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The wear of single flute gun drill and tool life tests

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1. Introduction

Gundrilling is widely used, e.g. in automobile manufacturing for machining deep holes in engine parts. In the automotive industry, there is always room for improvement in the gundrilling process to extend tool life, obtain sufficient quality in holes and, at the same time, increase productivity. In the car industry, production runs are extensive and the time used to machine one part has to be as short as possible while chip flow must be maximized. Changing the work piece material or tool geometry is always a challenge, and tool wear monitoring helps in these situations.

Wear can be measured directly (direct monitoring method) from the tool for example between chancing the work piece into the machine. This visual tool condition monitoring method is used especially during drilling tests in laboratory circumstances, for example when testing drills which have different geometry or coating or when testing new cutting parameters. Tool wear is also measured in order to find the relationship between cutting forces and tool wear. [1-3] However, it is quite time consuming to measure all forms of tool wear and it is also more difficult to draw conclusions on the test results while monitoring several wear types. Moreover, it is difficult to decide how often the tool should be measured (measuring frequency).

Flank wear is present in all cutting operations. It is the best known type of tool wear and it is also relatively easy to measure. At least for a single-point turning tool, the width of the flank wear maximum is a suitable wear measure, and a predetermined value of the flank wear maximum is regarded as a good tool life criterion [4].

In many drilling tests, flank wear is used as an indicator of tool condition, and several attempts have been made to predict the flank wear, e.g. by drilling force signals [1, 5-8]. Measuring the wear of the tool has still remained one of the best tool condition monitoring methods in drilling tests. During the years, many reports have been written concerning the wear of twist drills [2]. The wear of a gun drill differs a bit from the wear of a twist drill [2, 9] due to the special geometry of the gun drill tip, Fig. 1. The wear of a gun drill is less investigated.

The object of this study was to find out the wearing of the gun drill and which of the measured wear types the best indicate the tool condition. For comparing the chosen wear types, gundrilling tests were conducted by using two different kinds of drill geometries. After these tests, the best wear types for predicting the tool condition and suitable measuring frequency were discovered.

2. Gun drills and tool wear

Gundrilling is a deep-hole drilling process. The process produces deep, one–pass, high quality holes. In gundrilling, the cutting speed is high and the feed rate is relatively low, but the penetration rate is higher than that of a twist drill. The method allows the tool to drill the full length of the deep hole without retraction. In the method, cutting fluid is injected with high pressure through the hollow shank. Once the fluid has lubricated the cutting edges of the tip, it escapes along the v-shaped flute of the shank, taking the chips out of the hole. A gun drill needs guidance in the beginning of the drilling. When gundrilling in an NC machine, a pilot hole is used to guide the drill [9]. Drill manufacturers usually recommend the use of a lower feed at the beginning of the drilling and raising the feed after the drill tip has penetrated the material.

Drill wear has an influence on the hole quality, surface finish, straightness of holes, and also on the tool life. Tool life is usually determined by one criterion or several depending upon the drilling conditions and the operational requirements. The most common indicators of the end of tool life are fracture or chipping, excessive wear, and poor surface quality or accuracy of holes [10]. In turning operation, common criteria for sintered carbide tools are, for example, the maximum width of the flank wear land (if the flank is not considered to be regularly worn), the average width of the flank wear land (if the flank is considered to be regularly worn), and the depth of the crater [4]. It has been suggested that outer corner wear should be used as a performance index in drilling when categorizing the drill condition [3]. In several studies, the average flank wear of a twist drill has been measured from a few points on both cutting edges and possibly an average value is then calculated [1, 5, 7, 11]. It also has been recommended to measure, as a performance index in a standard drilling test, three types of outer corner wear and crater wear (width), two types of flank wear (mean and maximum wear), two types of chisel wear (width and length), and margin wear (length). Other wear types have also been used in drilling tests. Researchers have also used the width of the chisel, crater, margin and flank wear and the length of the outer corner wear as drill condition and drill life indicators [3, 8].

