HIGH-SPEED MILLING FOR DIE AND MOLD MAKING

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Abstract

High-speed milling machine is being sold mainly in the market of die and mold industries, because it reduces machining time greatly as proportion to the spindle speed of machine tool. From the experimental milling tests, it has been cleared that the ball end mill is quite suitable for high speed milling and also tool wear reduces in higher speed milling condition. And a new milling concept with ultra high speed over 100,000 rpm is proposed for solving the various problems such as NC cutter path generation and NC feed conformity etc.

Keywords: high-speed milling, ball end mill, dies and molds

1. Introduction

Recently the competition of developing new product is growing increasing intense. This is due not only to the birth of improved products, but also to the implementation of design changes. The strong need to manufacturing a variety of industrial products according to the respective demands of the users attests to the affluence of mankind, while the fact that diverse products can be manufactured demonstrates the progress of manufacturing technology. One of the greatest problems faced in the rush to develop new products lies in the shortening of the development lead-time.

Most mechanical parts are manufactured by the forming process. The production of the die and mold used for producing these formed parts poses a bottleneck in the development of new products. The manufacture of die and mold has been carried out by hand by skilled and experienced workmen since very long ago. Such manual work is gradually being replaced by advanced automatic operations centering around CAD data. As technological innovation advances rapidly for the manufacture of die and mold, more rapid die and mold manufacturing methods are being sought, and such demands are urging for the development of new technologies.

2. Free Form Surface by Ball End Milling

Most mold surfaces consist of free form surfaces, and the free form surfaces are machined by the ball end mill as shown in Fig.1. Milling by the ball end mill leave wave-shaped bumps on the surface. The height of these bumps can be reduced by using a small feed pitch of the tool path, but decreasing the feed pitch on the other hand increases the length of the machining process and subsequently the machining time. One method to solve this is using a high spindle speed to increase the feed speed of the tool, and completing milling in a short period of time.

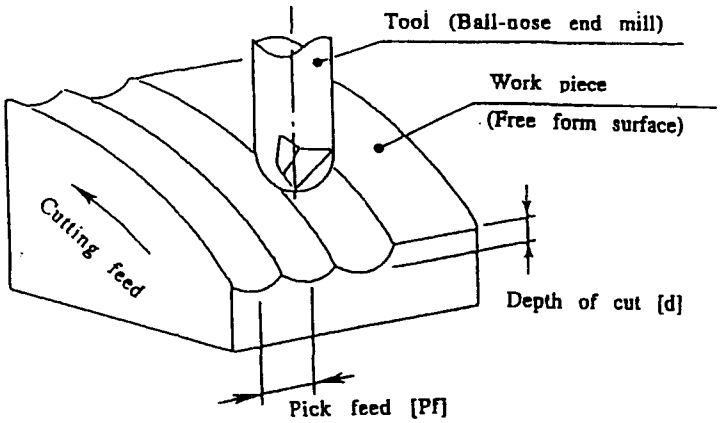

Fig.1 Ball end milling of free form surface

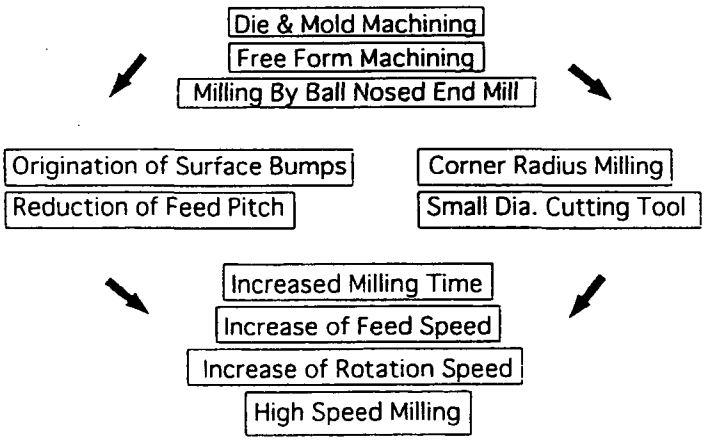

Fig.2 Necessity of high speed milling in die and mold making

The method is called high-speed milling which is drawing widespread attention currently. Molds in particular often have small corner radius and final finishing by ball end mills with small diameters are performed for machining such portions. For this reason, the machining time becomes long, and so realizing high speed ball end milling is very important. These are summarized in Fig.2. Furthermore, decreasing the feed pitch not only improves the dimensional accuracy, but also eliminates the need to carry out removal of the surface bumps later, resulting in shorter finishing time.

