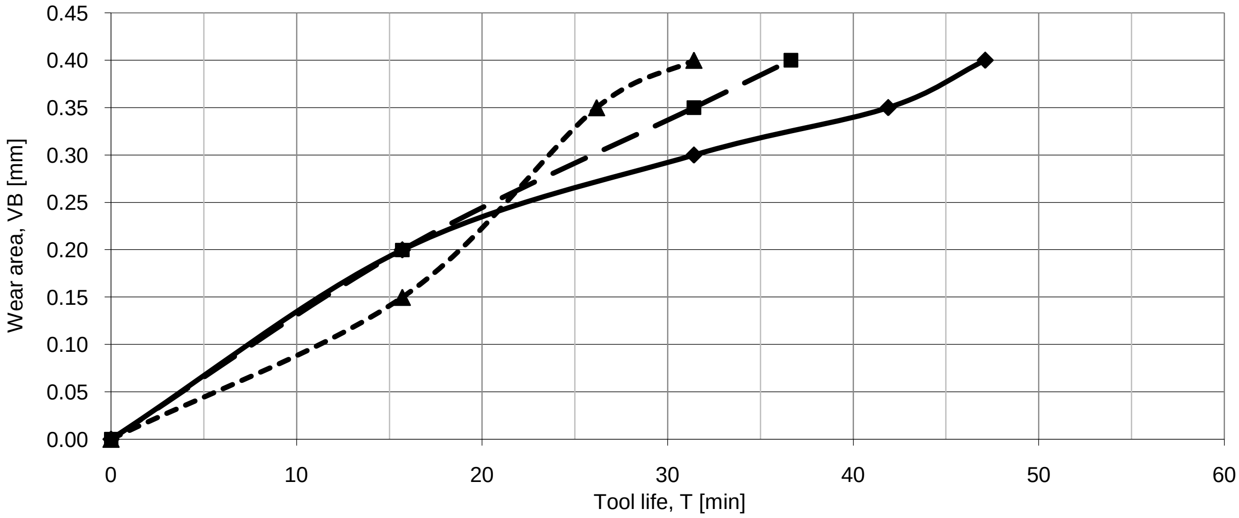
4 Assessment of the cemented carbide cutting inserts

Cemented carbide inserts produced by two global manufacturers: SANDVIK and SECO, were tested.

Fig. 3 shows the wear over time of the SANDVIK 4230 insert for dry cutting and milling with cutting fluid no.1. The graph shows that the application of cutting fluid to the cutting site negatively affects the tool life of the SANDVIK 4230 insert, reducing the tool life by an average of 20%. When dry milling, critical wear was reached on average after 51 min., while with cooling it was 39 min. The greatest tool life and best performance was attained during dry milling.



a) dry cutting



b) with cooling

Fig. 3 Wear over time of the SANDVIK 4230 insert

a) dry cutting; b) with cooling

Testing of the SANDVIK 1020 insert for both dry cutting and milling with cutting fluid no.1 showed that the application of cutting fluid to the cutting site positively affected the tool life of this insert, improving it on average by 23%. When dry milling, critical wear was reached on average after 21 min., or 26 min. when using cooling. The greatest tool life and best performance was attained during milling with cooling (Fig. 4).

Testing of the SANDVIK 4230 insert for both dry cutting and milling with cutting fluid no.1 showed that the application of cutting fluid to the cutting site negatively affected the tool life of this insert, decreasing it on average by 23%. When dry milling, critical wear was reached on average after 51 min., or 39 min. when using cooling. The greatest tool life and best performance was attained during dry milling (Fig. 4).

Testing of the SANDVIK K20D insert for both dry cutting and milling with cutting fluid no.1 showed that the application of cutting fluid to the cutting site negatively affected the tool life of this insert, decreasing it on average by 36%. When dry milling, critical wear was reached on average after 69 min., or 44 min. when using cooling. The greatest tool life and best performance was attained during dry milling (Fig. 4).

