Method of Testing Carbide Inserts for Premature Fracture by Face Millling of Cylindrical Workpieces

Ryozo Kitagawa*, Tadahisa Akasawa**, and Kitao Okusa*

(Received May 21, 1984)

ABSTRACT

Methods are proposed for face milling solid cyindrical workpieces or half-cut and hollow cyindrical workpieces prepared from rectangular blocks by continuously changing both or either of the angles of engagement and disengagement. Carbide inserts are tested for premature fracture before the onset of steady wear using these face-milling methods. The premature fracture indicates the insufficient toughness of carbides to perform a given machining job.

As carbides of higher wear resistance have lower shock resistance in general, they must be tested for premature fracture due to the lack of toughness to select suitable carbides for specific cutting applications. The test results obtained under the present study show that the premature fracture of carbides, whose toughness has been classified by static toughness tests, can be evaluated dynamically and easily by the proposed face-milling methods.

1. INTRODUCTION

Abnormal wear and edge chipping which occur at the initial stage of machining are said to be failures that develop during tool entry and are distinguished from normal wear. This type of failure may render the tool prematurely useless in extreme cases.

It is reported in particular that the magnitude of engagement and disengagement angles greatly affects the chipping of cutting edges when face milling with carbide-tipped cutters [1, 2].

Cutting test methods have been devised to continuously change the angles of engagement and disengagement simultaneously or independently. Short-term tests have been then conducted to study the edge chipping of carbide tools at initial cutting by using these methods and a single-toothed face mill equipped with a tool dynamometer.

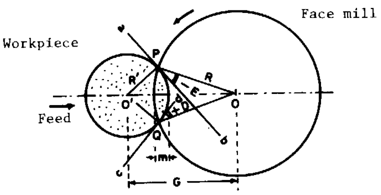
---

* Department of Applied Mechanical Engineering
Faculty of Engineering, Yamaguchi University, Tokiwadai, Ube-shi, 755 Japan
** Central Research Bureau, Nippon Steel Corporation, 5–10–1, Fuchinobe, Sagamihara-shi, 229 Japan

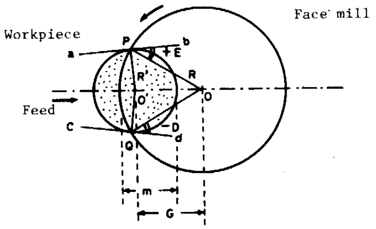
2. STUDY ON METHODS OF TESTING CARBIDE INSERTS FOR PREMATURE FRACTURE BY FACE MILLING

2·1 Method of Continuously Changing both Engagement and Disengagement Angles

The engagement angle (angle E) and disengagement angle (angle D) can be changed by changing the width of cut and offset of the workpiece and the diameter of the face mill [2]. The present study is concerned with the methods of continuously changing the angles E and D for the face milling of cylindrical workpieces.

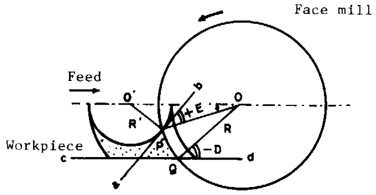


(1) Negative Angle E

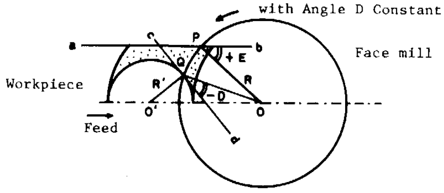


(2) Positive Angle E

(a) Method of Continuously Changing both Angles E and D.



(b) Method of Continuously Changing Angle E with Angle D Constant.



(c) Method of Continuously Changing Angle D with Angle E Constant.

Fig. 1 Three Face-Milling Methods.

