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Design Method for Controlling Cutter's Consumption in High Speed Milling on Large Hardened Steel Surface

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Abstract: In order to solve milling cutter service characteristics conflict such as high efficiency and long life induced process domain interference problem in the process of high speed milling large-scale hardened steel surface, using variable speed and variable overhang cutting method do the vibration and wear experiments of using coated carbide milling cutter high speed milling hardened steel, obtained the wear characteristics of high speed milling cutter cutting hardened steel. Through the experiment of high speed milling cutter cutting hardened steel, characterize the impacts of milling method, diameter of milling cutter, speed, row spacing and cutting path on high speed milling cutter cutting efficiency and service life. Basis on the high speed milling cutter life and efficiency function value and the analysis and evaluation of milling cutter consumption, put forward the process design method of control tool consumption in the process of high speed milling large-scale hardened steel complex surface, conduct process verification in high speed milling machining process of automobile panel hardened steel die.

Keywords: High-speed ball-end mill, hardened steel, cutting efficiency, cutter's service life, cutter's consumption.

1. INTRODUCTION

Ball-end mill is a typical tool of complex surface high speed cutting, it is applied widely in the profile finishing of automobile large hardened steel die [1-3]. To ensure the integrity of large hardened steel die profile and the forming quality of automobile panel, in one process, machining region with different hardness needs to be done by the same machine and the same tool. Tool life should be more than 4h, for high speed ball end mill's life and consumption control put forward higher requirements [4, 5]. Since the hardness of die quenching surface and insert is more than HRC55, there is a large elastic recovery and profile machining feature is changeable. When high speed ball end mill finishing, the cutting speed and cutting efficient greatly improve caused cutter distortion, vibration, wear and breakage is very easy to cause unanticipated tool injury, affect its life directly [6-8]. Led to aided working hour and milling cutter consumption increased significantly, this become a bottleneck of processing enterprise control process cost and process quality.

At present, on the aspects of research on the high speed milling cutter's service life and high speed milling cutter technology, mainly using controlling variable method for researching and modeling on a specific process parameters. Less comprehensive consideration the effect of multi-characteristic vector to the high speed mill cutter's service life and cutting efficiency [9-11]. Using the above methods and conclusions can't solve the problem of functional coupling of the cutting efficient and tool life, the problem is caused by the multi-feature vector interactions in the process of the high speed ball end mill cutting hardened steel, it is difficult to get the optimum scheme in the process. Under these conditions, for high speed milling of large hardened steel surface. The consequences are milling cutter extended service, safety and reliability are rapid decline. Not only can't guarantee the machining precision and surface quality, but also lead to milling cutter failure directly, cause a variety of security issues.

When high speed cutting the surface of the large hardened steel service performance, conflict of the cutter's high efficiency and long life causing process domain interference problem. For efficiently solve this problem, this paper through the research of tool wear and tool life in the process of high speed cutting of hardened steel, propose high speed milling of hardened steel process design methods. Realizing high speed milling cutter service life and tool consumption control under the condition of higher cutting efficiency levels.

2. EXPERIMENT OF VIBRATION AND WEAR OF HIGH SPEED MILLING ON HARDENED STEEL

To reveal the wear characteristics of high speed milling cutter cutting hardened steel cutter, using the cutting method of variable overhang and variable speed, do the wear experiment of coated carbide ball end mill for high speed milling of hardened steel. Experiment machine is MIKRON five-axis boring milling machining center, work piece is Cr12MoV hardened steel, hardness is HRC55~60, work