Fig. 4 presents a summary graph of the measured tool life of the SANDVIK 4230, SANDVIK 1020 and SANDVK K20D inserts when dry cutting and milling with cutting fluid no.1. The graph shows that with respect to insert tool life, the application of cutting fluid to the cutting site has a negative effect for the majority of inserts tested (with the exception of the SANDVIK 1020 insert, where it had a positive effect). The greatest tool life and best performance was seen when dry cutting with the SANDVK K20D insert. The worst performance was seen when dry cutting with the SANDVK 1020 insert, which was found to be 70% less durable than the SANDVK K20D insert.

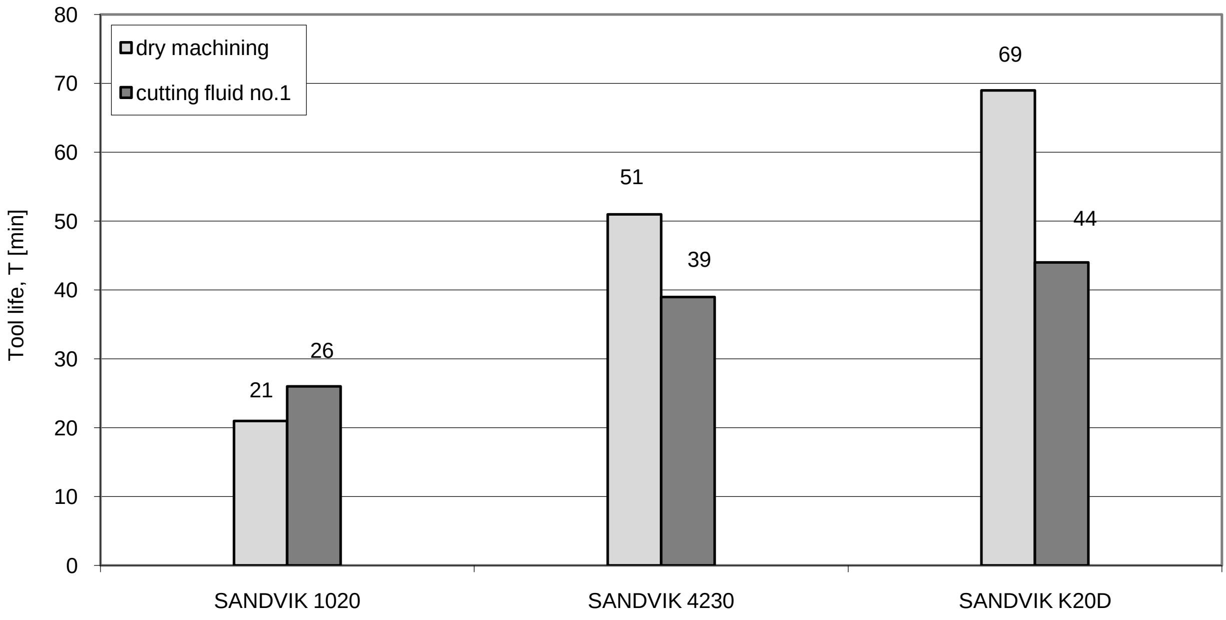


Fig. 4 *Summary graph of measured tool life of the*

VBD SANDVIK 1020, SANDVIK 423 and SANDVK K20D inserts

Testing of the SECO MK1500 insert for both dry cutting and milling with cutting fluid no.1 showed that the application of cutting fluid to the cutting site negatively affected the tool life of this insert, worsening it on average by 16%. When dry milling, critical wear was reached on average after 20 min., or 16 min. when using cooling. The greatest tool life and best performance was attained during dry milling. The application of cutting fluid to the cutting site had a negative effect on the tool life of the SECO MK1500 insert.

To compare the NKT SX6, KENNAMETAL KY3500 and SANDVIK 6190 inserts, length of cutting L, the working length at which the insert reached critical wear (since the milling machines were different diameters) was calculated. From these measurements, it was found that NKT SX6 inserts performed 5% better than KENNAMETAL KY3500 inserts in terms of working length when milling with cooling, and 12% better than SANDVIK 6190 inserts in terms of working length for both dry milling and milling with cooling.