In Fig. 1 (a), the center O of the face mill and the center O′ of the cylindrical workpices are lined up on the same horizontal line without offset in the direction of travel, and the center O′ is moved toward the center O for the face milling of the workpiecs. The cutter tooth engages the workpiece at the point P on the periphery of the workpiece and disengages the workpiece at the point Q. Let m be the overlap, R the radius of the face mill, R′ the radius of the cylindrical workpiece and G the center distance between the face mill and workpiece. then,

$$m=R+R'-G \tag{1}$$

$$G=\sqrt{R^2+(R')^2-2RR'\sin E} \tag{2}$$

Substitution of Equation (2) into Equation (1) yields Equation (3).

$$m=R+R'-\sqrt{R^2+(R')^2-2RR'\sin E} \tag{3}$$

In all tests under the present work, R=127 mm and R′=31.75 mm. When these valuse are substitued into Equation (3), the curves shown in Fig. 2 are obtained. The types of contact illustrated in Fig. 2 are determined by substituting tool geometry into Kronenberg's equations [3]. The angle D at the point Q shown in Fig. 1(a)is opposed to the above results in its sign only. These findings mean that a continuous change in the overlap m varies both angles E and D as shown in Fig. 2.

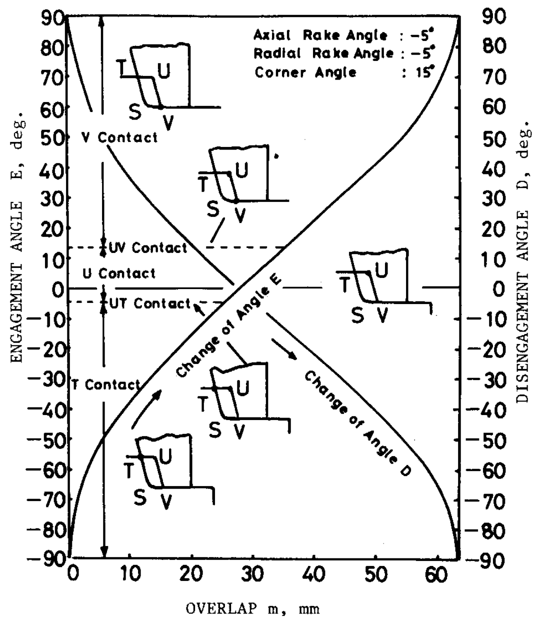


Fig. 2 Relation among Overlap m, Angles E and D, and Three Types of Initial Contact.

2·2 Methods of Continuously Changing Angle E with Angle D Constant and Angle D with Angle E Constant

In each of Fig. 1(b) and (c), the workpiece is a rectangular block whose center is hollowed out to a radius R′ and whose sides are faced with another cutter to prevent interference when face milling the dotted part. Figs. 1 (b) and (c) show the face-milling methods of continuously changing the angle E with the angle D held constant and the angle D with the angle E held constant, respectively.

2. 3 Time Required for Cutting Edge to Completely Engage Workpiece [3]

The premature fracture of carbide teeth for face milling is presumably affected by the time required for the cutting edge to completely engage or disengage the workpiece [3, 4], chip forming mechanism [2, 5] and transient phenomena at the start and end of cutting [6, 7]

Fig. 3 shows the Kronenberg's penetration time Tp or time required for the cutting edge to completely engage the workpiece. The smaller the Tp value, the greater

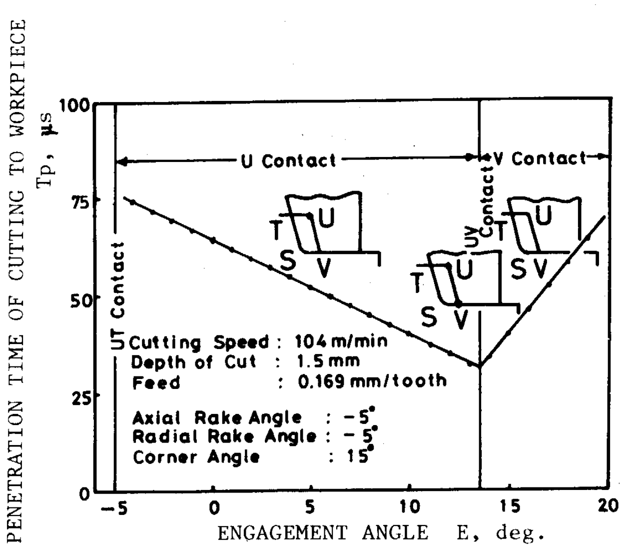


Fig. 3.

Relation between the Penetration Time of Cutting Edge to Workpiece and Engagement Angles.

will be the impact on the cutting edge.

