On the Wear of Carbide Tools in Machining Cast Iron Roll

—The Relation between Microstructure and Tool Wear—

Ryozo KITAGAWA*

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Abstract

Several types of tungsten carbide tools were formed with varying their microstructures, namely mean free-path for a binder phase. From experimental results it was found that the mean grain size and the mean free-path have a significant effect on tool wear in machining different materials of cement mortar, carbon steel and various cast iron rolls. As a result of this investigation, it is recommended to use the carbide tool's microstructrue for various cast iron rolls.

1. Introduction

An investigation of the chipping and failure of tool materials which are difficult to machining-work is a worthy problem. Moreover, the research upon tool life (especially the relationship between the microstructure and carbide tool's wear) is the most important relationship. One can determine the microstructure of carbide tools, mean grain size of carbide, mean free-path of binder phase in cobalt, and other parameters numerically$^{1)}$.

From the above we find a relationship between mean grain size or mean free-path of the binder phase and tool life when we machine different types of work materials. This kind of research has not previously been reported. We deal mainly with two different carbide-tool series, K and M as classified by JIS, and show how the parameter in the microstructure of the carbide tool affect tool life.

Furthermore, we identify the conditions which offer the greatest advantage in terms of wear resistance when machining three different work material groups, namely cement mortar, carbon steel and cast iron rolls.

2. Experimental Method

2. 1 Selection of Tungsten Carbide for the Investigation

In general, chips produced by machining cast iron rolls are discontinuous and the variation of cutting forces causes chatter vibration during machining. A carbide tool having higher strength WC-Co series (K-grade by JIS classification) is preferred to match these conditions.

Cast iron rolls contain harder carbide particles in their structure and the non-homogeneous material. Chips are produced by one of the shear types and there is no primary or secondary deformation, nor is the chip deformed plastically even though

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*Department of Industrial Mechanical Engineering

high cutting temperature is generated. In the machining of these work materials, we chose a type of cutting tool having resistance to chipping at the begining of the machining. The essential reason for the wear of cutting tools is not to produce any destruction of particles in the structure of the tool materials.

Wear of sintered tungsten carbide can be classified into two groups [2),3)] :

- A. abrasive wear
  - 1. the destruction of mechanically weakened part
  - 2. the destruction of projected particle
- B. attrition wear
  - 1. the wear of softened part of material structure
  - 2. the wear of particle

In machining cast iron rolls, tool wear is dominated by the reasons A-1 and A-2 and unlikely by B-1 and B-2. The latter reasons mostly occur during the machining of steel under higher cutting temperature.

Table 1 Properties of carbide tools used in this investigation.

Carbide tool	Vickers hardness	Coercive force, Oe	M.G.S.[x] μm	M.F.P.[xx] μm	Compositions, wt%			
					WC	TaC	TiC	Co
TOOL-H	1995	370	1	0.04	94.5	2.5		3
TOOL-M	1970	327	0.8	0.05	92	2		6
TOOL-T	1881	320	2.2	0.09	89	1	4	6
TOOL-G	1776	215	2.4	0.14	90.5		5	4.5
D10	1485	186	2.7	0.20	94.5			5.5
D20	1285	135	2.7	0.28	90			10
D40	1078	100	2.7	0.44	84			16
D60	853	82	2.4	1.15	75			25
S10	1661	125	3.6	0.20	80		15	5
S20	1593	155	4.7	0.22	83		12	5
S30	1465	135	2.9	0.32	87		5	8

[x] mean grain size of carbide

[xx] mean free path of binder phase

Table 1 shows various types of carbide tools, especially produced for this investigation. Tools H, M, T and G were for the machining of cast rolls and varied in the mean grain size of carbides and in the mean free-path of binder phase. In addition, seven different types of carbide tools (D series and S series in the table) in total were prepared to study the effect of hardness, mean free-path and content of TiC on tool performance. The size of carbide tip was 22 mm × 15 mm × 6mm. Table 1 shows hardness, coercive force, mean grain size, mean free-path and chemical composition of various carbide used in this investigation.