To compare the SECO MK1500 insert with the best performing cemented carbide insert, calculations were done on length of cutting L, the length of cutting at which critical wear was reached (since the milling heads had different diameters) – see Fig. 5. From these measurements, it was found that SANDVIK K20D inserts performed 60% better than SECO MK1500 inserts in terms of length of cutting when dry milling and 50% better when using cooling.

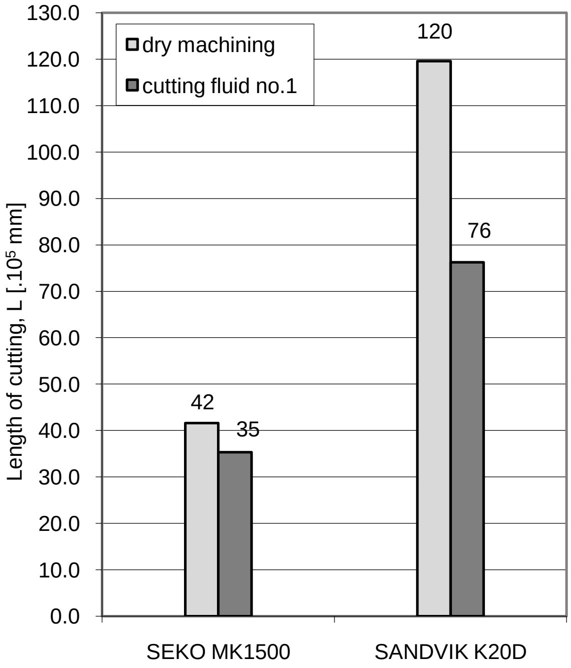


Fig. 5 *Summary graph of length of cutting L for SECO MK1500 and SANDVIK K20D inserts*

Experiments performed at KOM TUL showed that the application of cutting fluid no. 1 had a negative effect on the tool life of cemented carbide inserts (except for the SANDVIK 1020 insert) – see Fig. 4. When using cooling, the tool life of the SANDVIK K20D insert worsened by 36%, the tool life of the SANDVIK 4230 insert worsened by nearly 23% (Fig. 4). However for the SANDVIK 1020 insert, using cutting fluid increased the tool life by 23% over dry cutting (Fig. 4).

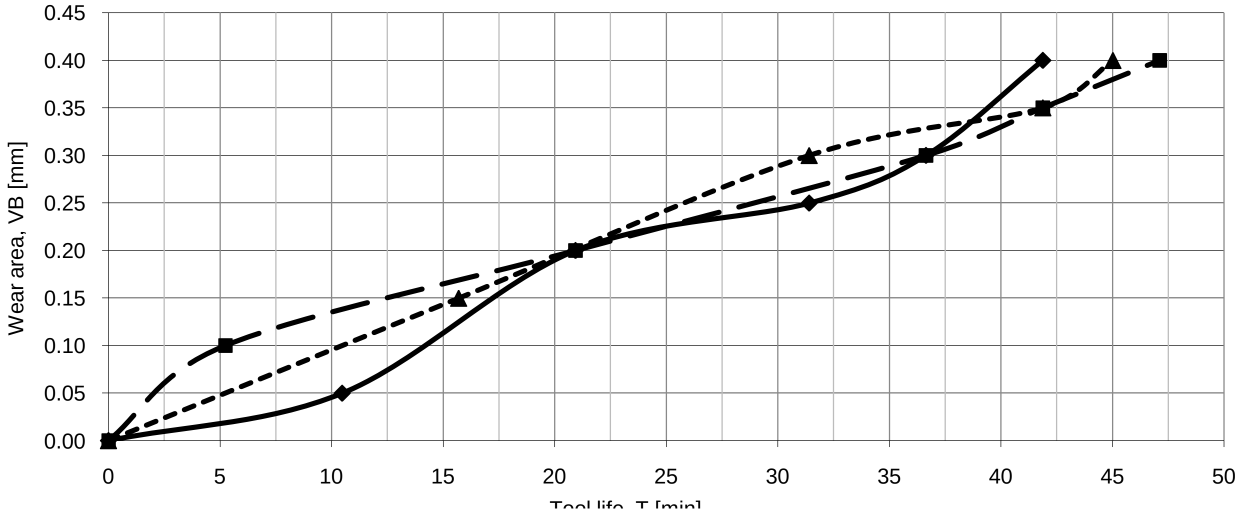
When comparing the performance of cemented carbide inserts (SANDVIK K20D vs. SECO MK1500) it was found that the best performance in terms of length of cutting until critical wear is reached was achieved by the SANDVIK K20D insert when dry cutting, while the SECO MK1500 insert was nearly 65% worse (Fig. 5).

