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DEVELOPMENT OF LAPPING TOOLS FOR MIRROR-LIKE SURFACE PROCESSING OF CEMENTED CARBIDE DIE

Recently, cemented carbide dies are used for many industrial products, due to their high stiffness and long life. Electric discharge machining is conventionally used and then, hand lapping is finally undergoes for mirror-like finishing of these products. In previous research, a simple lapping system for only plane surfaces of cemented carbide die was developed. In this study, several lapping tools for lapping of side, edge and corner were developed and evaluated by experiments. The system consists of a lapping tool, lapping vessel and conventional NC milling machine. The lapping vessel is placed on the table of the NC machine and the lapping tool is fitted with the spindle of the NC machine. Cemented carbide work piece is sunk and fitted in the lapping slurry and lapping processing is taken using the developed tools. Each lapping tool consists of a coil spring for supplying lapping pressure and the NC program was made possible to move the lapping head to contact and leave the work surface regularly for catching new grains and dressing. These lapping tools were finally evaluated by experiments. It is concluded from the results that the developed lapping tools were capable of lapping side, edge and corner of the cemented carbide work pieces for mirror-like surface finishing.

1. INTRODUCTION

Recently, cemented carbide materials are widely used for mould and die making processing. Generally, for making mold with carbide, electrical discharge machining or grinding is undergoes first and then hand lapping is taken for final finishing. For relieve the trouble of hand lapping there also invented some technologies such as, power mixed electrical discharge machining [1] and electron beam machining [2]. However, in making mold for high quality products, the mirror like mold surface is needed and it is still unavoidable to take hand lapping. Although most of the other metal processing can be done using CNC control machines, hand lapping can only be done by skillful workers taking very long time. This will effect on the productivity as well as product quality depending on the

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skill of workers. Therefore, the demands on application of auto lapping technology in the production also become increase in the industry [3], [4].

The authors have already invented the auto lapping tool in previous research. This lapping is capable of lapping flat surfaces and the evenly curved surfaces. Moreover, the optimum lapping condition is also investigated for product quality. However, it is still difficult to take lapping for side surfaces, edges and corners using this tool.

Therefore, in this research, the new lapping tools for side surface, edge and corner parts are developed and evaluated by experiments.

2. DEVELOPMENT OF LAPPING TOOL FOR SIDE, EDGE AND CORNER

2.1. THE PREVIOUS LAPPING TOOL FOR FLAT SURFACE

The schematic of the previously developed lapping tool A is shown in Fig. 1(a). The lapping tool is composed of round polypropylene PEO lapping head, spring for supplying lapping pressure and shaft for mounting in collet chuck. The design and structure of lapping tool is economy and these parts can be purchased easily. The purpose for choosing round lapping head is to make contact area as small as possible and the lapping position will also be controlled by NC controller so that to applicable also in curve surfaces lapping. Moreover, the purpose of choosing PEO as lapping head material is due to its property of catching and maintaining diamond grains from the lapping slurry during processing and thus, obtained relative movement between diamond grains and the work surface. The contact area between work surface and lapping head is calculated by using Hertz's contact theory. The lapping tool is made to be able to change easily the various size of lapping head. The soft and long spring for supplying lapping pressure is selected with stiffness 2.7 N/mm and 78 mm long. This will reduce the effect of positioning accuracy error of the NC machine and the tool setting error.