3. Tool Material and Tool Life in High Speed Milling

The main reason which realized the practical application of high-speed milling was the use of tool materials with excellent wear-resistance as shown in Fig.3. Milling tools made by coating cemented carbide with ceramics with both rigidity and wear-resistance are able to machine hard mold materials as well as demonstrate long life even in high-speed milling where very high temperature is generated. In particular, because they are able to machine quenched die steel, they are now replacing some parts of the EDM process.

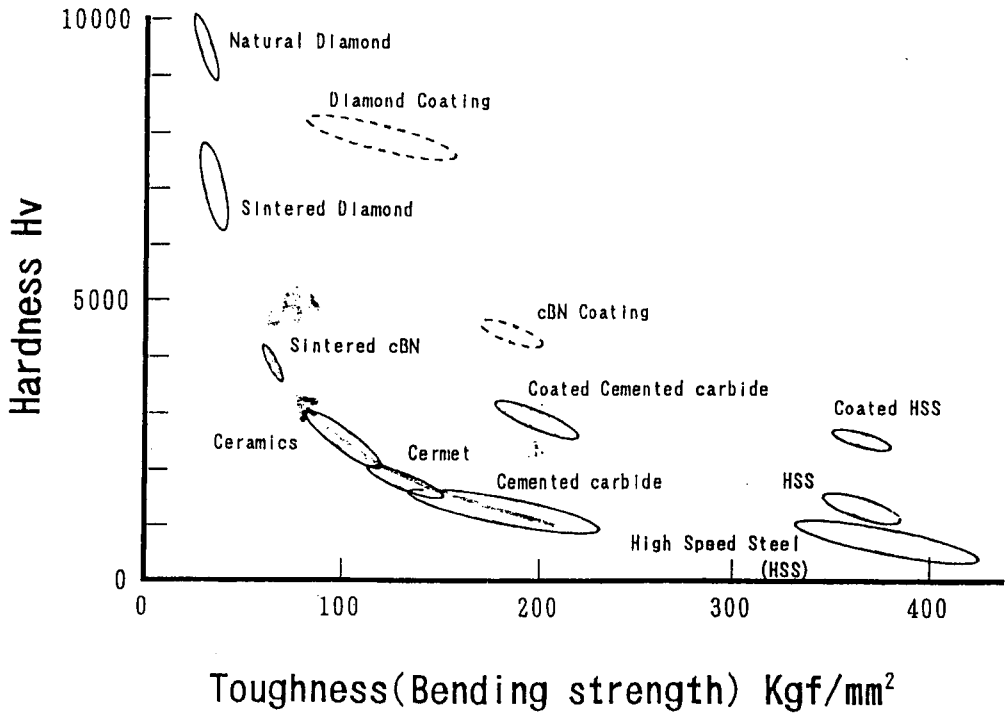

Fig.3 Relation between hardness and toughness of cutting tool materials

Recent studies are also gradually confirming that the higher the milling speed, the longer the tool life. Since wear decreases the higher the milling speed in this phenomenon as shown in Fig.4, the problem of tool life which poses as the greatest problem in the high speed milling of die and mold materials is gradually being resolved for the light milling of small diameter tools. The possible reasons for the reduction of wear at higher speed are estimated as in Fig.5.