The amount of chipping is evaluated to a certain extent by the maximum width of the flank wear. A deep, wide crater far from the cutting edge may be less dangerous to the tool than a less deep, narrow crater close to the cutting edge.

The distance from the cutting edge to the crater is sometimes a useful criterion which, if limited can eliminate catastrophic failure [4].

In principle the drill wear has been suggested to act as an accelerating process which takes place at the outer margin of the flute(s) of the drill due to the intimate contact and elevated temperatures at the tool work piece contact. It is also pointed out how there is a period of initial wear, followed by a period of moderate wear and in the third phase a period of excessive wear [12].

3. Research

In this study, the tool wear was evaluated in tool condition monitoring. Wear types detected in the gun drill are presented in Fig. 1. The selection of wear types measured in this research is based on different wear types detected in gundrilling tests preceding these tests (with two microalloyed steels, and drill different sizes, diameter 5 and 8 mm), and also the performance of the measuring equipment used (measuring software and a microscope which was attached to a tool presetting device). The measured wear types were:

- maximum (V'_B) and mean (V_B) flank wear of the inside and outside edge;
- flank wear in the drill tip (C_T);
- wear in the drill length (W_L);
- wear in the outside corner (W);
- mean crater wear (K_B);
- width of the build-up edge, BUE (average of width of the BUE in the inside and outside edge, measured separately).

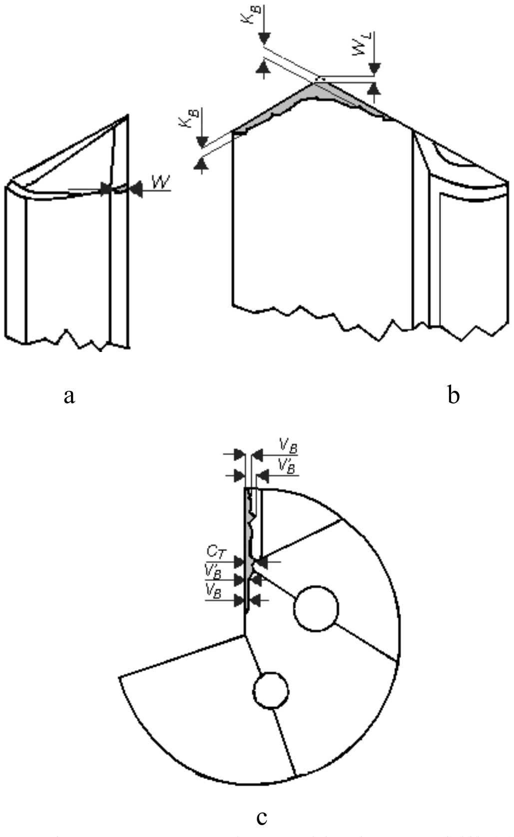

Fig. 1 Various wear types detected in the gun drill (a) outer corner, (b) flute and (c) top of the drill tip [13]

The minimum distance from the front edge of the crater to the cutting edge was not included in this study because it did not change in the previous test.

In this paper, the same kinds of symbols are used for different wear types as have been used generally for wear types of twist drills [3]. Different wear types in Fig. 1 are marked as follows: outer corner wear W, wear in the drill length W_L, mean width of the crater wear K_B, two types of flank wear V_B (mean wear) and V'_B (maximum wear), and flank wear in the drill tip C_T.

Gundrilling tests were carried out in the Horizontal Machine Center. Cylindrical billets (bars) were used as work pieces. Microalloyed steel, which is widely used in the automotive industry, was used as test material. Car engine parts like crankshafts can be made from microalloyed steel. The average Vickers hardness of the test material was 260 HV/30 (KV+20°C). Chemical composition of the test material is shown in Table.

Holes were drilled through the bar to the cross-section. The diameter of the billet was 87 mm and the length was 187 mm. A total length of seven meters was drilled into each bar (40 holes). The holes were positioned into the cross-section of the bar in the way that the minimum distance to the edge of the work piece was 5 mm and between holes at least 2 mm [14].