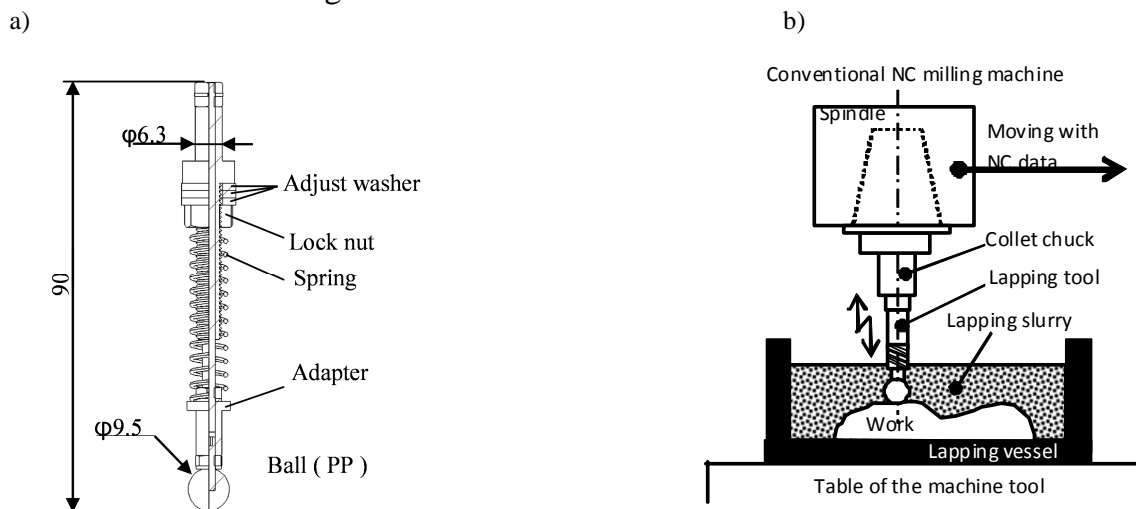


Fig. 1. Schematic view of old lapping tool and lapping system: (a) lapping tool A, (b) schematic view of new lapping system

Fig. 1(b) shows the schematic of the lapping tool and the lapping system. The developed lapping tool A is fitted on the NC milling machine and the work piece is fixed on the vice inside the lapping vessel. Then, the whole work piece is sank inside the lapping slurry and lapping process is undergoes using NC control. During lapping, lapping head is controlled to move up and down so that to make replacement of new diamonds grains (cutting edges) and old diamond grains automatically.

2.2. THE NEWLY DEVELOPED LAPPING TOOLS

Fig. 2 shows the schematic of the developed lapping tools by modifying the structure of lapping tool A to obtain three dimensional lapping processing. The developed lapping tools are capable of various surfaces depending on the machine being used, the vertical and horizontal working axis of the spindles, table movement and the shape of the lapping head.