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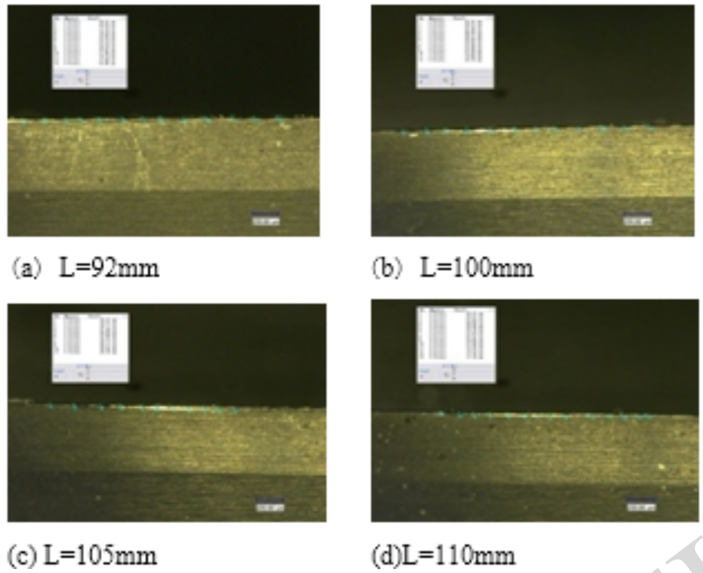


Fig. (1). Results of milling cutter flank face wear.

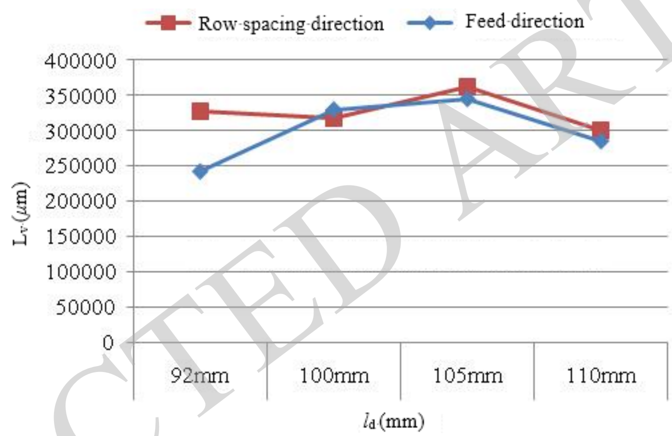


Fig. (2). Cutter vibration total stroke.

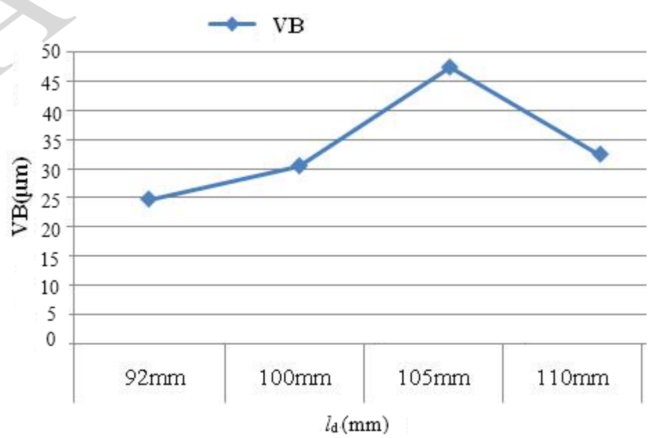


Fig. (3). Cutter flank wear.

piece size is 100mm×50mm×45mm, milling mode is down milling, feed per tooth of milling cutter is 0.4mm, axial depth of cut is 0.2mm, milling line spacing is 0.3mm.

Using 2 tooth ball-end mill with diameter of 20mm, under the condition of 92mm, 100mm, 105mm and 110mm extended length. Separately use 5000rpm, 6000rpm, 7000rpm and 8000rpm rotational speed for cutting hardened steel initial wear experiment. Cumulative cutting length 1600mm, obtained the wear experiment results of rake face and flank face of mill cutter as shown in Fig. (**1**) to Fig. (**3**).

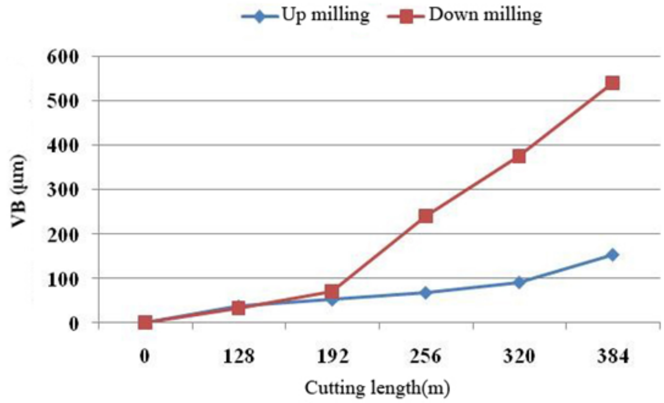


Fig. (4). Wear curve comparison between down and up milling.