The value of the mean grain size of the carbide and the mean free-path for the binder phase were determined by an microscopic observation (×2000) using Fullman's method [4]. Calculated values versus Vickers hardness for the prepared carbide tools are shown in Fig. 1. From this figure, it is recognized that the mean free-path is proportionally related to the vickers hardness which is consistent with Gurland's investigation [5] and Gensamer's theory [6]. However, the relationship between the mean grain size and vickers hardness was not as clearly proportion as the relationship with the mean free-path. The reason for this is due to the fact that the composition of carbide alloying and the processing methods are not identical.

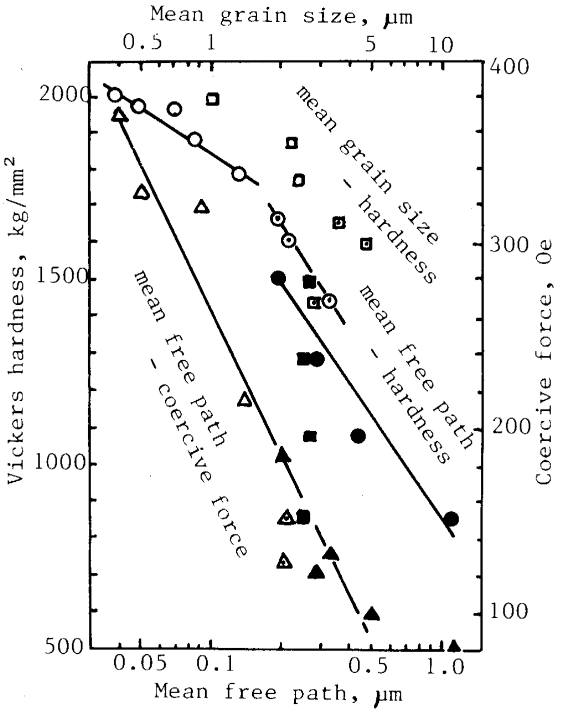

Fig. 1 Relationship between mean free-path, mean grain size, handness and coercive force.

2. 2 Cutting Conditions and Work Materials

A variable speed drive lathe having a 7.5 kw drive motor was used. Dry cutting was adapted, a depth of cut of 1.5 mm, and feed rate of 0.2 mm/rev were held constant under varied cutting speeds throughout this investigation. The carbide tip was clamped in the specially designed tool holder. The geometry of tool tip was varied as 0°, 6°, 6°, 6°, 8°, 45°, 1 R and each of them was ground with a # 220 diamond grinding wheel. The workpieces for this investigation were made of the hardened cast alloy, and their

Table 2 Properties of work materials.

Workpieces	Hardness HV	Chemical compositions wt %								
		C	Si	Mn	P	S	Cu	Ni	Cr	Mo
Carbon steel	224	0.53	0.25	0.77	0.024	0.033	0.26	0.16	0.13	0.04
Ductil roll	515	3.27	0.49	0.45	0.042	0.016	0.06	2.51	0.53	0.63
Grain roll	467	3.15	1.19	0.55	0.082	0.039	0.08	1.49	0.79	0.07
Chilled roll	659	3.55	0.51	0.28	0.344	0.054	0.05	2.44	0.90	0.03
Adamite roll	330	1.55	0.90	0.90	0.024	0.013	0.12	0.81	0.96	0.27
Cement-mortar		cement : sand : water = 1 : 2 : 0.6 , HS = 20.9								

composition is tabulated in Table 2. The workpieces were cast to a size of 210 mm in diameter and 1000 mm in length and were heat-treated after casting. Machining was conducted after the surface was turned to a depth of approximately 30 mm, where the hardness of the surface was uniform.