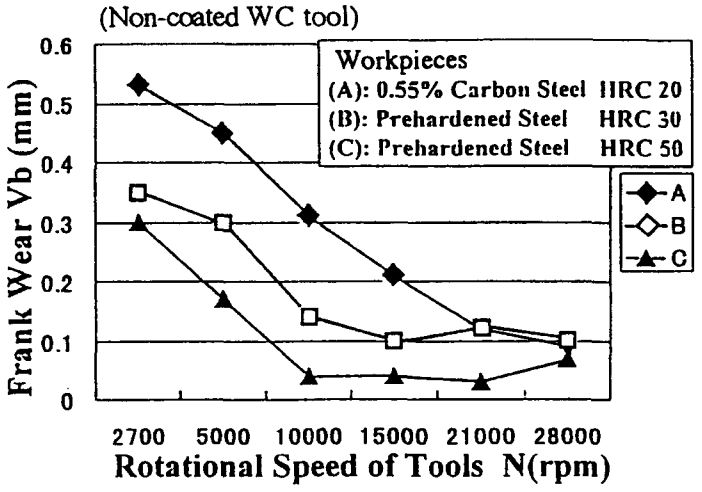

Fig. 4 Experimental results of wear reduction in higher milling speed by cemented carbide ball end mill

- Improved Machinability by Change of Shear Angle
- Material Brittleness
- Decrease of Friction
- Formation of Built up Edge
- Less Heat Transfer
- Material Softening by Heat Generation

***Fig.5** Possible Factors for decrease of tool wear at high speed*

4. Ball end milling appropriate for high-speed milling

The ball end mill tool has been confirmed as being extremely appropriate for high-speed milling. With this tool, milling is carried out mainly by the central blade. But due to the small depth of cut near the central blade, and the cutting speed near the central blade is considerable slower than the external circumference, the actual cutting speed is low even if the rotating speed is high. The criteria for judging tool life lies in the surface roughness of the workplace. Consequently, tool life is made longer as the surface roughness is determined by the wear near

the center.

Another reason for the durability of the ball end mill in high-speed rotation is the intermittent milling that is carried out. In other words, the actual time during which the blade of the tool is in contact with the workplace is less than half, and even below 1/5 according to the milling conditions. Consequently, most of the time, the workplace is being cooled by air or by the liquid coolant. In this way, intermittent milling is very advantageous for high-speed milling with which the high temperature of the blade poses the greatest problem. This is also the same for the side milling by the end mill. These considerations are summarized in Fig.6.

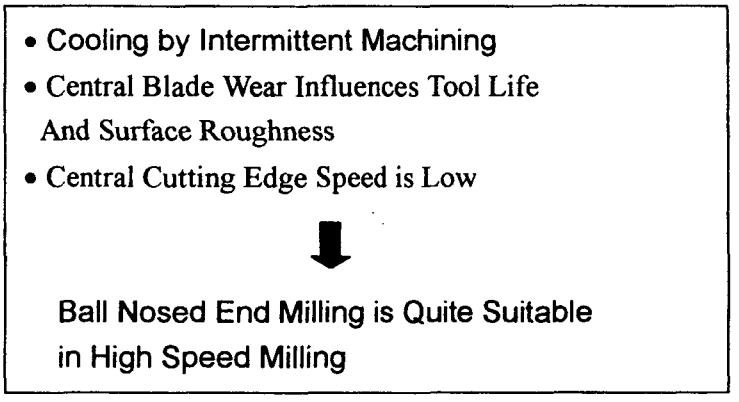

Fig.6 Characteristics of ball nosed end milling

5. High speed milling machines emerging on the market

Since it became evident that high speed milling can be applied to the manufacturing of die and mold, high speed milling machines and machining centers are emerging on the market one after the other. The first high-speed milling machine that appeared on the market is Niigata Engineering's 100,000-rpm rotation milling machine as shown in Fig.7. Developed about 7 to 8 years ago, it was the first machine of its kind and helped demonstrate the superiority of high speed milling in experimental researches using this machine. However due to its extremely high speed at that time, it was considered as having no marketability, and was not marketed thereafter.

Recent high speed milling machines were put on show at 1996 JIMTOF exhibition. Amongst the machines on display, there were five models with a main axis speed of more than 35,000-rpm rotations as shown in Fig.8. The use of magnetic bearings and air bearings also heralds a new trend. There were also machines with sharply increased table feed speed and acceleration exceeding 1G.