2.4 Cutting Force and its Variations in Three Face-Milling Methods

If the time required for the tool completely engage and disengage the workpiece and the cutting force at the tool can be accurately measured, the state of impact which is imposed on the cutting edge when the cutting edge engages and disengages the workpiece can be discussed. Since the cutting edge engages and disengages the workpiece in microseconds as shown in Fig. 3, a tool dynamometer with a natural frequency of over 1 MHz is required to measure the cutting forces. With such a type of tool dynamometer unavailable, a dynamometer with a natural frequency of approximately 1400 Hz was used as shown in Fig. 4(a) to measure the cutting force applied tangentially to the cutting edge [8]. When the depth of cut feed are changed as shown

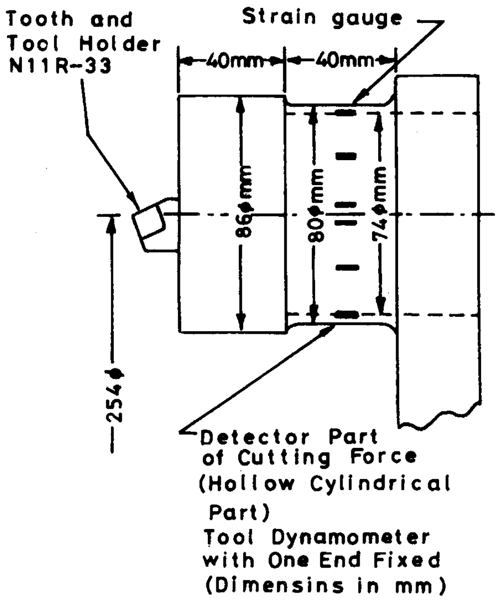
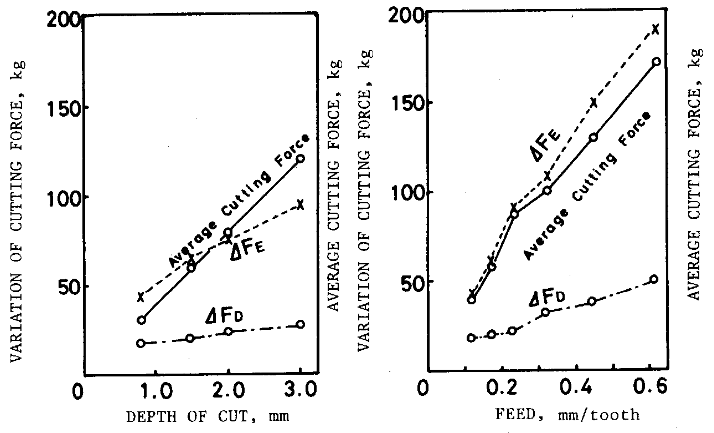


Fig. 4(a). Experimental Apparatus.



Cutting Speed: 104m/min, Depth of Cut: 1.5mm (Experiment of Feed Variable), Feed: 0.169mm/tooth (Experiment of Depth of Cut Variable), Carbide: M40, Work Material: SCM-4, E=0 deg., D=10 deg.

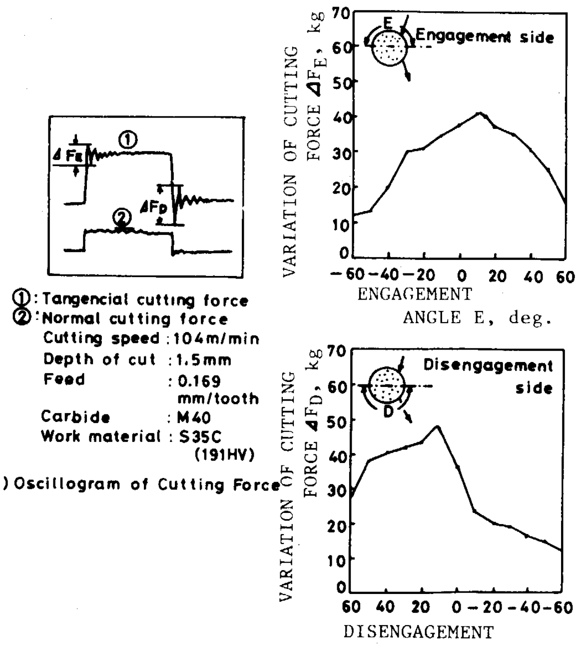
Fig. 4(b). Relation among Change of Depth of Cut, Feed and Variation of Cutting Force.

in Fig.4(b), the cutting force variation △FE is high in sensitivity and the cutting force variation △FD is low in sensitivity. These cutting force variations are considered to qualitatively coincide with the magnitude of impact stresses.