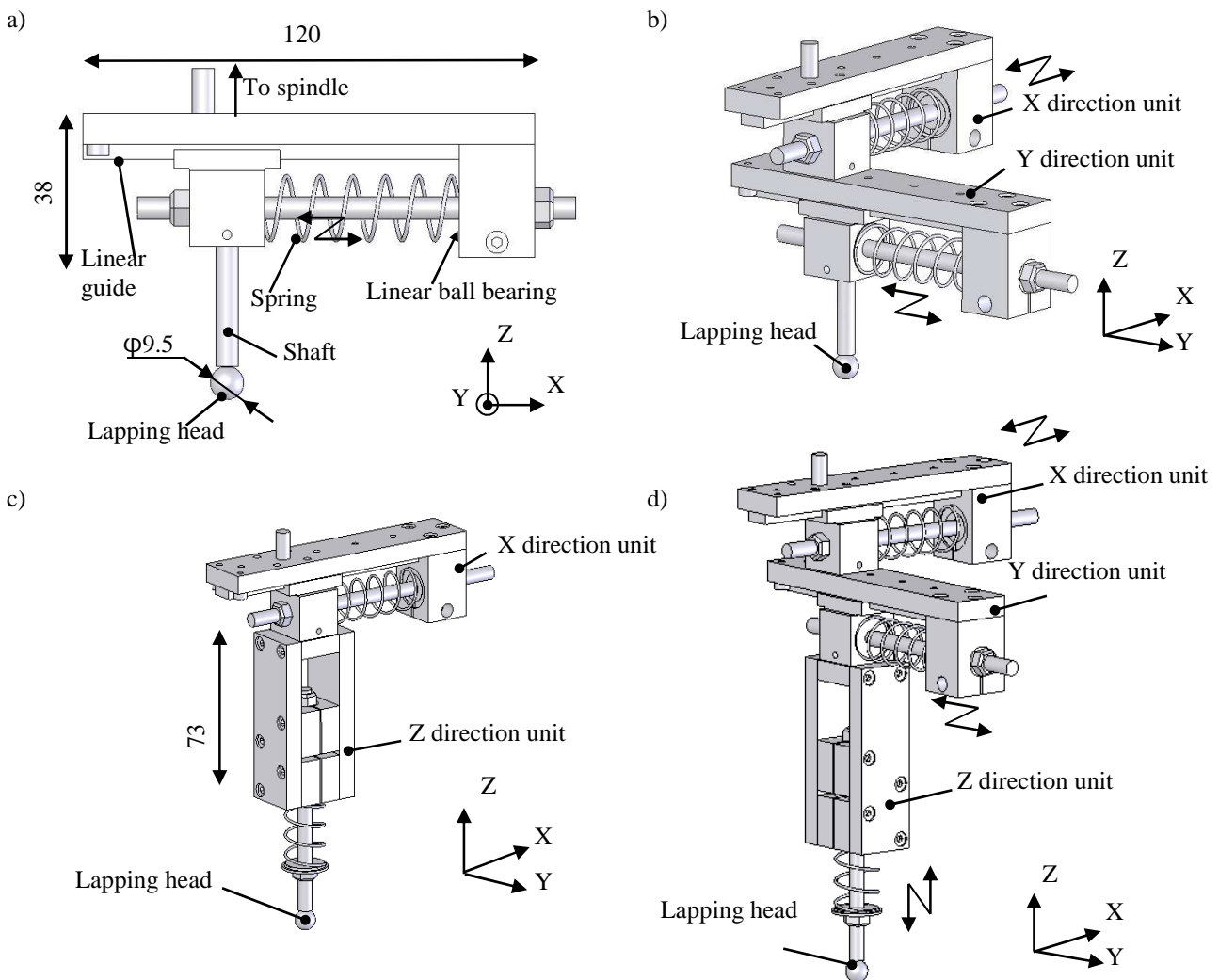


Fig. 2. Lapping tools for lapping side, edge and corner:
 a) lapping tool B for lapping of a side surface, b) lapping tool C for lapping of corner and edge, c) lapping tool D for lapping of corner and edge, d) lapping tool E for lapping of curved surface

Fig. 2(a) shows the side surface lapping tool B. This tool is just modified the vertical lapping tool A to the horizontal position and put the lapping head on a shaft for lapping deep concave side surfaces. The linear ball bearing and the linear guide will prevent the disturbance of moment due to the reaction forces during lapping by allowing only on X direction movement. It can be adjust the lapping pressure along X direction and the feed movement for Y and Z axis directions.

The lapping tool C is designed for the application of lapping edges and corners. This tool is constructed by adding similar unit on the lapping tool B with altering 90° angle as shown in Fig. 2(b). This tool can be applied for lapping of XY plane with desired inclination by applying the suitable lapping pressure on X and Y axis directions. At that time, the feed is given along Z direction. Similarly, the lapping tool D in Fig. 2(c) is capable of X and Z direction lapping on the XZ plane and at that time, the feed direction will be along Y axis.

Fig. 2(d) shows the lapping tool E for processing 3 dimensional curve surfaces. The tool is composed by adding the lapping tool C with lapping tool A in the place of shaft and then the lapping pressure is supply to all direction X, Y and Z axis. In the lapping processing, the feed direction is controlled by using multi axes processing machines and the lapping pressure is controlled for each direction perpendicular to the working surfaces so that to obtain uniform pressure through all X, Y, Z, A, B, C axes.

These lapping tools are applicable with using NC program by adjusting offset distance on the CAD data or NC data without any difficulties and effectively. Although there is possibility for applying lapping tool A with 5 axis processing machine to obtain same lapping surface as B, C, D and E. However, in this research, the conventional machine with 3 axis controlling system is objected to be applied as common and basic application.