In the picture, ld is extended length of milling cutter, Lv is the total trip of milling cutter vibration, it is equal to the product of amplitude of the milling cutter and number of vibration. VB is the average wear width of milling cutter flank face.

Experimental results show that, the impact energy generated by amplitude does not make the milling cutter breakage. There is no definite relationship between the initial wear width and amplitude of milling cutter flank face. But it is almost same with the change trend of vibration frequency and total stroke of vibration. That is within the exact cutting time and cutting length, the greater vibration frequency and vibration stroke of milling cutter, more serious of initial wear. So, in the process design of control initial wear of milling cutter should mainly consider the impact of process parameters to the milling cutter high frequency vibration.

3. IMPACT OF MILLING MODE ON TOOL LIFE OF HIGH SPEED MILLING CUTTER

In order to obtain the influencing characteristics of the milling mode of coated cemented carbide milling cutter cutting hardened steel on the service life. Under the condition of 8000rpm spindle speed, respectively using the down milling and up-milling within the wear experiment of high speed ball end mill cutting hardened steel. Work piece is Cr12MoV, hardness is HRC55-60. The wear curve of high speed ball end mill obtained from experiment is shown in Fig. (**4**).

In the picture, VB is the average wear width of milling cutter flank face. Milling cutter initial wear stage when cutting length is less than 128mm, there is no significantly different between the impact of down milling and up milling on the milling cutter wear. The length of down milling is longer than 192mm, when continue cutting the milling cutter wear is rising sharply. Milling cutter flank face wear width will reached dull standard only after cutting 64m. Up milling process has been in a state of stable cutting, cutting length is 384m, dull standard has not been reached. The experimental result show that, milling mode has a obviously impact on milling cutter cutting ability of remain normal wear stage in high speed cutting process. In down milling process, the sharp wear process have taken place within a relatively short stroke, shortened the tool service life. The wear is relatively stationary in up milling process, it is beneficial to prolong the tool service life under the condition of high speed cutting.

4. IMPACT OF MACHINING INCLINATION ANGLE ON TOOL LIFE

For obtaining the influencing characteristics of machining inclination angle on coating cemented carbide ball-end mill, under the condition of spindle speed is 8000rpm, adopting fixed machining inclination angle (15º) and variable machining inclination angle (0º~15º) to do a wear experiment on coating cemented carbide high-speed ball-end mill cutting hardened steel. Getting the wear condition and wear history of milling cutter as shown in Fig. (**5**) and Fig. (**6**).

It was found that the contact-length range of milling cutter's cutting edge is 2mm when fixed-angle cutting and 3.6mm when variable-angle cutting. Milling cutter's wear location is relatively concentrated when fixed-angle cutting. Under the condition of milling cutter's wear standard are all 0.2mm, the cutting length is 270m when fixed-angle cutting, 448m when variable-angle cutting. Variable-angle cutting extends cutter's life by 66%.

The experimental results show that fixed-angle cutting does not change the wear characteristics of cutter's rake face and rear face. However, by dispersing cutter's contact position, on the one hand, it makes more cutter's coating surface involved in cutting, on the other hand, by increasing the contact length of cutter and hardened steel, it makes the cutter's wear more uniform. So as to reduce the cutter's wear loss and prolong its effective length of cutting. Its wear rate is significantly less than fixed-angle cutting's.