The milling machine and workpiece-material used for these face-milling tests Hitachi Seiko Model 3ML (11 KW) and carbon steel S35C (191 HV), respectively. Machining conditions were selected to prevent the adhesion of chips and the formation of built-up edge as shown in Fig. 5. The carbide inserts used were all JIS SNP-432 and the tool material M40.

Test data are arranged as shown in Fig. 5(a) to observe qualitative tendencies of impact stresses. To measure the impact applied to the cutting edge at engagement and disengagement, oscilloscope waveforms of cutting forces were photographed and the cutting force variation △FE at engagement and the cutting force variation △FD at disengament were from the taken oscillograms. Fig. 5(b) shows the test results obtained when the face-milling method illustrated in Fig. 1(a) was employed. Figs. 5 (c) and (d) present the test results when the face-milling methods shown in Figs. 1(b) and (c) were adopted, respectively.

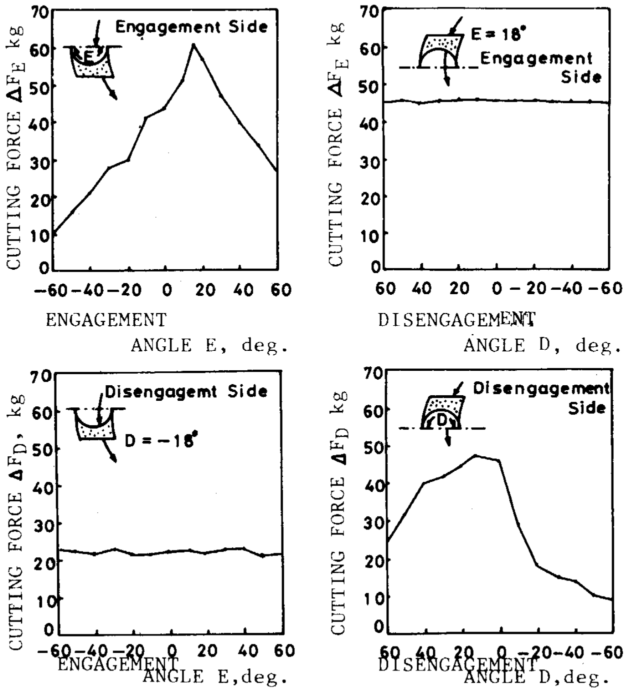
In Fig. 5(b), △FE exhibits a maximum value near D=+13°30′. This agrees well with the minimum value Tp shown in Fig. 3. The face-milling method of continuously changing both angles E and D can rapidly vary the impact on the cutting edge and thus can be used as a means for predicting premature fracture of the cutting edge. Using this method, however, it is difficult to determine whether an increase in the angle E or a decrease in the angle D is resposible for premature failuure of the cutting edge because the peak value of the impact on the cutting edge appears at each point on the engagement and disengagement sides.



(a) Oscillogram of Cutting Force

(b) Method of Continuously Changing both Angle E and D

Fig. 5 (a. b). Cutting Force Variations at Engagement and Disengagement under Three Face-Milling Methods.



(c) Method of Continuously Changing Angle E

(d) Method of Continuously Changing Angle D

Fig. 5(c, d). Cutting Force Variations at Engagement and Disengagement under Three Face-Milling Methods.

In Fig.5(c), △FE exhibits a maximum value near E = +13°30′ while △FD remeains virtually constant.

In Fig. 5(d), the angle E is constant at 18°and the angle D is varied from −90° to +90°. The △FE value on the engagement side remains practically constant and the △FD value on the disengagement side agrees well with the results shown in Fig. 5(b) when the angle D is changed.

It has been confirmed that the methods of continuously changing the angle E with the angle D held constant and the angle D with the angle E held constant help study the effects of independent variables alone.

These tests have qualitavely confirmed that the three face-milling methods can rapidly change the impact stresses on the cutting edge during the maching.