Now, we will consider the applicability of each lapping tool with corresponding shape of work piece. The various types of the surface of the product are listed in to convex, concave, bottom, side, edge, corner, flat, cylinder and rounded shapes as shown in Fig. 3.

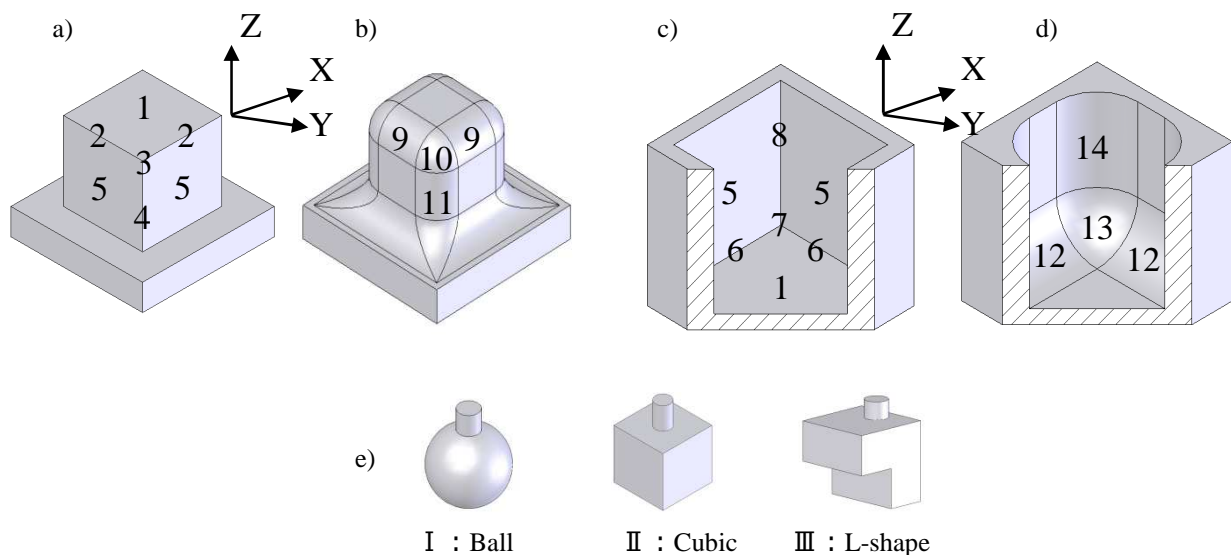


Fig. 3. Forms of lapping surface on three parts and forms of three lapping heads:
a) convex type by plane, b) convex type by curved surface, c) concave type by plan, d) concave type by curved surface, e) three lapping heads

Moreover, the possible lapping surface shapes with suitable lapping tool are also listed in table 1. The number listed in the table 1 represented the corresponding lapping place in Fig. 3. The possibility of the lapping process is determined by two facts (1) the selected lapping tool must be possible to apply lapping pressure perpendicular to the lapping surface, (2) possible to maintain uniform lapping pressure under moving with a feed rate during lapping process. In this research, apart from round shape lapping head, the cubic shape and L shape are also considered. Even there may considered various shapes of lapping tool head for more complicated work surfaces, only 3 kinds of lapping head is selected for experiments. Moreover, the there may have variety of solution relating to lapping tool shape depending on the specification of the machine being used. For that reason, this research is objected to use the conventional vertical machining center with 3 axis of X, Y, Z and only the case for lapping the complicated surface with lapping tool E is using multiple axes machine as an exception. The possibility of the lapping for each surface with corresponding lapping tools is confirmed by experiments. From the experiment results, it can be evaluated that the developed lapping tool A, B, C, D and E are applicable for the corresponding lapping process.