5 Assessment of cutting fluids during milling

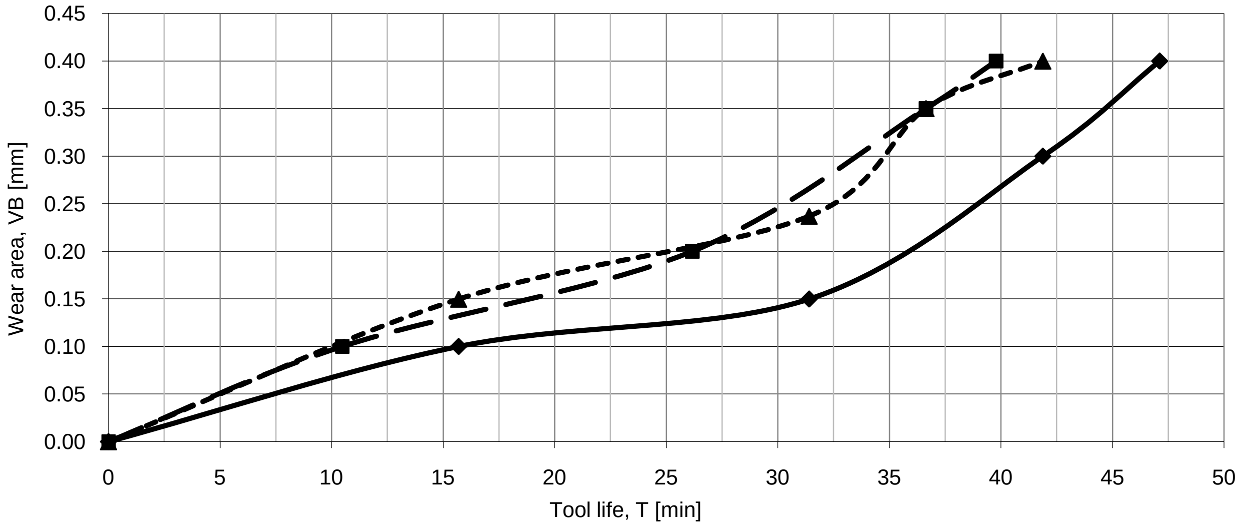
Three cutting fluids were selected. These were made by global manufacturers: cutting fluid no.1 (mineral oil-based cutting fluid), cutting fluid no.2 (semi-synthetic emulsifying oil), and cutting fluid no.3 (emulsifying petroleum oils).

Based on the previous results, the cutting fluids were tested during milling using the SANDVIK K20D and NTK SX6 inserts, which were deemed the best cutting inserts according to previous testing.

