Append-Fig. 2.

(10) The frequency distribution of tool life may not be normal, but the result in the paper may assume normal distribution. However in fact the result in the tests are analyzed on the small sample theory in statistics.

(11) The question pointed out by Dr. Sata concerns the wear mechanism of ceramics. According to hot wear tests which the authors performed, the chance of chipping of alumina particles increases besides the steady wear, as the testing temperature is elevated. Append-Fig. 3 illustrates it. The chipping is cotinuous with the temperature and does not suddenly occur. And also the fluctuation of wear volume will increase with an increase of breakage of particles.

Such wear mechanism of ceramics will be negligible the third term itself in Dr. Sata’s equation, namely the third term in the formula can include in \( w \) of the second term. Therefore our equation is useful for the analysis of wear process.

The crater wear of the ceramic tool was 20 to 30 microns deep at 500 m/min. Variance of the wear was not calculated.

(12) In machine shops, up to the present the instances of the ceramic tool having been used for a production process are very few. According to reports, the cutting speed of 300 to 400 m/min is recommendable for 0.4% carbon steel. The tool life at these speeds was 15 to 60 min. The authors consider from their tests that the testing conditions are sufficient practically, contrary to Prof. Wakuri’s comments. Moreover the wear mechanism of the ceramic tool is invariable under any conditions, though tool breakage may occur. In short, the ceramics would wear in the same mechanism as other tools until the tool breakage occurs.

621.914.1.027.4:669.018.9

Utilizing TiC Cermet in Face-Milling*

By Keiji Okushima** and Tetsutaro Hoshi***

A higher production rate of face-milling will be realized if a more abrasion resistant but less tough tool material can be used without breakage. For this purpose, titanium carbide cermet tool material is studied for utilization in steel face-milling. The main problem is to provide the effective land and the proper rake angle to the cutting edge. The land strengthens the cutting edge against the impact, while the proper positive radial rake recovers the sharpness which is lost by the land.

Basic studies with single bladed cutters presented enough knowledge for the design of a TiC cermet cutter. According to the basic data, a multi-bladed TiC cermet throw-away cutter was designed and examined in an experimental run. The trial multi-bladed cutter proved a good utility of TiC cermet in steel face-milling.

1. Introduction

Development of titanium carbide cermet tool material is highly appreciated in lathe turning. This material has a greater abrasion resistance than the carbide tool material as well as a greater toughness than the ceramic tool material. But in the field of face-milling, the toughness of a tool material is much more important than the abrasion resistance because of the shock of intermittent cutting. That is why the face-milling of steel today employs mainly a soft grade of carbide such as P30. If a harder grade can be safely used without breakage, a higher production rate of face-milling will be realized due to the higher abrasion resistance of the material which enables a higher cutting speed.

An idea to utilize a tool material of less toughness in face-milling has been brought up as a conclusion to a series of studies on the breakage of the carbide face-milling cutter\(^{14}\). As a trial of this idea, a series of studies was devoted to utilization of titanium carbide cermet (referred to as cermet in
the following) in face-milling of steel.

2. Problems of cermet cutter

2-1 Problem of low speed breakage

Previous study classifies the breakage of carbide milling cutter into two general types. One is a low speed breakage of the cutting edge which occurs without any preceding occurrence and growth of cracks inside the tool material. This type is so named for the fact that it tends to occur when the cutting speed is low.

A brittle tool material bears low speed breakage easily. It tends to occur also when the impact of contact between cutting edge and work material is intense, and when the tool tip is cooled enough before the contact. These facts lead to the conclusions that the low speed breakage is caused mainly by the impact of contact, and that when the tool material is brittle, including when it is brittle due to low temperature, the breakage occurs easily. Another cause of the low speed breakage is the fact that the built-up edge or the chip sometimes remains adhesive on the cutting edge during the non-cutting period. At the next contact between tool and work, a part of the tool material is split with the built-up edge or the chip.

Since the cermet is far more brittle than the carbide, it is quite easy to bear low speed breakage. The first problem with a cermet cutter is to find a successful way to prevent this breakage. Possible ways are:

(1) To so select the cutter diameter as to make a short non-cutting period and have the tool tip temperature fluctuation in a high range.