3. TEST OF CARBIDE INSERTS FOR PREMATURE FRACTURE

3·1 Study on Method of Indicating Toughness of Carbide Inserts

Four types of grade P carbides in lots different from those used for the face-milling tests were tested for their transverse rupture strength, and the total length 1 of cracks developed at four corners of indentations for Vickers hardness determiation was measured[9]. Fig. 6 shows the results of measurement, where are regognizable good relationships between transeverse rupture strength and Σ1. Σ1 is measured at each testing load of 5, 10, 20 and 30 kg, and p−Σ1 lines are obtained accordingly. None of these lines passes through the origin, which suggests the effect of surface preparation when making test pieces for measureing Vickers hardness[10]. Therefore,

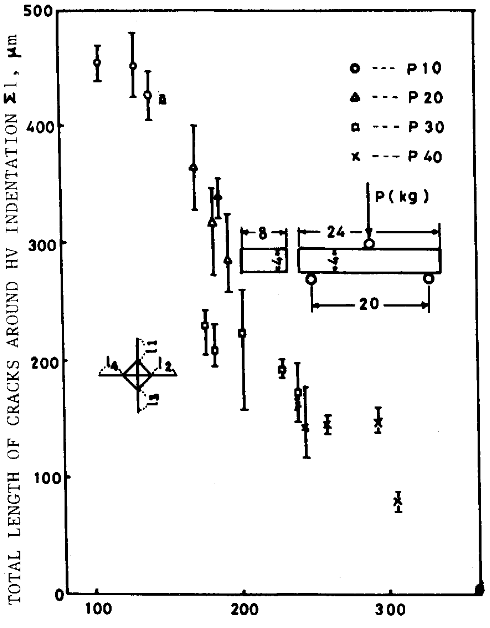


Fig. 6. Relation between Transverse Rupture Strength and Total Length of Cracks around HV Indentation (HV Load 30 kg).

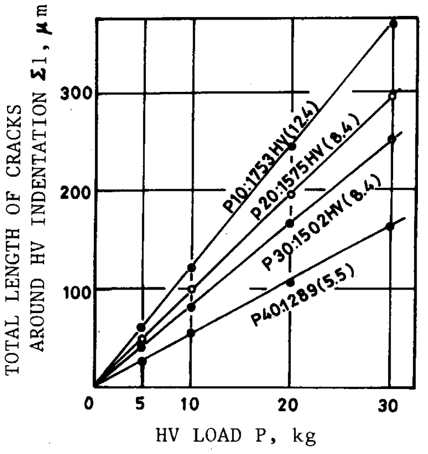


Fig. 7. Relation between HV Load and Total Length of Cracks around HV Indentation for Grade P Carbide Inserts.

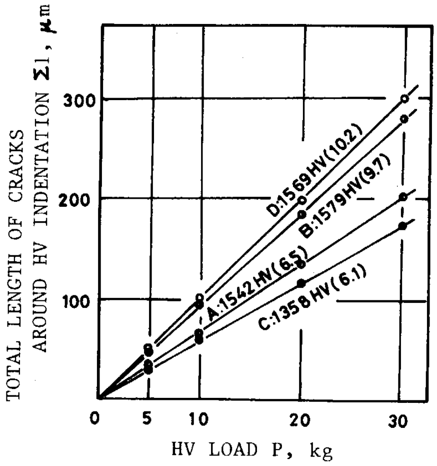


Fig. 8. Relation between HV Load and Total Length of Cracks around HV Indentation for Grade P25 Carbide Inserts by Four Different Manufacturers.

each test piece was annealed in vacuum at 800°C for 2 h to eliminate the influence of surface prepartion[11] and the total length of indentation cracks was then measued in the same manner as described above.

Figs. 7 and 8 show the test results of P10 to P40 carbides, all made by the same manufacturer, and P25 carbides made by four different manufacturers. The slope ($\Sigma l/P$) of each line is given in parenthses as the constant that denotes brittleness. Fig. 7 show that hard P10 has a maximum slope while soft P40 is tough. It can be seen from Fig. 8 that carbides of the same grade, when made by different manufacturers, considerably differ in hardness and toughness.