Table 1 Relationship between lapping tools and lapping surface on the three parts

Surface type	Shape	Shape No. (Fig.3)	Lapping tool used (Fig.1 & Fig.2)					
			A	B	C	D	E	
Plane	Convex type	Plane	1	○(I , II)				
		Edge (Side surface & plane)	2 (1+5)	○(I , II)			○(III)	
		Corner (Edge & Plane or Side surface)	3 (1+4)	○(I , II)		○(III)		
		Edge (Both Side surfaces)	4 (5+5)		○(I , II)	○(III)		
		Side surface	5		○(I , II)			
	Concave type	Bottom	1	○(I , II)				
		Edge(Side surface & Bottom)	6 (1+5)	○(II)			○(II)	
		Corner (Edge & Bottom or Side surface)	7 (1+8)	○(II)		○(II)		
		Edge (Both Side surfaces)	8 (5+5)		○(II)	○(II)		
		Side surface	5		○(II)			
Curved surface	Convex type	Edge(Side surface & Plane)	9				○(I)	
		Corner(Edge & Plane or Side surface)	10					○(I)
		Edge (Both Side surfaces)	11			○(I)		
	Concave type	Edge(Side surface & Bottom)	12				○(I)	
		Corner(Edge & bottom or Side surface)	13					○(I)
		Edge (Both Side surfaces)	14			○(I)		

() --- No. of lapping head used from Fig. 3 (e); I --- Ball, II --- Cubic, III --- L-shape

2.3. LAPPING SLURRY FOR STABILITY OF LAPPING CONDITION

When the diamond grains purchased from the market is used in lapping slurry, there occurs non uniform distribution of diamond grain concentration due to gravity and it will become difficult to get the stable lapping condition for finishing surface. Especially, as the objective of this research is for lapping of side surface and complicated surfaces, it is important to make uniform surface roughness, brightness and mirror like property for every work surface. Thus, the lapping slurry which is already revealed by the researchers [5] is used in this research.

Table 2 shows the specifications of the lapping slurry and Fig. 4 shows the dropping rate for each kind of lapping slurry. Here, the PEO percentage is made to be increased for improvement of lapping rate and keep the precipitation of diamond grains (#400~500, #1200, #2500) under $3\mu\text{m}/\text{min}$. The maximum PEO percentage is revealed by preliminary experiments and determined. The optimum condition of lapping slurry used in the experiment is 2wt% of PEO mixed with water and then, 2wt% of diamond grain. This optimum condition was chosen to use in the experiments.

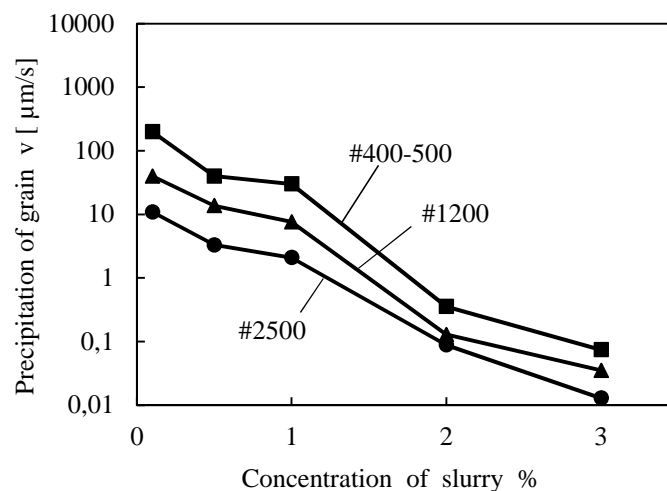


Fig. 4 Result of relationship between drop speed and PEO density

Table 2 Specifications regarding the lapping slurry

Slurry viscosity	PEO:1wt%	8 Pa.s
	PEO: 2 wt%	5
	PEO: 3 wt%	1.8
Size of grain	#400~500 #1200 #2500	
Density of grain in slurry	0.1,0.5,1,2,3	
Drop velocity of grain (PEO:2wt%)	#400	0.35 $\mu\text{m}/\text{s}$
	#1200	0.13
	#2500	0.09

3. THE EVALUATION OF THE LAPPING PROPERTY OF THE DEVELOPED LAPPING TOOLS

3.1. THE SPECIFICATION OF THE LAPPING PROCESSING SYSTEM

Table 3 shows the specification of the lapping processing system. The specifications included NC milling machine, lapping tool, lapping slurry, work piece and lapping condition. An ordinary NC milling machine with positioning accuracy 5~7 μm is used in experiment.