(2) To use a cutting fluid, which has a good lubricating effect but the least cooling effect. This prevents a built-up edge or chip adhesion on the cutting edge.

(3) To make a land on the cutting edge. The first two may not be expected to produce much effect. The last way of making a land on the cutting edge will be very effective in preventing low speed breakages. The land renders the cutting edge insensitive to mechanical impacts. If the land is not wide enough, there remains a possibility of low speed breakage; if it is unnecessarily wide, however, the tool life suffers from it.

2-2 Problem of high speed breakage

The other type of the breakage of carbide face-milling cutter occurs as the result of the growth of cracks which have been initiated near the cutting edge. Therefore, it is believed to be a fatigue of the tool material. This type of breakage is further classified into several types, each of which is due to a singular crack. Since these breakages occur earlier at a higher cutting speed, they are called high speed breakages. When a milling operation is stable without any low speed breakage, a high speed breakage often determines the tool life of the cutter; otherwise, the ordinary tool wear determines it.

Among several types of high speed breakages, the chipping from the flank is considered due to impact fatigue. This is caused by a growth of a crack on the flank which initiates on the flank or on the land nearly parallel to the cutting edge. Chipping from the flank appears at a rather low cutting speed compared with other types of high speed breakages. It readily occurs when the shock of contact is intense and when the tool tip is cooled enough before the contact. It also tends to occur when a coolant is used as the cutting fluid. It is saved by providing a land to the cutting edge. These facts yield the inference that a chipping from the flank is due to mechanical impacts, and that the carbide suffers from impact especially when it is cooled.

Another type of high speed breakage is considered due to a high temperature fatigue. This is a chipping from the rake face which is caused by a cross crack on the rake face near the cutting edge. This crack initiates on the rake face, near the cutting edge, and parallel to the cutting edge. Chipping from the rake face occurs at a higher cutting speed than the chipping from the flank. From the behaviours of this breakage under many variations in cutting conditions, it is inferred that this breakage is due to a high temperature fatigue of the carbide under repeating stresses which are caused by the cutting force at a high temperature. Hence, in general, this breakage tends to occur when the mechanical stress caused by the cutting force is larger, and when
the temperature of tool tip attains higher values during the cutting period.

The boundary cutting speed between the range of chiping from the rake face and that of chipping from the flank is illustrated in Fig. 1. In a logarithmic cutting speed-tool life diagram, the tool life curve by the chipping from the rake face (A) is a little steeper than that by the chipping from the flank (B). The intersection of these two curves gives the boundary cutting speed. A variation in the cutting condition varies the inclination and elevation of both curves. Ascertained knowledge about these variations are listed in Table 1. For example, when either using a cutting fluid or increasing the cutter diameter with a constant width of the work piece, the tool life curve AB in Fig. 1 shifts to something like C. Increasing the feed rate in using a cutting edge without a land shifts AB to something like D.

A variation in the tool material also changes the type of breakage. A tougher but a less abrasion resistant grade, compared with the opposite case, has a longer tool life as far as the chipping from the flank is concerned, because a greater toughness means more resistance to impact fatigue.

Since a greater abrasion resistance is associated with a higher hardness at an elevated temperature, a more abrasion resistant grade probably has a larger resistance against high temperature fatigue. Additionally, since a more abrasion resistance results in a less wear which ensures a less increase in the tool force and cutting heat, the situation of high temperature fatigue after a long time of use is easier for a more abrasion resistant grade than for the opposite case. Thus, replacing the tool material with a more abrasion resistant but more brittle grade transforms a tool life curve as AB in Fig. 1 into something like C. This is the case when a carbide is replaced with a cermet. Namely, a cermet cutter has a far wider region of the chipping from the flank than a carbide cutter. When it is successfully used with a land on the cutting edge, the cermet cutter will mostly end up with a chipping from the land as shown in Fig. 2.