6. Ultra high speed milling by cBN tool

The maximum cutting speed of the cemented carbide tool is said to be 300 to 500 m/min. However when cBN tools are used, the heat-resistance increased to a considerable extent, paving the way for even higher speeds. High-speed milling using sintered tools especially face problems in heat-resistance of the binder. The high-

density cBN using as little binder as possible is thus also suitable for ultra high speed milling exceeding 1000 m/min as shown in Fig.9. Since less binder is used, the toughness of the cBN tool is poorer and chipping occurs readily. Chipping can however be prevented by using a negative rake angle. In high speed milling, the machined surface does not deteriorate even if a negative rake angle is applied due to the enhanced machinability. High-speed milling using the cBN tool has also been confirmed to show decreased wear the higher the speed.

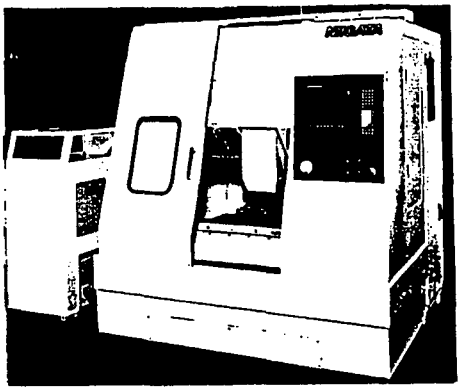

Fig. 7 100,000 rpm ultra high speed milling machine developed in 1990 by NIIGATA ENGINEERING

Name of maker	RPM ($\times 10^3$)	Other specifications
NIGATA ENGINEERING *	100	Ceramic ball bearing; Tool dia=10 ϕ ; No ATC; f=10m/min
MORI SEIKI	70	#40; Magnetic bearing; f=60m/min; 1.3G
TOSHIBA MACHINE	50	Air bearing; Spindle dia 50 ϕ; f=20m/min
MATSUURA MACHINERY	40	#30; Bearing dia(Internal) 40 ϕ
MITSUI SEIKI KOGYO	40	#30; Spindle dia 40 ϕ ; f=20m/min
MAKINO MILLING MACHINE	32	Spindle dia 23 ϕ; Tool dia 6 ϕ; f=16m/min
YAMAZAKI MAZAK	25	#40; Bearing dia(internal) 70 ϕ; f=60m/min, 1G
KITAMURA MACHINERY	25	#40
OKUMA	25	#40

* : Developed in 1990

Fig.8 Japanese high speed milling machine in the market

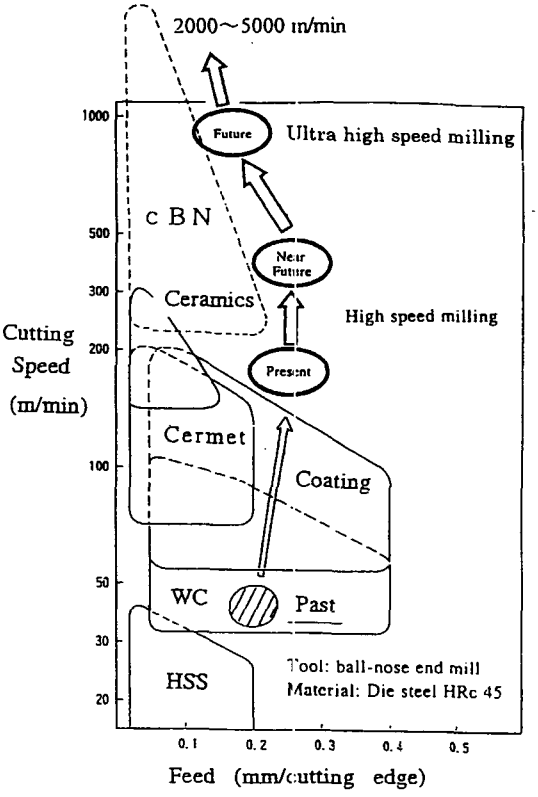

Fig.9 Ultra-high speed milling by cBN cutting tool

At the moment, the limit speed of the cBN ball end mill cannot be determined because very high speeds are possible.

7. Tasks for ultra high speed milling

Should the use of the cBN ball end mill resolve tool life problems, it means that the age of ultra high speed milling with milling speeds from 1000 to 2000 m/min is not far away. This speed range indicates high speeds several times the cemented carbide tool.