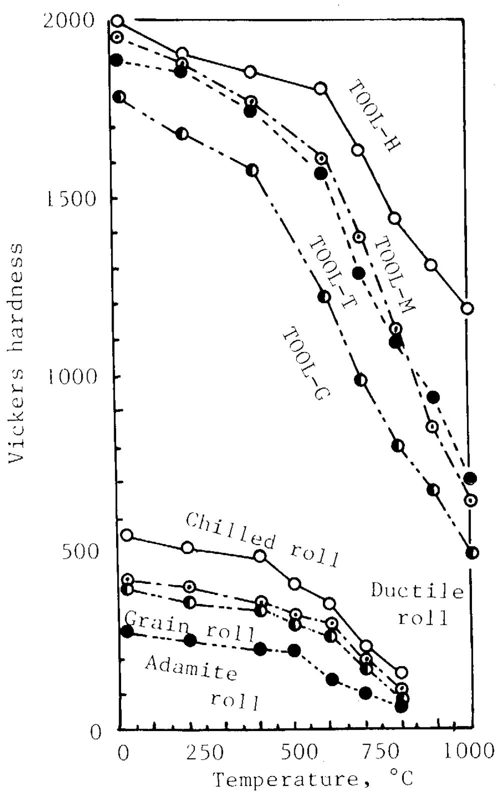

Fig. 2 Hot hardness of carbide tools and work materials.

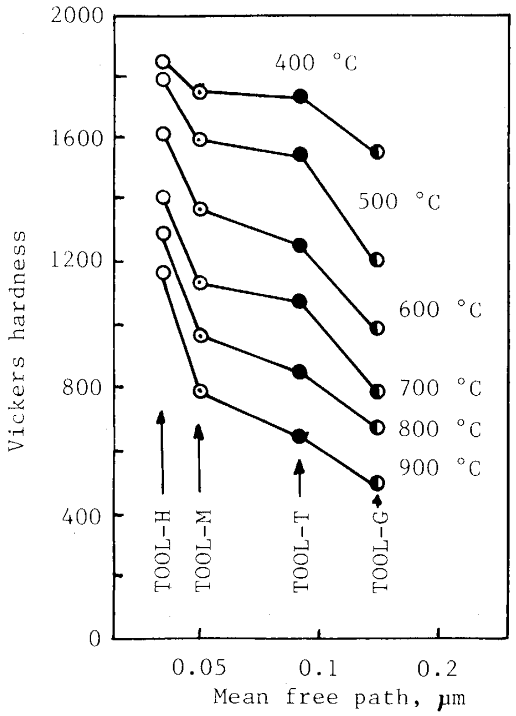

Fig. 3 Relationship between mean free-path and hot hardness.

Hot hardness testing was conducted on both carbide tools and work materials, and the results are shown in Fig. 2. The relationship between vickers hardness and the mean free-path under varied temperature for four cutting tools is shown in Fig. 3.

Tool wear when turning cast iron roll can be classified into two types: abrasive or attrition wear. In practice, both types of wear processes are combined when actually turning cast iron roll.

In order to isolate the effect of abrasive wear effects upon tungsten carbide, a special work material of cement mortar, was prepared.

This nonmetallic work material is identified as the material which has a resistance to abrasive wear for a tungsten carbide tool [7]. The effect of the micro-structure of tungsten carbide on abrasive wear was examined using two different series of tungsten carbide, having same compound system of WC-TiC-Co sintered carbide.

Besides this work material, carbon steel was prepared for the study of attrition wear of tungsten carbide. Table 2 summarizes the hardness and chemical compositions of these work materials.