2-3 Selection of land width and radial rake

Since a land improves the impact strength of the cutting edge, it prevents both low speed breakage and impact fatigue breakage. But the cutting edge with a land generally tends to bear cross cracks on the rake face near the cutting edge. Two cutting edges, one with a land and another without, are compared in Fig. 3 after the identical cutting time under the identical cutting conditions. One with a land bears a cross crack on the rake face near the cutting edge. This fact possibly means that the land promotes the high temperature fatigue of the tool because it dulls the cutting edge. It is also for this reason that the cutting edge with a land wears faster than the sharp edge as seen in Fig. 3.

From the view point of the cutting force, a cermet cutter is disadvantageous because it needs a land in order to be free from low speed breakage. In order to improve this situation, it is recommended to make the radial rake positive.

It was proposed by Armitage and Schmidt in 1944 to decrease the cutting force by providing a positive second radial rake to the carbide cutter. According to them, primary -6° radial rake face has a width of 1 to 2 times the feed per tooth; thus main chip formation is achieved by the primary rake face. The land in the present paper is a primary negative rake face which is just a chamfer of the edge, and the second rake face is expected to achieve the main chip formation.

Although a larger radial rake decreases the cutting force, it again weakens the cutting edge

Tool material: cermet, work material: S45C, cutter diameter: 94 mm, width of land: 0.2 mm, radial rake: +15°, width of cut: 90.0 mm, cutting velocity: 267 m/min (905 rpm), feed: 0.30 mm/tooth, depth of cut: 1.50 mm, number of cutting cycles: 2520.

Fig. 2 The typical chipping from land on cermet cutter

<table>
<thead>
<tr>
<th>Variation</th>
<th>Cause</th>
<th>Line A</th>
<th>Line B</th>
<th>Boundary speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased cutter diameter (Constant width of cut)</td>
<td>Increased impact and lowered temperature cycle</td>
<td>Lowered</td>
<td>Raised</td>
<td>Increased</td>
</tr>
<tr>
<td>Increased cutter diameter (Constant cutting time ratio)</td>
<td>Unchanged impact and raised temperature cycle</td>
<td>Unchanged</td>
<td>Lowered</td>
<td>Decreased</td>
</tr>
<tr>
<td>Increased feed (Cutting edge without land)</td>
<td>Increased impact and raised temperature cycle</td>
<td>Lowered</td>
<td>Lowered</td>
<td>Decreased</td>
</tr>
<tr>
<td>Application of cutting fluid (Cooling action)</td>
<td>Lowered temperature cycle</td>
<td>Lowered</td>
<td>Raised</td>
<td>Increased</td>
</tr>
</tbody>
</table>
against the impact. Then a larger radial rake has an effect on the breakage just opposite to a wider land. The optimum radial rake and land width should be determined in relation with both the low speed and the high speed breakages.

3. Procedure, material, and equipment for the experiment

Cutting experiments are carried out for the quantitative research on the cermet cutter problems. Basic experiments employ a single bladed face-milling cutter, but not any cutting fluid. Main parameters to be varied are the cutter diameter, land width, and radial rake. The experiment consists of the following five series:

1. Determination of the land width necessary to prevent low speed breakage.
2. Cutting force measurement on a lathe for various land widths and radial rakes.
3. Effect of land width and radial rake on high speed breakage.
4. Comparative tool life test of cermet and carbides.
5. Test run of a trial multi-bladed cutter.

The material and equipments are as follows:

Tool: Throw-away inserts are used with a holder which is attached to a cutter body so as to make a single bladed face-milling cutter. Some tips of cermet inserts have grooves parallel to the peripheral cutting edge so as to have the intended radial rake angle. Fig. 4(A) shows an insert with grooves.
The land is ground by a hand lapper (220 grit) to the shape as Fig.4(B), namely so as to make the angles equal between the land and the rake face and between the land and the flank, and to have a constant width along the peripheral, nose, and face cutting edges. Carbide grades for the comparative tool life test are triple carbides P05, P10, P15 and P25. Tool geometries are listed in Table 2.