Table 3 Specification regarding the lapping machining

Specification of NC milling machine		
Table working surface	mm	610×381
Table loading weight	kg	250
Table movement stroke X-axis	mm	510
" Y-axis	mm	381
" Z-axis	mm	460
Distance from the table top face to the surface of the spindle nose	mm	100~560
Spindle speed	min ⁻¹	130~5000
Feed speed	mm/min	0~5000
Power of motor for spindle	kW	5
Machine weight	kg	2600
Specification of lapping tool		
Diameter of ball	mm	9.5
Material of Lapping head	--	PP
Length of spring	mm	78
Strength of spring	N/mm	2.726
Specification of lapping compound (Slurry)		
Material of grain	--	Diamond
Size of grain	#	400~500, 1200, 2500
Ratio of PEO (for water)	wt%	2
Rate of grain (slurry : diamond)		50 : 1
Specification of work piece		
Material of work piece		Cemented carbide (V10)
Surface roughness Rz	μm	2 (By grinding)
Lapping condition		
Spindle speed	min ⁻¹	0, [200]
Feed speed	mm/min	3000
Lapping pressure	MPa	60, [0.25]
Area of lapping	mm ²	100, [375]

※[]---at lapping of the work piece with ball shape

In the experiment, each lapping tool A, B, C, D are fitted on the spindle without revolving and only controlling feed with applying pressure on X, Y, Z directions. For the case of lapping tool E, the lapping pressure is applied on the X, Y, Z axes and the feed is controlled with C axis (i.e. spindle revolution). The diamond grains used in lapping slurry are #400~500, #1200, #2500 of three kinds and used with the order of rough to fine grain so that to obtain the mirror like surface with surface roughness (maximum height Rz) less than $0.1\mu\text{m}$. This lapping slurry is already revealed by the authors previously mentioned. The carbide V10 work piece is used and the initial surface is processed by using electrodeposited diamond tool to get the initial roughness Rz $2.0\mu\text{m}$. For the case of lapping tool E, it is too difficult to make processing. Therefore, S45C material is used and the lapping process is taken with the condition shown in []. The main spindle is made to be moving up and down periodically for replacing of diamond grains (cutting edges) at contact area. Here, the lapping pressure exerting on the lapping head is controlled so that to create the same lapping pressure whatever the shape of lapping head is round, cubic or L shaped. Thus the lapping condition can be controlled as same condition in all cases. The factors influencing on the surface roughness and the lapping rate can be considered as the size of diamond grains, lapping pressure, lapping head material and feed rate. In the experiment, the optimum lapping condition obtained from the preliminary experiments shown in table 3 is used.

3.2. EVALUATION OF THE LAPPING TOOLS

The evaluation for each lapping tools with corresponding surfaces, lapping tool A for bottom surface, B for vertical side surface, C for vertical cylindrical surface, D for the corner R connecting bottom surface and the side wall surface, E for the rounded surface are done by experiments using the lapping condition shown in table 3.

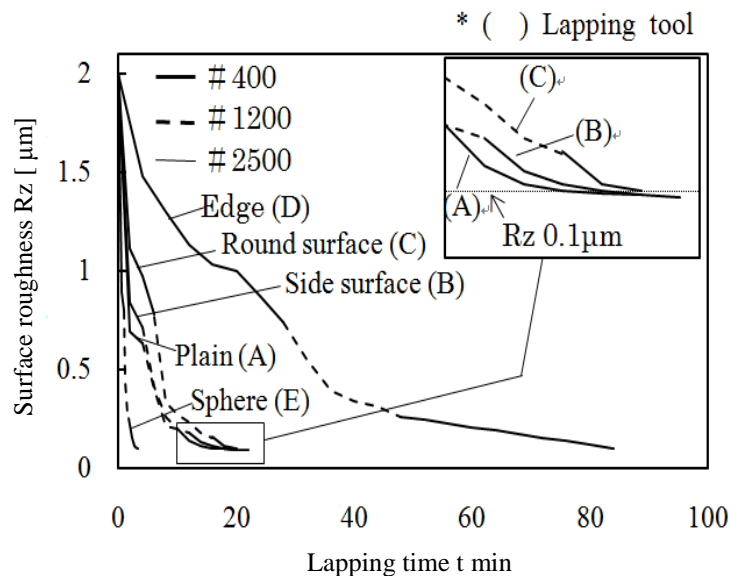


Fig. 5. Surface roughness of side surface, edge and corner using each lapping tool