3. Experimental Results and Discussion

3. 1 Investigation of Cutting Temperature

The microstructure of a cast iron roll consists of ledeburite (Hv 800～1000) and cementite (Hv 300～400) where the hardness varies within the each structure. Therefore, small hard particles on the back side of chips remove the particles of tool materials during cutting, and abrasive wear is accelerated when the cutting temperature under increased cutting speeds to obtain a clear explanation of tool wear. Cutting temperature measurements were conducted by placing the thermocouple between the workpiece and the cutting tool for the ductile roll and the carbon steel. An inserted chromel-almel thermocouple was used in the cement mortar work material. The cutting temperature measurements for cutting speeds between 10-200 m/min are shown in Fig. 4. From this figure, one can see that the two work materials, that is the ductile roll and the carbon steel, show a parallel increasing curve, while the cement mortar exhibits a very low cutting temperature when the cutting speed is under 100 m/min.

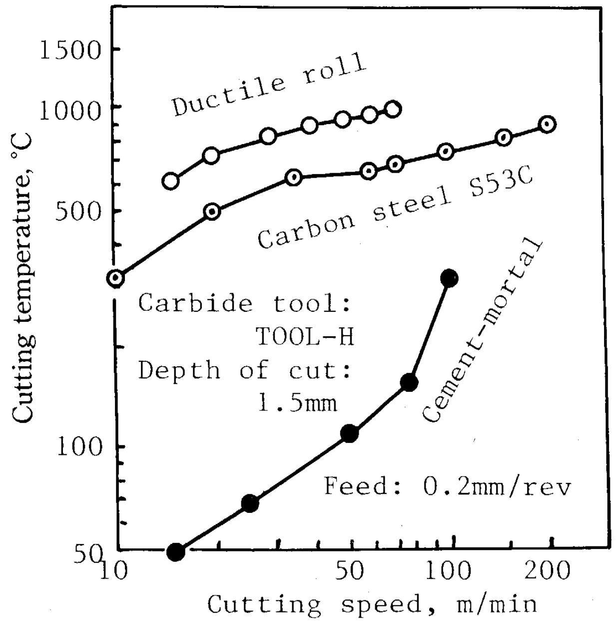

Fig. 4 Cutting temperature of various work materials.

From these observations, it can be assumed that when machining the cement mortar, the tool wear at lower cutting speeds is not affected by the hot hardness. The main reason for the tool wear is likely due to the hard quartz particles in the cement mortar which dig out softened particles from the carbide tool.

3. 2 The Effect of Tool Microstructures on Tool Life When Turning Cement Mortar

This investigation was designed to determine effects of microstructure of a carbide tool upon tool wear when a nonmetallic work material of cement mortar, is machined. Wear characteristics for this invesigation. Each of the tools T, M and H has a different mean grain size and a mean free-path. This figure confirmed that the smaller the mean grain size and the mean free-path the larger the resistance to tool wear. Fig. 5 shows the difference of wear progression for both tools H and T.

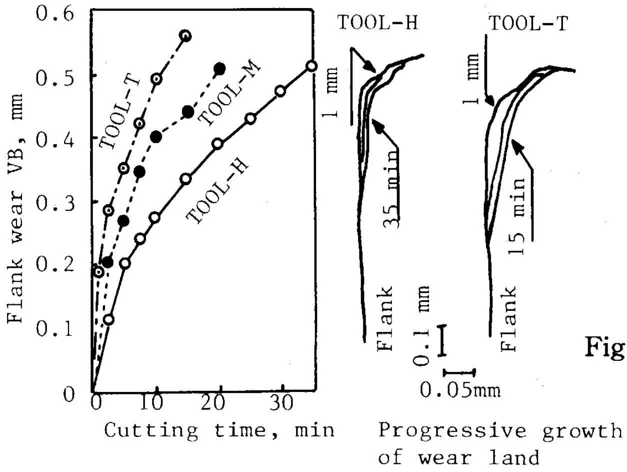

Fig. 5 Flank wear when machining cement mortar.

Since the weakest particle in the tungsten carbide is binder phase cobalt, it can be shown that the smaller the content of the binder phase of cobalt and smaller the content of the binder phase of cobalt and smaller the mean free-path the longer the tool life. Fig. 6 summarizes the relationship between tool life and carbide tool microstructure, using all information and the cutting tools shown in Table 1. As shown in this figure, the mean grain size is proportional to tool life.