Work material: S45C is tested mainly, whereas S50C is tested in some parts. The comparative tool life tests are conducted on both of them. Their composition and hardness are listed in Table 3. The cut widths are 90.0 mm and 102.0 mm. The cutting time ratio and the engage angle for various cutter diameters and cut widths are listed in Table 4. The center of the cutter is always located at the center of the width of cut.

Milling machine: Hitachisesakusho No.2 horizontal milling machine. Main motor power 7.5 HP. Spindle speed 33-2000 rpm. Table speed 8-1000 mm/min.

4. Determination of the land width necessary to prevent low speed breakage

Low speed breakage should be prevented in practical cutters. Since the largest impact occurs with the largest cutter, the land width sought for a 393 mm cutter diameter will suffice for other smaller diameters.

With a constant depth of cut of 2.0 mm, a certain combination of cutting speed and feed per tooth is examined whether a low speed breakage occurs under that condition after machining 50 mm length of the work piece. After examining many combinations of cutting speeds and feeds per tooth, a boundary curve of low speed breakage is drawn.

4-1 Effect of land width

Fig.5 shows the boundary curves for 0.05 mm and 0.1 mm wide lands. The upper side of the curve

<table>
<thead>
<tr>
<th>Cutter diameter</th>
<th>90.0 mm width of cut</th>
<th>102.0 mm width of cut</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cutting time ratio</td>
<td>Engage angle</td>
</tr>
<tr>
<td>94</td>
<td>0.40</td>
<td>72°</td>
</tr>
<tr>
<td>111</td>
<td>0.30</td>
<td>54°</td>
</tr>
<tr>
<td>172.5</td>
<td>0.275</td>
<td>31.5°</td>
</tr>
<tr>
<td>393</td>
<td>0.075</td>
<td>13.5°</td>
</tr>
</tbody>
</table>

Table 3 Composition of cutter diameters and widths of cut

<table>
<thead>
<tr>
<th>Cutter diameter</th>
<th>90.0 mm width of cut</th>
<th>102.0 mm width of cut</th>
</tr>
</thead>
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<tr>
<td></td>
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<td>111</td>
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<td>54°</td>
</tr>
<tr>
<td>172.5</td>
<td>0.275</td>
<td>31.5°</td>
</tr>
<tr>
<td>393</td>
<td>0.075</td>
<td>13.5°</td>
</tr>
</tbody>
</table>

Feed mm/tooth

Tool material: cermet, work material: S45C, cutter diameter: 393 mm, radial rake: 5°, width of cut: 90.0 mm, depth of cut: 2.00 mm

Fig. 5 The boundary curves for 0.05 mm and 0.10 mm wide lands

Feed mm/tooth

Tool material: cermet, work material: S45C, cutter diameter: 393 mm, width of land: 0.10 mm, width of cut: 90.0 mm, depth of cut: 2.00 mm

Fig. 6 The boundary curves for various radial rakes with a 0.10 mm wide land
is the region without low speed breakage; the lower side is the region with the breakage. When the cutting edge has no land, a low speed breakage occurs over the entire examined region. It is noted that a wider land prevents low speed breakage more effectively. When the land is as wide as 0.15 mm, a low speed breakage does not occur over the entire examined region.

4-2 Effect of radial rake

Fig. 6 shows the boundary curves for various radial rakes with a 0.1 mm wide land. Although the effect from the radial rake appears at the lower feed than 0.2 mm/tooth, it does not appear otherwise. When the land is as wide as 0.15 mm, no low speed breakage occurs at any range regardless of the radial rake. Then it is concluded that the necessary land width to prevent low speed breakage is 0.15 mm for every examined radial rake.

5. Cutting force measurement for various land widths and radial rakes

Comparative tool force measurement is conducted on Niigata 4SSD High Speed Lathe. The main cutting force and the feed force are measured with a strain gage type tool dynamometer. The same tool holder that composes the face-milling cutter is mounted on the tool post of the lathe. The bar of S45C steel is machined with a constant depth of cut of 1.5 mm, an almost constant cutting speed (138~156 m/min), and various feeds.