To realize milling at such high speeds, several tasks must be resolved. First the milling machine will require a main axis that can produce such high speeds. Although a main axis speed of 300,000 rpm is desirable, at the moment, there exists no such high-speed bearing. In the future, high speed feeding may be realized by the drive of linear motors, but at present, due to insufficient rotational speed of the main spindle, the required speed is being attained with the regular ball screw. However, since acceleration carries more importance than the feed rate, such measures as making the main axis drive portion as light as possible are required.

NC conformity however poses as a more serious problem than the feed rate. As widely known, the movements of the tool do not conform to the NC data accuracy in high-speed contour milling using the current machining center. Moreover, a solution is also required for the tool holder which expands due to the centrifugal force and becomes loose. In the replacement of the tool, since the tool length cannot be controlled accurately due to effects of temperature rise, errors occur after every replacement, erasing the high accuracy milling effects that had been attained. In addition, should the cutter path be incorrect, there will be risks of tool damage caused by unexpected excessive cutting depth. Due to the need to implement measures to prevent unmilled areas in rough finishing and prevent the risk of tool overload caused by groove-shaped contour shapes, high speed feeding is difficult.

Once all of these problems have been understood, the age of ultra high-speed milling will not be far. However in the actual situation, even if the milling time is 1/10 of the current speed, the overall die and mold manufacturing time cannot be reduced sharply if the rough finishing time and cutter path data generation time remain as they are.

8. Attempts on reciprocating layer milling by ultra high speed milling

Resolving the technological problems mentioned above is considerably difficult as long as normal milling is carried out using machining centers. In view of this, a new ultra high speed milling method by reciprocating layer milling was attempted. First, contour milling of the external circumference or internal circumference of the die and mold is performed at the normal feed rate. This is followed by the milling of thin layers by single-axis high speed reciprocating feeding. By repeating this for every layer, 3-dimensional milling of the final shape can be performed.

With this method, as long as 3D profile data of the mold exists, the tool cutter path can be generated at real-

time. The software for this has already been developed for the layer laminate manufacturing method, and can be used by making slight corrections. Since reciprocating tool feeding is carried out, and the feed accuracy is determined only by the start and end points of the table feeding of the milling machine, the problem of NC data conformity is resolved. The use of cBN tools eliminates the need to replace tools due to their long lives. Should this ultra high speed milling be realized, it should be more economical to perform finishing from the beginning without performing rough milling. Considering only the milling time, the milling efficiency may be poor, but with this method, ultra high-speed milling is employed to shorten the overall die manufacturing time including the generation of the cutter path. In one sense, the repeated machining of the same mold such as hot forging die is not necessarily suitable for this special mold manufacturing. Fig.10 shows the characteristics of high speed milling of reciprocating layer machining.

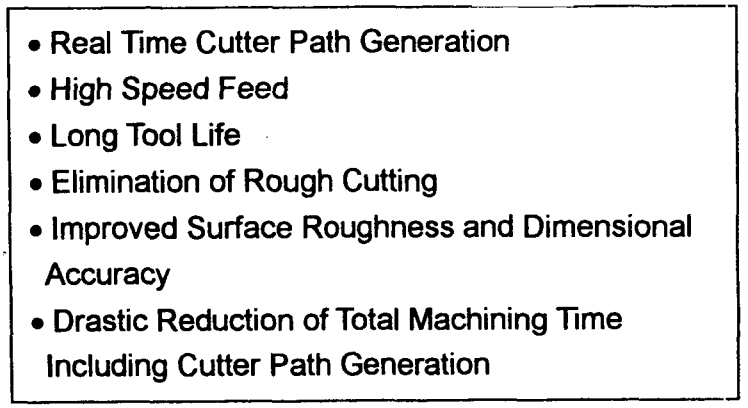

***Fig. 10** Characteristics of high speed milling of reciprocating layer machining*

9. Conclusion

The reduction of time and cost in die and mold making is increasingly important in the rapid development of new products and in the coming age of small lot production of various models. For this purpose, it is necessary to reduce machining time and then high speed milling using coated cemented carbide tool is contributing very much to solve this. Ultra high speed milling by cBN tool will be also quite hopeful in the future for further reduction of machining time.

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