5. EFFECT OF DIAMETER AND SPEED ON THE TOOL LIFE

To reveal the influence degree of cutter's diameter on its wear and service life, adopting coating cemented carbide

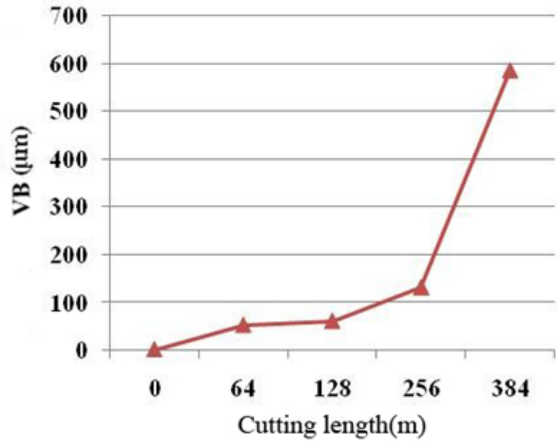


Fig. (5). Wear curve of fixed-angle cutting.

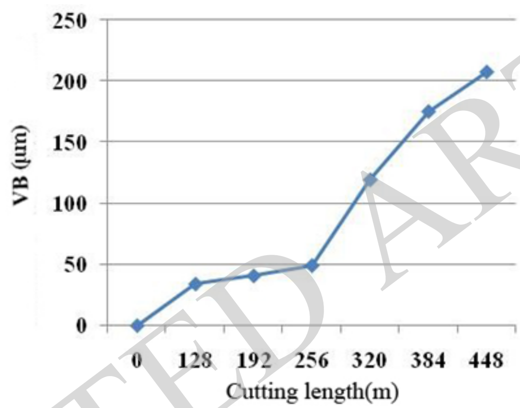


Fig. (6). Wear curve of variable-angle cutting.

high-speed ball-end mill whose diameter is 20mm and 30mm, doing an experiment on cutting hardened steel. Among them, the cutter's overhanging volume is 92mm, tooth number is 2, feed per tooth is 0.3mm, cutting depth of axial direction is 0.2mm, row spacing of milling is 0.4mm~0.45mm. The experiment and analysis results are shown in Table **1**. Among them, cutter's life is the cutting time of severe vibration caused by cutter's sharp wear making milling process.

From Table **1**, when the cutter's diameter is 30mm and spindle speed is rising from 3200rpm to 6000rpm, cutting efficiency is increased significantly, but its service life is greatly reduced. There is strong incompatibility between cutting efficiency and service life of cutter. It has great influence on the cutter's cutting performance. Under the condition of the spindle speed is 6000rpm, keeping machining efficiency of high speed milling hardened steel unchanged, reducing the cutter's diameter from 30mm to 20mm, the service life of cutter will increase significantly. The results show that under the condition of high speed cutting parameters are relatively stable, by varying cutter's diameter, controlling and adjusting the cutting speed and the contact relationship between the cutter and hardened steel, it can effectively reduce the action intensity between cutting efficiency and service life, and then at the high level of efficiency inhibiting cutter's wear and increasing its service life.

6. PROCESS DESIGN METHOD OF HIGH SPEED MILLING HARDENED STEEL AND ITS CONSUMPTION

To further clarify the relationship between the consumption of cutter and the cutting efficiency, its service life when high-speed milling hardened steel, the cutter's consumption is calculated as follows.

$$A = T \times S_t = T \times (\frac{\partial S}{\partial t}) = \frac{S}{m} \quad (1)$$

In formula, A is function value of high-speed milling cutter's efficiency life (m^2/a), T is cutter's service life, S_t is cutting area of hardened steel profile in unit time (m^2/min), S is cutting area of hardened steel profile (m^2), m is the number of cutters's consumption.

Table 1. Cutter performance contrast.