Under a relatively low cutting speed of 50 m/min, where the influence of cutting temperature can be excluded, there is a clear influence of the mean free-path on the tool wear. This means that the smaller the mean free-path, the larger the resistance against abrasive wear. Fig. 7 summarizes the effect of the mean free-path and the mean grain

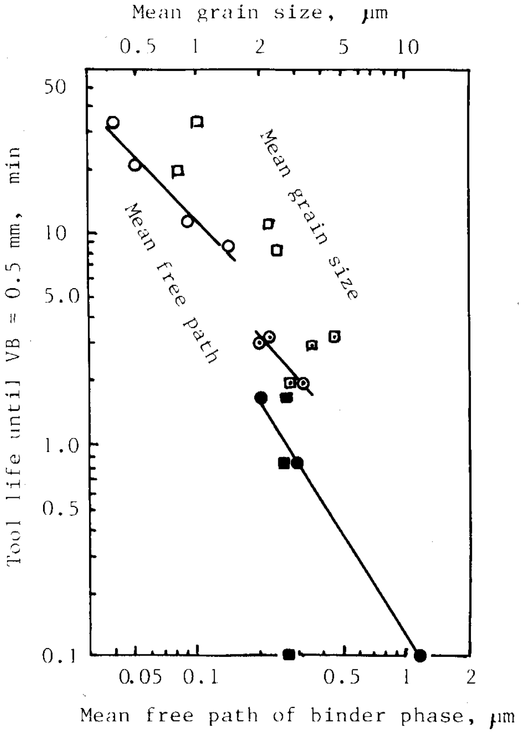

Fig. 6 Relationship between mean free-path, mean grain size and tool life when machining cement mortar.

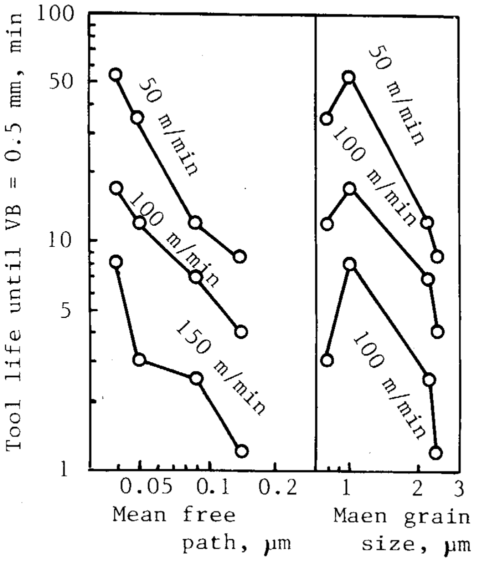

Fig. 7 Relationship between tool life, mean free-path and mean grain size when machining cement mortar.

size on the tool life under varied cutting speeds, using the four different tungsten carbide tool recommended for machining the cast iron rolls. It is noticed that as the mean free-path decreases, the tool life increases in this figure. The mean grain size of the tungsten carbide tool also influences the tool life. The tool life tends to increase when the mean grain size is decreased. This trend is not as clear as in the case of the mean free-path dependence. The tool M, which had the smallest mean grain size among other cutting tools, showed no significant performance in term of the fact cutting temperature with a cutting speed over 150 m/min reaches more than 700°C, and this temperature causes a decrease of hot hardness for the tool M.

3. 3 Effect of Microstructure of Carbide Tool on Tool Life When Machining Cast Iron Roll and Carborn Steel

From the above investigation, it was confirmed that the abrasive wear of a tool is related to the mean free-path while attrition wear is influenced by the mean grain size. Fig. 8 presents the results of tool life tests using four different carbide tools, H, M, T, and G, when turning carbon steel. In this investigation, it was found that the mean grain size of a carbide tool was directly related to the tool life. The tool life increased as the mean grain size increased. This trend is more clear than the case of mean free-path dependence. Fig. 7 shows the reverse result ; The tool life increases as mean grain size decreases. Generally, it is known that a large grain size in tungsten carbide used for machining steel has more thermal stability and more resistance to crater wear.