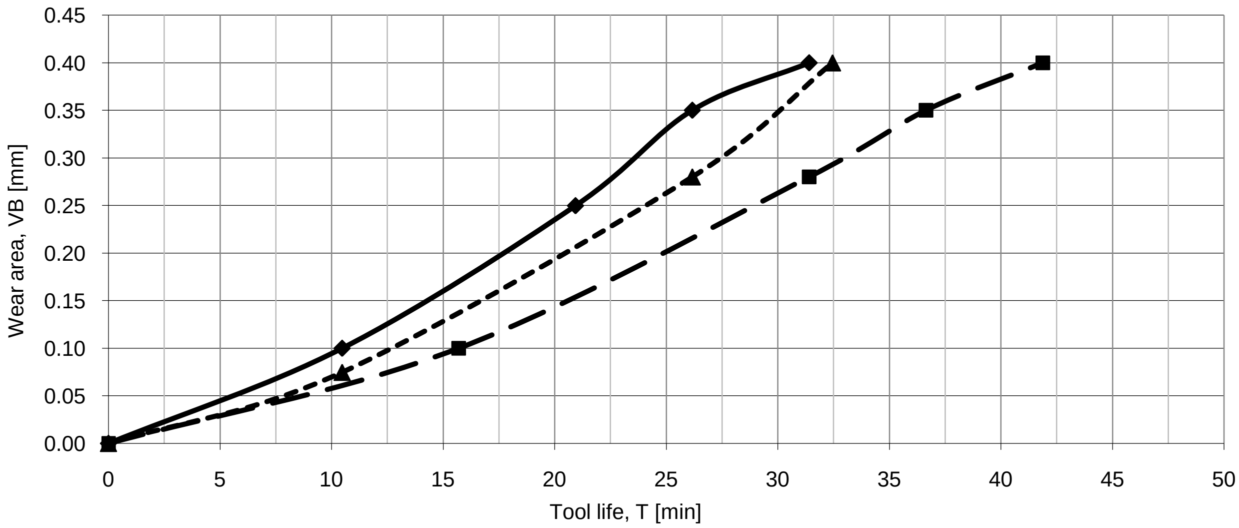
Fig. 6 shows the wear over time of the SANDVIK K20D insert when using cutting fluid no.1 (mineral oil-based cutting fluid), cutting fluid no.2 (semi-synthetic emulsifying oil) and cutting fluid no.3. The graph shows that critical wear was reached on average after 44 min. when using cutting fluid no.1, 42 min. when using cutting fluid no.2, and 38 minutes when using cutting fluid no.3. The greatest insert tool life and best performance was found when using cutting fluid no.1 (mineral oil-based cutting fluid).



a) cutting fluid no. 1



b) cutting fluid no. 2



c) cutting fluid no. 3

Fig. 6 *Wear over time of the SANDVIK K20D insert for various cutting fluids*

a) cutting fluid no. 1; b) cutting fluid no. 2; c) cutting fluid no. 3

Fig. 7 presents the summary graph of the measured tool life of the SANDVK K20D insert for cutting fluid no. 1, cutting fluid no. 2 and cutting fluid no. 3. It is clear from the graph that the greatest insert tool life and best performance was observed when using cutting fluid no. 1. The worst results were seen when using cutting fluid no. 3, where the measured insert tool life was nearly 22% lower than for cutting fluid no. 1.

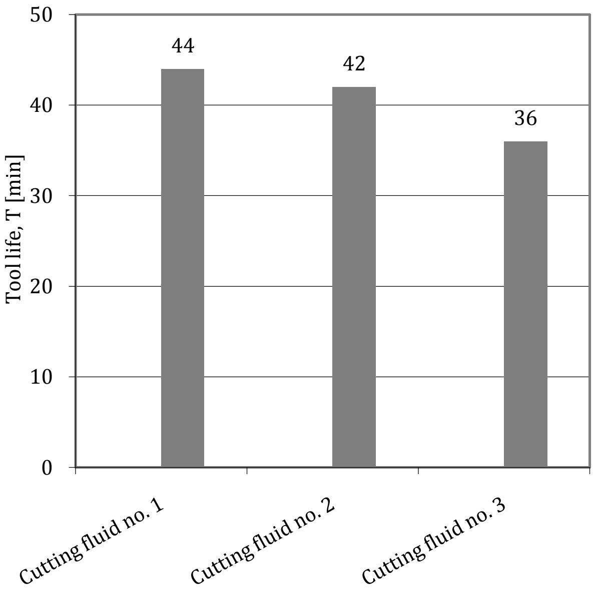


Fig. 7 *Summary graph of insert tool life of the SANDVIK K20D insert for various cutting fluids*