(1-1)

Workpiece Hardness (HRC)		**HRC55-HRC60**		
Milling Cutter's Diameter (mm)		**30**		
Process Conditions		**A**	**B**	**C**
Spingdle speed (rpm)		3200	6000	6000
Feed per tooth (mm/z)		0.3	0.3	0.3
Cutter's life	Cutting efficiency (mm^2/min)	880	1440	1440
	Cutter's life (min)	300	111	240

(1-2)

Workpiece Hardness (HRC)		**HRC55-HRC60**	
Milling Cutter's Diameter (mm)		**20**	**Increasing Range of Index**
Process Conditions		**4.608**	**5.880**
Spingdle speed (rpm)		(B-A)/A	(C-B)/B
Feed per tooth (mm/z)			
Cutter's life	Cutting efficiency (mm^2/min)	+63.64%	0.00%
	Cutter's life (min)	-63.00%	+116.22%

Using absolute value method to the Equation (1) to analysis function value of high-speed milling cutter's efficiency and life, it shows that the function value of high-speed milling cutter's efficiency and life not only reflects the cutter's cutting efficiency and life, but also directly reflects the area of hardened steel profile each cutter could cut, and the number of cutters consumed by cutting the predetermined area of hardened steel profile. The higher function value of the cutter's efficiency and life when cutting harden steel, the lower incompatibility between high efficiency and long-life cutting program, the stronger wear resistance when cutting harden steel, the smaller consumption. So aiming at controlling the cutter's consumption of high-speed cutting hardened steel can significantly increase the finishing efficiency of single cutter when cutting hardened steel.

Based on the analysis results above, getting process design flow chart of controlling high-speed cutter's consumption when cutting hardened steel as Fig. (**7**) shows.

In the process design, it makes cutting force and vibration dropped greatly by reducing row spacing, cutting stability is improved significantly. When machining hardened steel surface, with the contact position changing between the cutter and workpiece, there are often existing conditions of down-milling and conventional-milling alternately cutting. So the important element should be considered in cutting tool path selection is to ensure cutter in up-milling cutting from beginning to the end.

7. PROCESS TECHNIC VERIFYING EXPERIMENTS OF HIGH SPEED MILLING HARDENED STEEL DIE

Using the above methods to solve cutter's function value and assess its consumption when high-speed milling hardened steel car plate die. The comparison of processing effect between new and original process scheme is shown in Table **2**. Among them, the process 1 is the original process, process 2 is the intermediate process and 3 is the new process.

From Table **2**, to ensure the surface forming quality of car's covering parts, when improving process 1 to 2, the improvement of hardened steel's machined surface quality caused the decline of cutting efficiency and the increase of cutter's consumption. Comparing process 3 with 1, the cutting time reduces by 17.2%, the machined surface quality increases by 75%, the cutter's consumption reduces by 14.3%.

Comparing the experimental results of process 2 and 3, finding that process 3 makes the cutter's cutting force decrease by 8.4%, the amplitude along feed direction reduces by 6.1%~16.5%, the amplitude along row spacing direction reduces by 4.1%~12.8%, the cutter's life increases by 9.7%, the cutting efficiency improves by 38.5%, the machined surface quality improves 50%, the cutter's consumption reduces 40%, die type surface finishing and polishing time reduces from 270 hours to 92 hours and the machining efficiency are improved significantly.