3·2 Test of Carbide Inserts for Premature Fracture by Three Face-Milling Methods

The face-milling method of continuously changing both angles E and D can be used to test tool toughness under machining conditions in which tool wear is negligible.

Tests which investigate carbide inserts for premature fracture must pay particular attention to reproducibility. In the fracture test under the present study, each carbide insert took at least ten corner cuts. The two sets of carbides whose toughness is discussed in the previous section were investigated for premature fracture by the above-mentioned face-milling method. When the distance m (overlap) is measured, the angles E and D can be obtained from Fig. 2 to indicate fracture resistance of the carbide insert.

3·3 Test Results and Discussions

Fig. 9 shows permature fracture of the commercial carbide P10, P20, P30 and

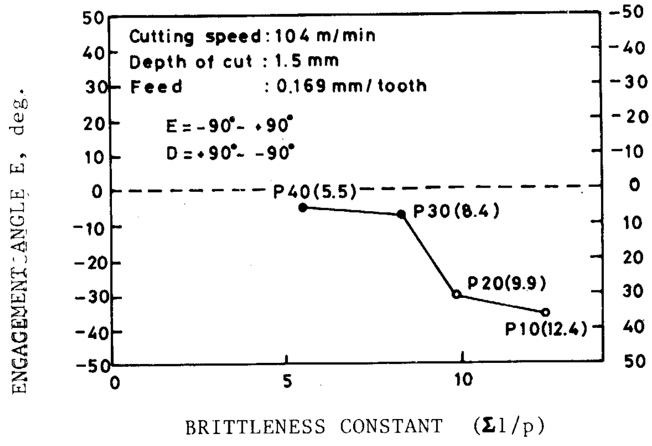


Fig. 9.

Test Grade P Carbide Inserts for Premature Fracture by Continuously Changing both Angle E and D.

P40 that were made by the same manufacturer and tested by the method of continuously changing angles E and D. The abscissa indicates the brittleness constant while the ordinate denotes the angle E when the premature fracture occurred. Under this face-milling method, the angle E starts at $-90°$ and increases toward $+90°$. In general, carbide inserts which fractured at a small angle E are liable to chip, while those which fractured at a greater angle E are difficult to chip. The test results shown in Fig. 9 do not run counter to the order of fracture resistance conventionally said about grade P carbides. Fig. 9, however, shows the test results obtained when both angles E and D are changed. When Fig. 5(b) is considered together, some premature fractures occur when the angle D is decreasing and some occur when the angle E is increasing.

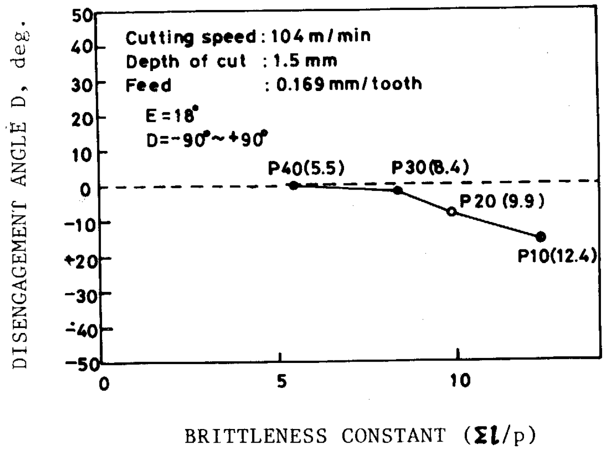


Fig. 10.

Test of Grade P Carbide Inserts for Premature Fracture by Continuously Changing Angle D.

Fig. 10 shows the premature fracture of carbide inserts shown in Fig. 7 and investigated by the face-milling method of continuously changing the angle D with the angle E held constant. As the impact increases in magnitude with an increase in the angle D, fracture develops. This fracture exhibits the same tendency as indicated by the test results of Fig. 9. The method of continuously changing the angle D with the angle E held constant is simpler than the method of continuously changing both

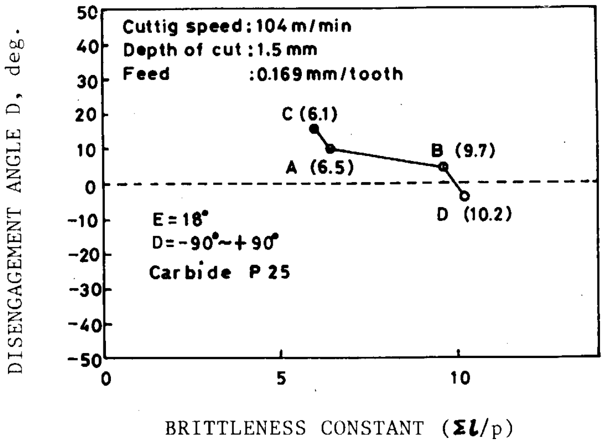


Fig. 11.