Fig. 5 shows the improvement of surface roughness for each lapping tool during experiment and fig. 6 shows the photograph of each surfaces. The results for every kind of tool achieved the mirror like surface with roughness R_z less than $0.1\mu\text{m}$. The developed lapping tools are applicable for lapping of bottom surface, side surface, edge, corner, as well as complicated surfaces with using uniform lapping pressure during whole processing.

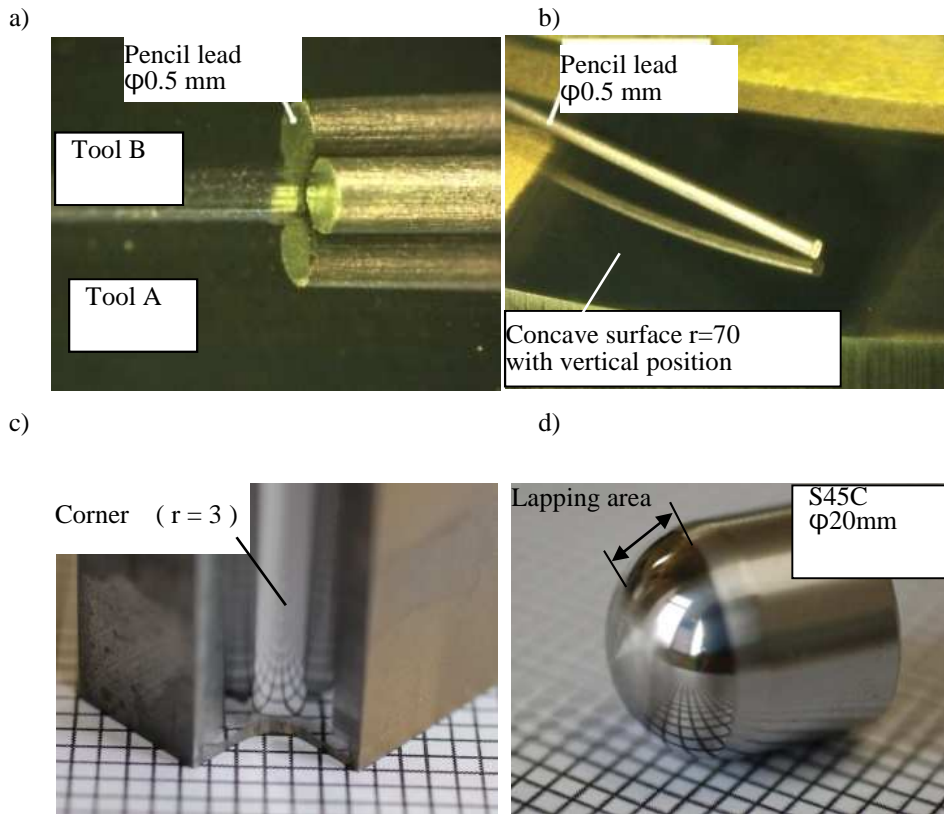


Fig. 6. Photograph of several lapping surfaces: (a) lapping tool A & B, b) lapping tool C, c) lapping tool D, d) lapping tool E

4. CONCLUSION

- (1) The developed lapping heads and lapping tools are capable of lapping various kinds of work surfaces such as bottom, edge, corner and complicated curve surfaces.
- (2) Mirror like surface lapping processing with uniform surface roughness is obtained by using the proposed lapping tools and proposed optimum lapping conditions.

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