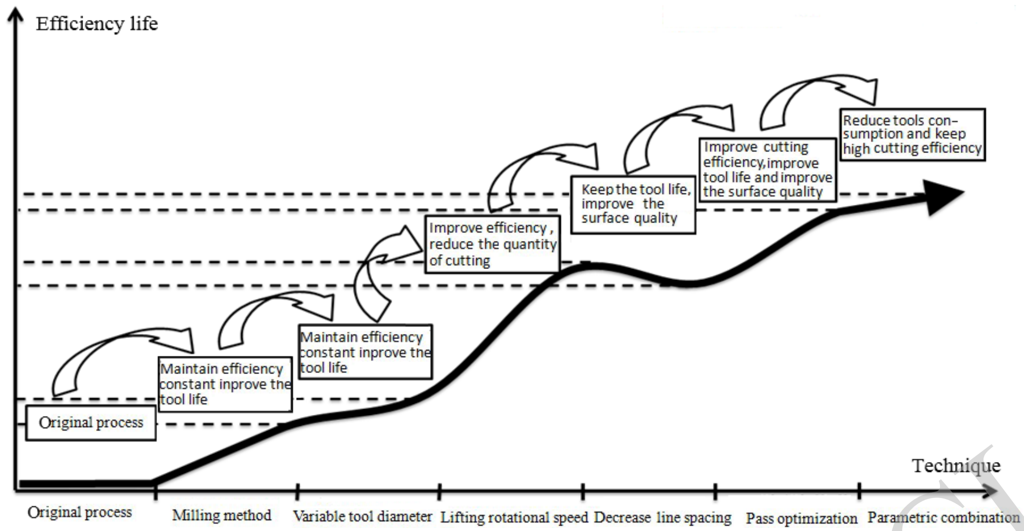


Fig. (7). Process of controling cutter consumption.

Table 2. Results comparison of process experiment.

(2-1)

Mold processing Surface and Specifications				**Mould Material and Hardness**	
 **1640 × 1230 × 150 (mm)**				**Cr12MoV (HRC55～60)**	
Cutting Parameter and Experimental Results					
Process	Cutting Path	Cutter	Spindle Speed (rpm)	Feed Rate (mm/min)	Row spacing (mm)
1	Parallel Processing	D30	4000	3000	0.4
2	Regional Ring Digestion	D20	4000	3000	0.3
3	3d Bias	D20	6000	4800	0.3

(2-2)

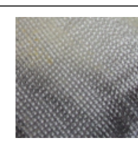
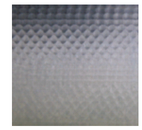
Machine Tool and Models				**Cutter and its Specification**
Five-axis Bridge Type High-speed NC Milling Machine				**Coated Cemented Carbide Ball-end Mill (2 Teeth)**
Cutting Parameter and Experimental Results				
Process	Cutting depth (mm)	Processing time (h/min/s)	Cutter's Number	Machined Surface (μm)
1	0.3	29:09:39	7	 Ra3.2~6.3

Table **2**. contd…

Machine Tool and Models				**Cutter and its Specification**
Five-axis Bridge Type High-speed NC Milling Machine				**Coated Cemented Carbide Ball-end Mill (2 Teeth)**
Cutting Parameter and Experimental Results				
2	0.2	39:06:20	10	 Ra1.6~3.2
3	0.2	24:17:44	6	 Ra0.8~1.6

CONCLUSION

Through wear and vibration experiment of high speed milling hardened steel, revealing the influencing characteristic of multi-characteristic vector, such as cutter's vibration, milling mode, cutter's diameter, spindle speed, row spacing, cutting path and so on, on the cutting efficiency and service life of high speed milling cutter. Taking advantage of the cutting time needed by the high-speed milling cutter reaching its service life and cutter's cutting efficiency, building a function-value model of efficiency and life, showing the interaction relationship cutting efficiency and service life of cutter, obtaining the calculation method of high-speed milling cutter's consumption.

According to function-value dimension of the high-speed milling cutter's efficiency and life, its function value of efficiency and life refers to a milling cutter's cutting area on hardened steel when reaching its service life. The efficient and life function of high-speed milling cutter, not only reflects the cutter's cutting efficiency and its level of service life, but also directly reflects the surface area of hardened steel profile that a cutter can cut before its wear reaches the standard of wear.

Aiming to make high speed milling cutter achieve maximum function value of efficiency and life, through the process design of high-speed milling hardened steel, solving the problems of process domain's interference caused by service performance's conflict, such as cutter's high efficiency and long life, when milling large hardened steel surface. This method not only has high sensitivity on measuring service performance of high-speed milling hardened steel, but also has the function of decoupling and process schemes' optimization.

Putting forward a process planning method on high speed milling hardened steel's surface. It can get higher machined surface quality in a relatively short period of time and with smaller cutter's consumption. Solving the significantly increasing of cutter's consumption and aided man-hour caused by cutting speed and cutting efficiency improved greatly when high-speed ball-end cutter for finishing. Controlling the high-speed milling cutter's consumption under the condition of higher cutting efficiency levels. Reducing the influence on machined surface quality caused by changing cutter frequently during the hardened steel surface finishing process, shortening the subsequent polishing time of large hardened steel surface significantly.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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