Testing of the NTK SX6 insert when using cutting fluid no. 1, cutting fluid no. 2 and cutting fluid no. 3 showed that when milling with cutting fluid no. 1, critical wear was reached on average after 38 min.; when using cutting fluid no. 2 it was reached after 36 min. and when using cutting fluid no. 3 after 30 min. of milling. The greatest insert tool life and best performance was found when applying cutting fluid no. 1.

Fig. 8 presents the summary graph of insert tool life measured for the NTK SX6 insert when using cutting fluid no. 1, cutting fluid no. 2 and cutting fluid no. 3. The graph shows that the greatest insert tool life and best performance was observed when using cutting fluid no. 1. The worst performance was seen when using cutting fluid no. 3, where measured insert tool life was 26% lower than when using cutting fluid no. 1.

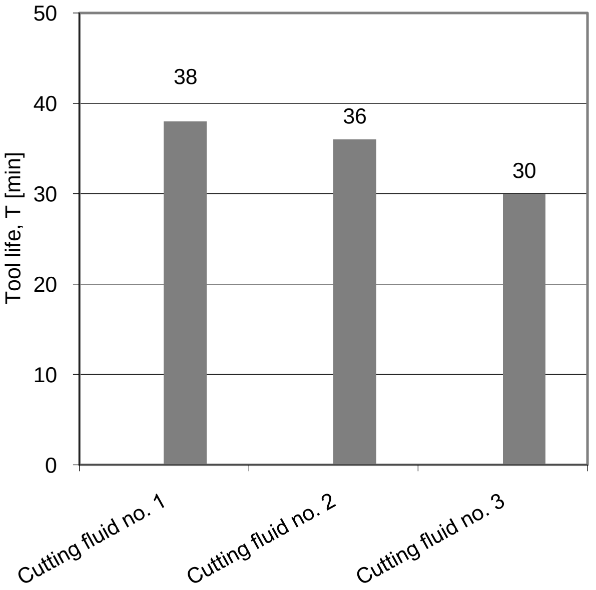


Fig. 8 *Summary graph of insert tool life of the NTK SX6 insert for various cutting fluids*

The experiments performed at KOM TUL showed that the best performance with respect to insert tool life was achieved by cutting fluid no. 1, both when using cemented carbide inserts (SANDVIK K20D), and ceramic inserts (NTK SX6). Cutting fluid no. 2 was found to be second best, performing 6% worse than cutting fluid no. 1. With respect to duration in both cases (cemented carbide, ceramic inserts), cutting fluid no. 3 was found to be about 22% worse – see Fig. 8.

6 Final assessment and practical results of the research

It was proved during the experiments that the use of cutting fluids may cause a negative effect on tool life. During the milling of cast iron, the use of cutting fluids reduces the tool life up to 50%.

It is clear from the experiments conducted at KOM TUL that when milling gray cast iron without the application of a cutting fluid at the cutting site (dry cutting), the best choice is to use a cemented carbide insert. The best results in terms of tool life were achieved by the SANDVIK K20D insert (Fig. 4).

When milling gray cast iron while applying a cutting fluid at the cutting site, it is best to use a ceramic insert. The best results in terms of tool life were achieved by the NTK SX6 insert. NTK inserts performed 5% better when milling than KENNEMETAL inserts (based on technological parameters) and nearly 14% better than SANDVIK inserts (Fig. 2).

With respect to selecting the best cutting fluid for insert tool life, mineral oil-based cutting fluid no. 1 was found to perform best, both when using cemented carbide inserts and ceramic inserts. Semi-synthetic emulsifying oil-based cutting fluid no. 2 performed about 6% worse than cutting fluid no. 1 in terms of insert tool life (Fig. 7 and Fig. 8).

7 Acknowledgments and References

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