Single flute gun drills with a solid carbide tip (carbide type H15) and with two different kinds of grindings (drill A and B) were used. In drill A, the inside angle X is 20° and outside angle Y is 30°. In drill B, the X is 25° and the Y 36°, see Fig. 2. The diameter (D) of the drill was 8 mm and the total length 270 mm.

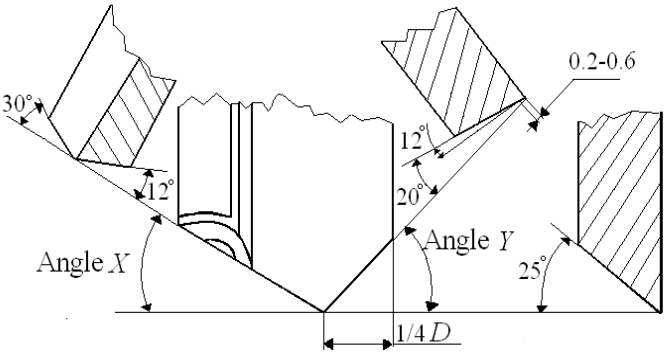

Fig. 2 Geometry of the gun drill

Cutting parameters from the recommended area were used so that the data corresponded to conventional drilling conditions in the industry. Cutting conditions were such that no fractures or chipping would occur before 100 meters (the drill could be reground) and the quality of the holes was good (e.g. arithmetical surface roughness R_a abroximately 1 μm). Surface roughness was measured by a stylus instrument for controlling the quality of the holes. Also chip formation (length, color and form of the chips) was controlled. The coolant used in these test was deep-hole drilling oil (as a base molecularly converted oil, 40 cSt/+20°C).

The cutting parameters were:

- guide hole: length 12 mm and diameter 8 mm;
- gundrilled hole: depth 187 mm;
- spindle speed: $n = 3200$ 1/min (cutting speed $v_c = 80$ m/min);
- feed: f_1 for the first 50 mm of the hole 80 mm/min (0.025 mm/r), and after 50 mm depth f_2 = =96 mm/min (0.03 mm/r);
- oil pressure: $p = 6$ MPa (60 bar).

Table

Chemical composition (%) of the test material

C	Si	Mn	P	S	Cr	Ni	Mo	V	Ti	Cu	Al	N
0.36	1.26	1.08	0.01	0.059	0.2	0.14	0.03	0.117	0.014	0.18	0.016	0.011

Tool wear was measured and the tool was photographed regularly after drilling. Because of the adhering material, many of the wear types in the drill are difficult to measure. Therefore, pictures of the drill were taken and used to help to compare the tool wear. The drilling was stopped after each bar, and the drill was taken out of the machine to measure the tool wear. After measuring, the test continued with a new work piece.

With both drills, 49 meters was drilled. After that, the drills were compared and the drilling continued with a less worn drill until the maximum flank wear (V'_B) was 0.3 mm in the flank wear land.

4. Results

After 49 meters of drilling, tool A was found to be less worn. Pictures of the worn tools A and B are presented in Fig. 3. Drilling continued with drill A. The total drilled length with drill A was 105 meters (a flank wear limit of 0.3 mm was achieved in the drill tip). Fig. 4 includes figures of drill A after 105 meters drilling.