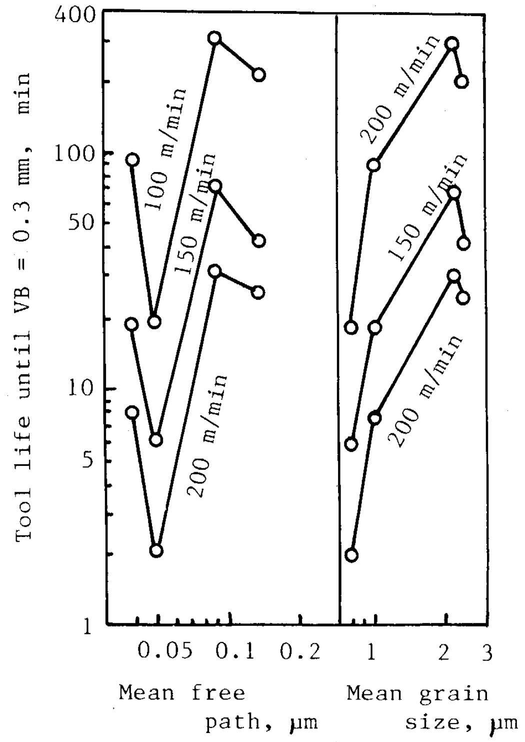

Fig. 8 Relationship between tool life, mean free-path and mean grain size, when machining carbon steel.

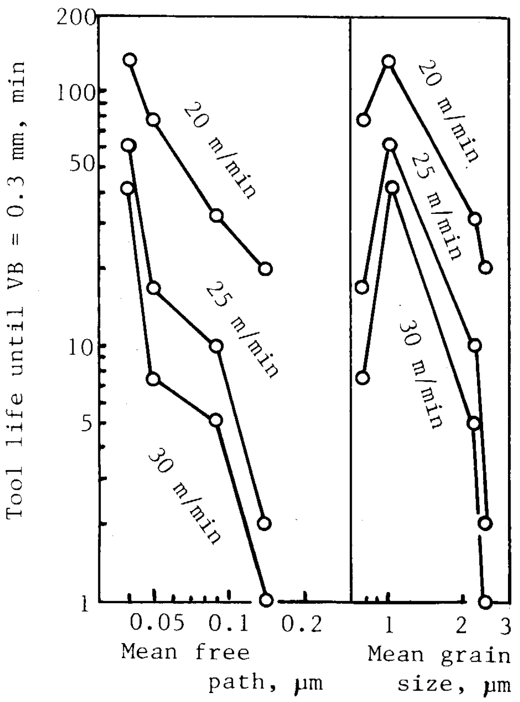

Fig. 9 Relationship between tool life, mean free-path and mean grain size, when machining ductile roll.

The results in Fig. 8 can be considered with the general explanation regarding the relationship between the mean grain size and the tool wear.

On the other hand, the results using the ductile roll are significantly different from the case of machining carbon steel (Fig. 9). Four different carbide tools (H, M, T and G) which have different microstructures were tested with a ductile roll. As in the cast of machining cement mortar, when machining a ductile roll, the mean free-path in the tools influence stronger on the tool wear than the mean grain size. From both figures (Fig. 7 and 9) the tool wear when machining cast iron roll can be shown to be caused by the falling off of carbide particles, attaching to the hard particles in cast roll. We note that this effect does not happen when machining carbon steel.

Table 3 Summary of tool life equation and tool life time for cutting speed of 20 min.