Fig. 7 summarizes the results of measurement. As seen in the upper figures, with any cutting edge geometries, a larger feed decreases the specific main cutting force as far as the feed is below about 0.3 mm/rev. The lower figures indicate that a larger feed decreases the specific feed force even beyond 0.3 mm/rev feed. Thus so far as the tool force is concerned, it is recommended to adopt a large feed, as large as 0.3 mm/rev if possible. Since the cutting edge is double raked with the land, too small a feed possibly results in an abnormal force on the cutting edge and lowers the tool life. Particularly in face-milling, since the true thickness of cut is equal to or smaller than that in lathe work depending on the angular position of the tool tip to the direction of feed, it is desirable to take as large feed as possible to be accepted by other factors.

6. Effect of land width and radial rake on high speed breakage

The effect of land width and radial rake on high speed breakage depends on the cutter diameter. Fig. 8 (a) and (b) shows the tool life (number of cuts till high speed breakage) of 94 and 393 mm diameter cutter respectively with a 90 mm width of cut. The difference in cutter diameter brings about the opposite effects of the radial rake and the land width on the
tool life.

In the case of the smaller cutter, a smaller land width and a larger radial rake generally bring about a longer tool life. The microscopic observation reveals that every breakage is due to the cross crack on the land which is the same as seen in Fig. 2. According to the previous discussion, such crack means the predominance of impact fatigue. If the tool material were carbide, the situation of such a small cutter would make the high temperature fatigue predominate. The character of the cermet as previously described is reconfirmed by the observation above. The general tool life tendency in Fig. 8(a) yields the conclusion that, even when impact fatigue is predominant, a sharper cutting edge tends to fatigue more slowly, provided the cutter diameter is small and near the width of cut. But a cutting edge with 0.1 mm wide land and +15° radial rake is an exception because too sharp shape lessens the strength of the edge and results in a poor tool life.

In the case of the larger cutter, the impact strength of cutting edge is the main factor to breakage because an impact on the cutting edge is so severe. The cutting edge with a wider land and a smaller radial rake generally has a longer tool life in Fig. 8(b), because it is stronger against impact. But since radial rakes of −5° and +5° with a 0.3 mm wide land possibly make the cutting edges so dull that they fatigue rather fast because of a large cutting force.

Above results yield the following principle for selecting the land width and radial rake:

(a) Sharp edge is preferable when the cutter diameter is small and near the width of cut.
(b) Strong shape of the cutting edge is preferable when the cutter diameter is large, and much more than the width of cut.

Next experiment is conducted to know the effect of the cutter diameter on the high speed breakage with the land width as a parameter. Two series of tests are carried out, one with a constant width of cut and the other with a constant cutting time ratio. The width of cut and the cutter diameter for each series are listed in Table 5. P20 carbide is used in these experiments because it does not bear the low speed breakage even without a land. Three variations of land width, namely 0, 0.05 and 0.1 mm are examined. The tool life (number of cuts till high speed breakage) for an approximately constant cutting speed is illustrated in Fig. 9. It is understood that the variation of land width changes both the height and the inclination of the curve in the constant width of cut test, but only the height in the constant cutting time ratio test. The latter only results in a parallel shift of curve. This fact leads

![Graph](image)

**Table 5 Combination of cutter diameter and width of cut**

<table>
<thead>
<tr>
<th>Cutter diameter mm</th>
<th>Width of cut mm</th>
<th>Cutting ratio</th>
<th>Engage angle deg</th>
<th>Width of cut mm</th>
<th>Cutting time ratio</th>
<th>Engage angle deg</th>
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</thead>
<tbody>
<tr>
<td>94</td>
<td>90.0</td>
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<td>73</td>
<td>66.5</td>
<td>0.25</td>
<td>45</td>
</tr>
<tr>
<td>111</td>
<td>90.0</td>
<td>-</td>
<td>-</td>
<td>78.5</td>
<td>0.25</td>
<td>45</td>
</tr>
<tr>
<td>172.5</td>
<td>90.0</td>
<td>0.175</td>
<td>31.5</td>
<td>122.0</td>
<td>0.25</td>
<td>45</td>
</tr>
<tr>
<td>303</td>
<td>90.0</td>
<td>0.075</td>
<td>13.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
to the conclusion that the optimum edge shape uniquely depends on the engage angle or on the cutting time ratio. Then the foregoing principle for the edge shape design can be revised as follows:

(a) Sharp edge is preferable when the engage angle is small.
(b) Strong edge is preferable when the engage angle is large.