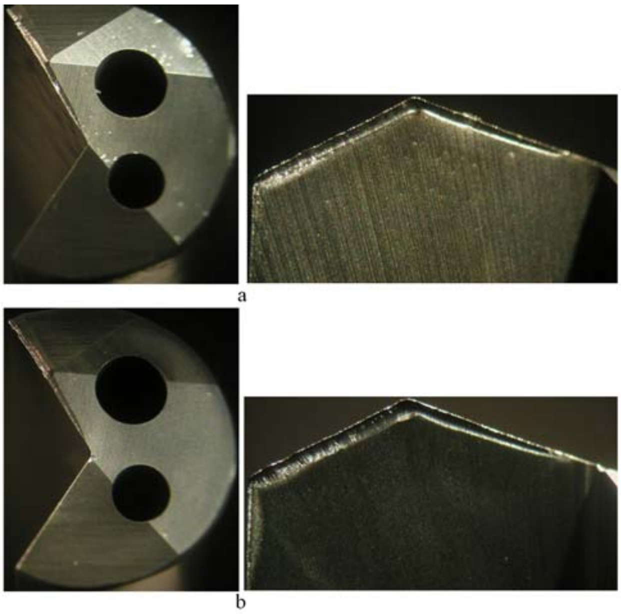

Fig. 3 Drills A (a) and B (b) when 49 meters was drilled. Flute (right) and top of the drill tip (left)

Figs. 5 and 6 present the progress of the drill wear. Wear in the outer corner (*W*) increased quickly at first (during the first 7 meters), but later increased slowly (Fig. 5). Other wear forms presented in Fig. 5 increased at a constant rate.

The maximum values of flank wear in the drill tip, in Fig. 5, were measured after there were clear maximum peaks in the worn area.

In addition to the mean and maximum flank wear, the average flank wear was calculated. It consisted of four values: mean and maximum flank wear values on outside and inside edges. The average flank wear was calculated as follows:

$$\text{Average flank wear} = \frac{V'_{B1} + V_{B1} + V'_{B2} + V_{B2}}{4} \qquad (1)$$

where V_{B1} is the mean and V'_{B1} the maximum flank wear on the inside edge and V_{B2} is the mean and V'_{B2} the maximum flank wear on the outside edge. During the first 49 meters there was no clear maximum flank wear value on the inside edge.

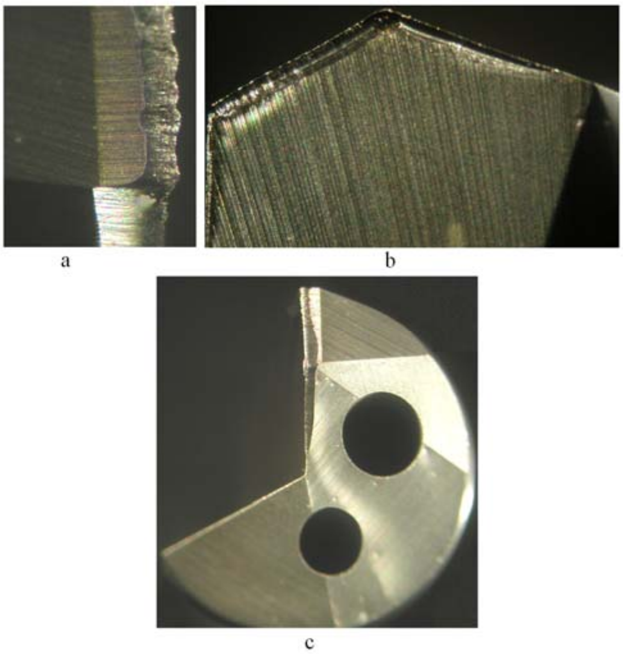

Fig. 4 Drill A when 105 meters was drilled (right). (a) outer corner, (b) flute and (c) top of the drill tip

5. Discussion

The greatest differences between the wear of the two drills, A and B, were in the width of the flank wear of the tip (C_T) and the wear in the drill length (W_L). The flank wear measuring was not always easy. In the flank wear area there was not always a clear point for the maximum (V'_B) and mean flank wear (V_B), especially when the drill was quite new (less than 49 meters was drilled). Comparison of the wear of different drills was easy with the pictures taken.

The average flank wear (V_B average) seemed to be a more reliable indicator of the tool condition than a single value measured from the wear area. Hence the significance of a single value is smaller, and for example small dimensional errors do not have a significant effect on the wear curve. The maximum (peak) values of flank wear are important and those measurements should be included when calculating the average flank wear, like in this study. As it can be seen from the results, the calculated flank wear average value indicates the tool condition sufficiently.