	Workpiece	Carbide tool	TOOL-H	TOOL-M	TOOL-T	TOOL-G
Vd = 0.5 mm	Cement - mortar HS = 20.9	V=15~75 m/min	$VT^{1.00}=2182$	$VT^{1.32}=5078$	$VT^{1.65}=2736$	$VT^{1.40}=1092$
			$T_{(V=20)}=109$	$T_{(V=20)}=61$	$T_{(V=20)}=20$	$T_{(V=20)}=18$
		V=75-200	$VT^{0.66}=612$	$VT^{0.71}=203$	$VT^{0.54}=261$	$VT^{0.52}=217$
Tool Life VB = 0.3 mm	Carbon steel HV = 224	V=50-100	$VT^{1.14}=17927$	$VT^{0.54}=481$	$VT^{0.89}=16642$	$VT^{0.72}=4705$
		V=100 - 300 m/min	$VT^{0.29}=359$	$VT^{0.30}=250$	$VT^{0.39}=663$	$VT^{0.38}=695$
			$T_{(V=100)}=79$	$T_{(V=100)}=21$	$T_{(V=100)}=250$	$T_{(V=100)}=200$
	Ductile roll HV = 515		$VT^{0.23}=64$	$VT^{0.17}=41$	$VT^{0.20}=40$	$VT^{0.15}=29$
			$T_{(V=20)}=156$	$T_{(V=20)}=68$	$T_{(V=20)}=32$	$T_{(V=20)}=12$
	Grain roll HV = 467		$VT^{0.34}=95$		$VT^{0.26}=60$	
			$T_{(V=20)}=98$		$T_{(V=20)}=58$	
	Chilled roll HV = 659		$VT^{0.22}=27$		$VT^{0.20}=20$	
			$T_{(V=20)}=4$		$T_{(V=20)}=1$	
	Adamite roll HV = 330		$VT^{0.44}=144$		$VT^{0.43}=155$	
			$T_{(V=20)}=88$		$T_{(V=20)}=115$	

Table 3 summarizes the results of tool life tests using work materials described in table 2. A comparison of tool life equations under various tool life criteria and under different tool materials can be made in table 3. From this summary, it is concluded that tool life for machining cast iron rolls can be extended at carbide tools a smaller mean free-path is used, with the only exception of the adamite roll.

The cutting speed for a tool life of 20 min (V 20) is closely related to the size of the mean free-path, as shown in Fig. 10. This result corresponds to the cast of machining cement mortar, in spite of the disagreement in the cast of machining carbon steel.

4. Conclusions

The resistance against abrasive wear was investigated using cement mortar. It

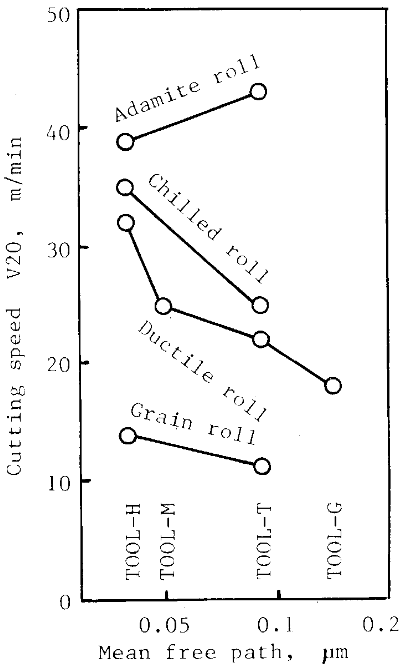

Fig. 10 Relationship V20 and size of mean free-path.

was found that tool life increased as the mean free-path decreased.

The resistance against attrition wear was investigated using also carbon steel, and it was concluded that tool life was extended with larger mean grain size.

The mean free path of binder phase cobalt is an important factor when machining cast iron roll which is similar to cement mortar. Hard particles in the cast roll cause abrasive wear of the tungsten carbide tool. As the mean free-path decreases, the tool wear becomes less, since the mean free-path controls the resistance of strain between each particles.

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