But it should be noted that this principle is available as far as the center of the cutter coincides with the center of the width of cut.

7. Comparative tool life test of cermet and carbides

7-1 Performance for S45C and S50C steels

Comparative tool life test among cermet, P05, P15, and P25 is carried out with a $-5^\circ$ radial rake and a 0.1 mm wide land cutting edge. The tool life is measured in terms of the number of cuts until a high speed breakage occurs, or until the flank wear attains 1.0 mm when a breakage does not occur. Figs. 10 and 11 show the performances with the work materials S45C and S50C respectively, each consisting of the cases with a small and a large cutter.

The result shows that the cutter diameter does not affect the order of the tool materials in terms of the tool life. But the work material affects the order. That is to say, the cermet has almost the same tool life as P05 for S45C; whereas it drops in between P15 and P25 for S50C. This resultpossibly means that the performance of the cermet depends on the carbon content of the work material, and that the cermet is favourable for the low carbon steel. Some domestic articles(6)(7) about the performance of cermet in turning report a different observation that the cermet has a longer tool life regardless of the work material.

7-2 Effect of cutter diameter

The result above that the cutter diameter does not affect the order of tool materials in terms of tool life supposes that every tool material has an identical cutting edge shape. But some tough carbide grades, when applied without a land, sometimes show a longer tool life than when applied a land. Fig. 12

![Diagram](image-url)

**Fig. 9** The effect of cutter diameter on the high speed breakage with the land width as a parameter

![Diagram](image-url)

**Fig. 10** Number of cuts till high speed breakage with the work material S45C, consisting of the cases with small and large cutters
Utilizing TiC Cermet in Face-Milling

comparatively small tool life. In the case (a) with a larger cutter diameter, P10 without a land shows the longest tool life; whereas P10 with a land shows the shortest one. This result endorses the theory that a sharp cutting edge is preferable when the engage angle is large. But it should be noted that the cermet can not be used without a land by way of low speed breakage prevention.

On the other hand, in the case of Fig. 12(b), with a larger cutter, P10 without a land breaks earliest and the cermet with a land lasts longest. This means that the cermet is advantageous in such a situation where the width of cut is small compared with the cutter diameter and the carbide would fail due to impact fatigue. In this situation, although a

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**Figure 11**

Number of cuts till high speed breakage with the work material S50C, consisting of the cases with small and large cutters

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**Figure 12**

The comparison of numbers of cuts till high speed breakage among cermet, P10, each with a 0.15 mm wide land and P10 without land, consisting of the cases with small and large cutters.
hard grade carbide as P05 has the same tool life as cermet, the cermet is more advantageous because it has better abrasion resistance than the carbide so that it makes a less increase in the tool force after the identical time of cut.

7-3 Character of cermet in high speed breakage

Two characteristic aspects of the high speed breakage of cermet are introduced. One is the predominance of the cross crack on the land due to impact fatigue, and the other is the merit of the cermet particularly under such circumstances where the carbide would fail due to impact fatigue. It should be noted, however, that these characters are not related to the fact that the cermet hardly bears the other kinds of cracks. In Fig. 13, the cutting edge of cermet and one of P05 are compared under the identical cutting conditions except the cutting time. Although the cermet cuts less often, it suffers a network of more cracks. It is the general observation that the cermet bears more cracks than the carbide. But it takes longer time for the cracks of cermet to cause a breakage than the cracks of carbide. The cermet possibly has the nature that the crack in it grows slower than one in carbide. This nature is associated with a practical convenience that a primary breakage from the land does not propagate so rapidly. But this is not the case for the low speed breakage. Both low speed breakage and breakage due to unfavourable shock in tool handling should be avoided carefully because they occur on a large scale, ruining the cutter in an instant.