Some wear types, for example crater wear (K_B) and wear in the drill length (W_L), were difficult to measure accurately mostly because of the BUE (build-up edge)

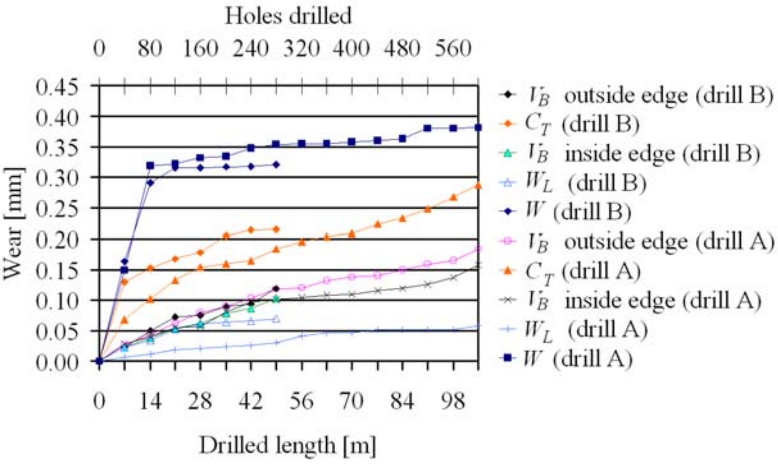

Fig. 5 Mean (V_B) and maximum (V'_B) flank wear on the edges, flank wear in the drill tip (C_T), longitudinal wear (W_L) and outer corner wear (W)

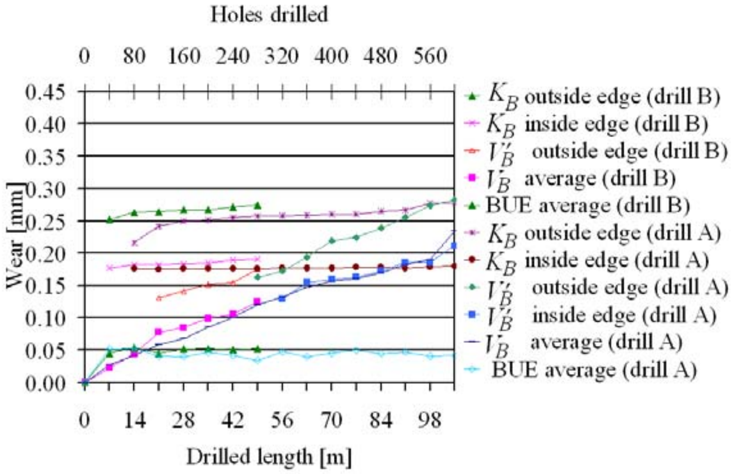

Fig. 6 Crater wear (K_B), build-up edge and maximum (V'_B) and average (V_B average) values of flank wear

formed on the inside and outside edges. The amount of build-up edge changed slightly during drilling, but no stable increase in the drawn curve was detected. On the inside edge the width of the crater wear did not increase much after 7 meters of drilling. The depth of the crater was not measured because measuring of the crater wear depth is not possible using only a microscope. The pictures show that the depths of the craters increased when the drilling length increased. The depth of the crater wear on the outside edge should not be forgotten because it affects the regrinding. Gun drill manufacturers recommend that the flank wear limit for regrinding should be 0.3 mm. After the limit is passed, regrinding is not cost-effective. However, the depth of the crater and the distance from the cutting edge to the crater can, in some cases, grow very fast and cause tool failure. That is why inspecting the size and position of the craters of a drill few times during the drilling tests is important. Measuring it constantly does not bring additional value to tool condition monitoring. The drill has to be inspected so that there is no chipping or preliminary failure in the tool and at same time craters can be checked.