Test of Grade Carbide Insrts for Premature Fracture by Continuously Changing Angle D.

angles E and D to test carbide inserts for premature fracture.

Fig. 11 shows the results of P25 carbides made by four different Japanese manufacturers and testes in the same way as shown in Fig. 8. It is recognizable from this diagram that differences in fracture of carbide inserts of th same material but made by different manufacturers can be fully discriminated by the method of continuously changing the angle D with the angle E held constant.

The three face-milling methods described so far can test carbide teeth for premature fracture alone before progress of wear because the rate of metal removal is extremely small. They also permit a repetition of tests to improve experimental accuracy. When machining conditions are changed and, in particular, machining speed is increased in face-milling methods, tough tool materials do not prematurely fracture but their wear proceeds in a steady state. Namely, the three face-milling methods can evaluate the machinability of a specific work material using a small amount of material.

4. CONCLUSIONS

(1) The angles E and D can be continuously changed when face milling cylindrical workpieces. Three simple methods are devised to test carbide teeth for premature fracture by face milling : continuously changing both angles E and D, continuously changing the angle E alone with the angle D held constant and continuously changing the angle D alone with the ange E held constant.

(2) When the angles E and D are continuously changed, the values of angles E and D can be found at which the cutting force of angles E and D can be found at which the cutting force variations △FE and △FD become maximum. These maximum △FE and △FD valus are considered to correspond to the impact on the cutting edges. These relations can be used to investigate carbide teeth for premature fracture.

REFERENCES

1. H. Takeyama and A. Yamada,"Face-milling of Crabon Steel S50C with Carbides ; Study on Carbide Milling (No. 1)", J. Jpn Soc. Precis. Eng., **26,** 647 (1960)
2. T. Hoshi and K. Okushima, "Optmum Diameter and Position of a Fry Cutter for Milling 0.45C Steel, 195 BhN and 0.4C Steel, 167 BhN at Light Cuts", Trans. ASME, Ser. B, **87,** 442 (1965)
3. M. Kronenberg, "Analysis of Initial Contact of Milling Cutter and Work in Relation to Tool Life", Trans. ASME, **68,** 217 (1946)
4. M. Ohgoshi annd Y. Shinozaki,"On the Carbide Face-Milling Cutter (1st Report)", Report of the Inst. of Physical and Chemical Research, **33,** 137 (1957)
5. K. Hoshi and T. Hoshi,"On the Art of Cutting Metals"., Kogyo-Chosakai Co, Tokyo, (1981) , p. 157.
6. S. Kato, H. Fujii and S. Yamada,"Study on Milling (1st Report)", Trans. Jpn. Soc. Mech. Eng., **33,** 145 (1967)
7. ibid p. 153.
8. K. Okusa and R. Kitagawa,"On the Failure of Carbide Face-Mill Cutter at the Continuous Change of Engagement Angle (3rd report)", Preprint for the Spring Meeting, Apr., 1970, Jpn. Soc. Precis. Eng., p. 55.
9. S. Palmqvist,"Rissbildungsarbeit bei Vickers Eindrucken als Mass fuer die Zaehigkeit von Hartmetallen", Arch. Eisenhuettenw., **33,** 629 (1962)
10. A. Miyoshi, A. Hara and Y. Sugimoto,"An Investigation of the Crack around the Vickers Indentation in CementedCarbides", J. Jpn. Inst. Met, **31,** 1123 (1967)
11. M. Yokohama and T. Sadahiro,"The Influence of Surface Finishing on Crack Length of Cemented Carbides", J. Jpn. Soc. Powder Metall., **11,** 345 (1970)