8. Test run of a trial multi-bladed cutter

A multi-bladed cutter is designed according to the basic data. The above mentioned experiments with a single-bladed cutter are summarized as follows:

(1) The land width necessary to prevent the low speed breakage from occurring in the cermet is 0.15 mm for every radial rake tested.

(2) A feed as fast as 0.3 mm/tooth is preferable from the view point of the tool forces.

(3) Concerning the tool life determined by high speed breakage, the theory for designing the optimum cutting edge shape is presented in the 6th chapter. The data in Fig.8 are available for a practical design.

(4) Compared with carbide, cermet is advantageous when the width of cut is small relative to the cutter diameter, and when the work material contains less carbon.
Special precautions to be taken in designing a multi-bladed cutter are:

1. To provide a double rake face with a land.
2. To adopt a feed as fast as about 0.3 mm/tooth.

These two points cannot be fulfilled by the conventional face-milling cutters of insert blade type. Since the recently developed throw-away type face-milling cutter satisfies these requirements, a multi-bladed throw-away cutter is designed for a test run. Fig. 14(A) shows the trial cutter. The performance is summarized as follows.

Work material: S45C steel block of 490~495 mm length and 90.0 mm width.
Cutter: Throw-away cermet cutter of 153 mm diameter with 5 blades.
Tool geometries: Radial rake +10°, axial rake -5°, peripheral relief 5°, face relief 5°, peripheral cutting edge angle 15°, face cutting edge angle 15°, nose radius 0.8 mm and land width 0.2 mm.
Cutting conditions: Spindle speed 300 rpm, table speed 366 mm/min (cutting speed 144 m/min, feed 0.24 mm/tooth), and depth of cut 2.0 mm.
Cutting fluid: Dry.
Formed chip: Fig. 14(B), light brown colour.
Tool life: Before the tool life was declared expired by visual observation, the cutter worked for 46 min. The flank wear of each blade at the end of tool life was from 0.35 mm through 0.40 mm with an average of 0.38 mm.

Since actual shop practice sometimes deals with the workpiece surface with holes or grooves in it, the trial cutter was tested on the workpiece with 43 mm diameter holes as shown in Fig. 14(C). Although such a work piece made severe impacts, reducing the feed to 270 mm/min (0.18 mm/tooth) a successful performance was secured.

9. Conclusion

A higher production rate in steel face-milling can be realized by utilizing a tool material with a good abrasion resistance but with a poor toughness, by applying a land which strengthens the cutting edge and compensates for the brittleness of the tool material. This theory is exemplified in the research to utilize the titanium carbide cermet in face-milling. Basic studies with a single-bladed cutter presented enough informations for the design and use of the cermet cutter. A multi-bladed throw-away cermet cutter was used in test runs. The result of the test run is enough to prove the utility of cermet cutter. It is recommended to carry out more of this kind of security tests for further references.

Acknowledgement

The authors express sincere thanks to The Sumitomo Electric Co. and The Sumitomo Metal Industry Co. for their great assistance in providing materials.

References


Discussion

H. Takeyama: (1) The authors conclude in 4-2 at page 810 that the width of land enough to prevent the so-called low-speed breakage should be more than 0.15 mm. However, the value cannot be determined uniquely, but it depends upon the feed and other factors.
(2) The authors describe that the entering shock becomes small at larger engage angles, but the stress at the cutting edge must be extremely large in such the case on the contrary. The reason for this can be attributed to the plastic deformation of material cut. This is the reason why the cutting edge should be sharp to remove the metal not by plastic deformation but chip disposal due to cutting.

Authors' closure

(1) It is considered, as the discussor points out, that the land width for prevention of low speed breakage is dependent on the feed, etc. A sufficient amount of chamfering should be made for milling cutters in practical-use.
(2) Milling cutters with sharp edges produced less breakage than those with dull edges at a large engage angle. This is because the plastic deformation of work material until the initial formation of the chip may be small, as pointed out by the discussor.