Wear in the outside corner (W) grew quickly at first (during the first 14 meters), but later increased slowly. Measuring the outside corner wear was one of the most challenging tasks. Corner wear, from the direction seen in Fig. 7, could be a good indicator of tool condition but is difficult to measure because of the build-up edge. It is a suitable measure for cases where BUE forming is small. The width of the margin of a new tool seemed to affect the width of the corner wear. A solution to this problem could be found by using a non dimensional parameter: the ratio of width of the wear land on the outer corner to the width of the margin of a new drill [15, 16].

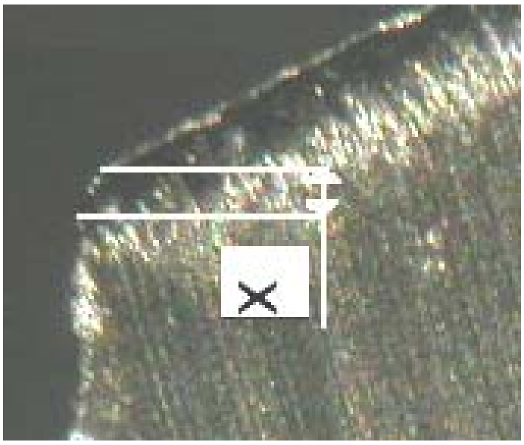

Fig. 7 Corner wear from another direction (marked as X)

In the present study one type of corner wear was detected in addition to the one which was measured, number 2 shown in Fig. 8. Based on the measurements and pictures taken in this study, the outer corner wear should be measured from two places, as in Fig. 8, or at least value 1 should be measured. In this research, wear type 2 increased quickly to a nearly constant value and thereby it did not give any additional information on the tool condition when the drilling continued. From the pictures taken it could be seen that wear type 1 grew steadily until the drilled length of 105 meters was reached.

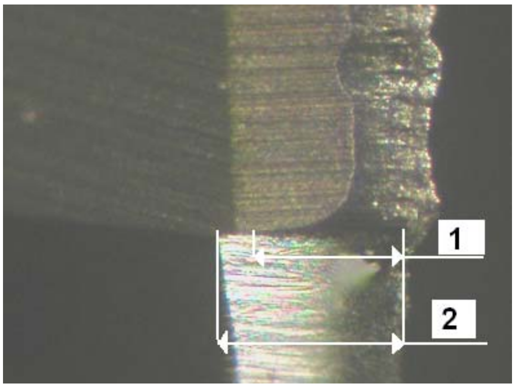

Fig. 8 Outer corner wear types

The surface roughness did not change significantly when the drilled length increased. The R_a-value was mainly below 0.8 µm. The forms and shapes of chips with both drills were about the same with the new and the worn drill.

6. Conclusions

Based on this study, the best wear types for predicting the condition of a gun drill when the work piece material is microalloyed steel are flank wear in the drill tip (C_T), the average flank wear (V_B) and the mean and maximum flank wear (V'_B ,V_B) on the outside edge. If calculating the average flank wear then the mean and maximum flank wear values are not needed when monitoring tool condition.

The width of the crater wear (K_B) on the outside edge and wear in the drill length (W_L), the mean and maximum flank wear on the inside edge (V_B, V'_B) and the type of outside corner wear measured in this study are not such good indicators of the end of tool life or did not give any more valuable data than those mentioned above. Although the maximum flank wear value on the inside edge would, in some cases, be an accurate tool condition indicator, is not a very suitable variable for example when comparing the maximum flank wear of two drills because during the first 49 meters there was no clear maximum value on the inside edge.

The build-up edge and width of the crater wear (K_B) on the inside edge were the least informative measured parameters in predicting tool life. None of the measured wear types in this study is alone adequate to indicate the tool condition.

In the case of drilling other steels than microalloyed steel, the tool wear can be slightly different. The difference would probably be in build-up edge formation which depends mainly on the hardness of the material (the lower the hardness is, the more build-up edge tends to form). When there is less BUE formation the measuring of wear is easier. Other difference can appear in the width of the crater wear. In the case of this study the crater wear was quite wide. As concluded earlier, in the end the crater wear is not a good parameter for predicting the tool condition and other wear forms are more significant. Otherwise the wearing of the drill should be similar when drilling different steels.

In these tests the measuring distance was 7 meters, and especially when the drill was slightly worn the wear did not increase significantly. The measuring frequency could be longer with a new drill and shorter with a worn drill. If the cutting parameters had been higher, the wear could have been more aggressive already with a new drill, making the 7-meter measuring frequency appropriate. It can be said that a 5-10-meter measuring distance in gundrilling tests is adequate.

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VIENAŠMENIO ŠAUTUVŲ GRĄŽTO NUSIDĖVĖJIMO IR ILGAAMŽIŠKUMO TYRIMAS

Reziumė

Mašinų gamyboje didelis našumas pasiekiamas gerinant pjovimo parametrus, kuriant naujus įrankius, darbines medžiagas. Gręžimo sąlygų patikra padeda parinkti tinkamus pjovimo parametrus esant ypatingoms apdirbimo sąlygoms, pavyzdžiui, apdirbant naujas technologines medžiagas. Įrankio nusidėvėjimą laboratorinėmis sąlygomis galima išmatuoti gana lengvai.

Šių tyrimų tikslas – nustatyti šautuvų grąžto nusidėvėjimą ir išmatuotų nusidėvėjimų tipus, kurie geriausiai apibūdina įrankio būklę. Tyrimų metu buvo nustatyti įvairūs šautuvų grąžto nusidėvėjimo tipai. Išbandant juos, buvo naudojami dviejų skirtingų geometrinių formų šautuvų grąžtai. Atrodo, kad šautuvų grąžto būklę geriausiai apibūdina jo antgalio užpakalinio paviršiaus nusidėvėjimas (C_T), vidutinis užpakalinio paviršiaus nusidėvėjimas (V_B) ir pagrindinio užpakalinio paviršiaus išorinės briaunos nusidėvėjimo vidutinė reikšmė (V_B, V'_B).

I. Sihvo, J. Varis

THE WEAR OF THE SINGLE FLUTE GUN DRILL AND TOOL LIFE TESTS

Summary

In the machining industry, the demand for higher productivity can be gained with higher cutting parameters and also by developing new tools and work materials. Drill condition monitoring assists in choosing suitable cutting parameters for specific applications, e.g. for new work material. In addition, tool wear can be measured quite easily in laboratory conditions.

The object of this study was to ascertain the wearing of the gun drill and the measured wear types that the best indicate the tool condition. In the present study, different tool wear types were found in the gun drill. To test these wear types, gundrilling tests were carried out by using two different kinds of drill geometries. The best wear types for predicting the condition of a gun drill seem to be flank wear in the drill tip (C_T), the average flank wear (V_B) and the mean and maximum flank wear (V_B, V'_B) on the outside edge.

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ИССЛЕДОВАНИЕ ИЗНОСА И ДОЛГОВЕЧНОСТИ ОДНОЛЕЗВИЙНОГО ПУШЕЧНОГО СВЕРЛА

Резюме

Высокая продуктивность в машиностроении обеспечивается путем улучшения параметров резания, созданием новых инструментов и рабочих материалов. Контроль условий сверления помогает подобрать подходящие параметры резания в особых условиях обработки, например при обработке новых рабочих материалов. Износ инструмента в лабораторных условиях может быть измерен сравнительно легко.

Цель исследований – установка степени износа пушечного сверла, установка типа измеренного износа, который наилучше характеризует состояние инструмента. Во время исследований пушечного сверла устоновлены типы износа. При тестировании использовались два сверла с различной геометрией. Установлено, что состояние пушечного сверла наилучше характеризует износ наконечника его задней поверхности (C_T), средний износ его задней поверхности (V_B) и средняя величина максимального износа на внешней стороне его основной задней поверхности (V_B, V'_B) .

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