Pressure variation of developed lapping tool on surface roughness

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Abstract. Improving the surface roughness is always one of the major concerns in the development of lapping process as high precision machining caters a great demand in manufacturing process. This paper aims to investigate the performance of a newly designed lapping tool in term of surface roughness. Polypropylene is used as the lapping tool head. The lapping tool is tested for different pressure to identify the optimum working pressure for lapping process. The theoretical surface roughness is also calculated using Vickers Hardness. The present study shows that polypropylene is able to produce good quality and smooth surface roughness. The optimum lapping pressure in the present study is found to be 45 MPa. By comparing the theoretical and experimental values, the present study shows that the newly designed lapping tool is capable to produce finer surface roughness.

1. Introduction

Lapping is literally known as one of the oldest machining processes where the work pieces are lapped inside the hole by twisting a stick and sand between them. Lapping is also known as an abrasive machining process. Bronze mirrors, jewels polishing and polishing glass are the products of lapping process. Having the capabilities to produce high quality surfaces, flatness, minimum subsurface damage and high dimensional accuracy make lapping to be known as the modern grinding process since 20th century ago. Metals, non-ferrous metal, ceramics, and some semiconductor are the examples of materials that are possible to be lapped which makes lapping as one of the best method to use for economical machining compared to the other manufacturing method.

According to DIN 8589 part 15 [1], lapping is defined as cutting process with loose abrasive grains dispersed in the paste which is guided by lapping tool with non-directional parts. Nowadays, manufacturing process requires very high machining precision for machine parts and tools. Those critical factors that contribute to current goals such as tolerances, parallelism, flatness, and smooth surface are the finishing processes [2]. According to Klocke [3], characteristics of lapping need to be emphasized especially in the lapping processes. Moe et al. [4] mentioned that lapping was possible to produce excellent surface finishing and higher geometrical form. The author explained various factors that affect the process of mirror-like finishing such as material remover, limit surface roughness and

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geometrical form improvement by series of experiments. Tam et al. [5] investigated the influences of processing parameters such as rotating speed, abrasive size on the surface roughness of optical devices. Zhao and Chang [6] examined the influence of polishing parameters on material removal rate by the chemical mechanical polishing method where they used silicon as the material to improve surface roughness for their research. Yang and Lee [7], on the other hand, introduced method of lapping to a smaller aspherical lens die by using a spherical tool. They stated that local removal rate was obtained around the contacting points of curvature change of the aspherical surface. According to Yi et al. [8], the typical optic machining consumed longer time cycle and labour intensive, thus there were several computer control being introduced for improving the process. The authors also mentioned that even though there was a precision machining in the industry, but these either had some limitations on materials selection or cycle time. Therefore, polishing system assisted by computer controlled process was introduced. In some other cases, lapping head material is one of the important part in fine finishing process. Lapping head helps in distributing the lapping pressure evenly on the work surface. Thus, mirror-like surface finishing can be achieved and a higher accuracy can be obtained.

The purpose of this research is to investigate the effect of pressure variation on the material surface roughness for a newly designed lapping tool [9]. The specimen material that is used in this research is mild steel, SKD1. Theoretical prediction of surface roughness using Vickers Hardness is implemented as well to have comparison with the outputs of this new lapping tool.

2. Methodology

New lapping tool is designed to achieve the objective of the research. The lapping tool is consists of lapping head, linear guide, soft coil spring, main body, block, and shaft, as shown in figure 1. The main body is machined from a block of mild steel. The total length of the main body is 241.50 mm with width and thickness of 36 mm and 50 mm, respectively. This part was processed with several machining method inclusive of milling as the vital process, drilling, turning by using 4-jaws lathe machine for block, and threading for the bolts and screws holes. The dimensions of linear guide are 122.50 mm x 13.65 mm x 5.20 mm in length, width and thickness respectively. A linear carrier is attached on the rail to keep the carrier always move in the right track. Spring is used to generate lapping pressure on the lapping head. It is located between the holder and collar on the base of lapping head. In order to change the lapping pressure, the spring must be adjustable, changing the relative distance between the holders and the lapping head. The specifications of the spring are shown in table 1. In order to get an optimum improvement of surface roughness, low stiffness of spring is considered to avoid the change in lapping pressure variation with small amount of the spring relative distance.

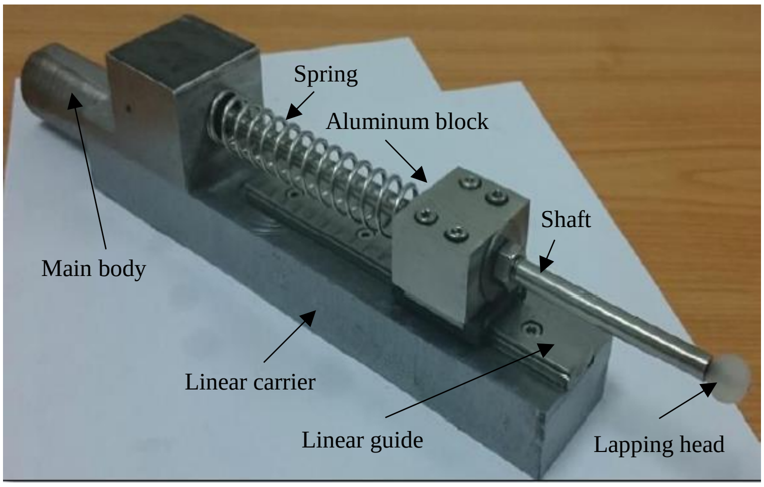

Figure 1. the newly designed lapping tool [9]

Table 1. Specifications of spring

Material	Stainless Steel
Spring Stiffness	1.5 N/m
Inner diameter	2 mm
Length	85.2 mm
Pitch	16 mm

In this research, polypropylene is chosen as the lapping head due its long chain type of the inner molecular. Because of this characteristic, the lapping grains can attach to the lapping head without falling off. The workpiece material is mild steel (SKD1).

The developed lapping tool was mounted on the tool post of the VMC machine (vertical direction towards work surface). Figure 2 shows the lapping tool that is installed in the milling machine. The work piece (SKD1) was fixed on the work table and the lapping slurry was placed on the upper side of work specimen. The function of lapping slurry is to ensure the abrasive grains engage in the lapping process. The CNC program is written on the CNC computer block. Then the simulation is operated to ensure all the movement is under the circumference of work piece. Measurement of surface roughness is conducted using Mitutoyo 178-561-02A Surftest SJ-210 Surface Roughness Tester.

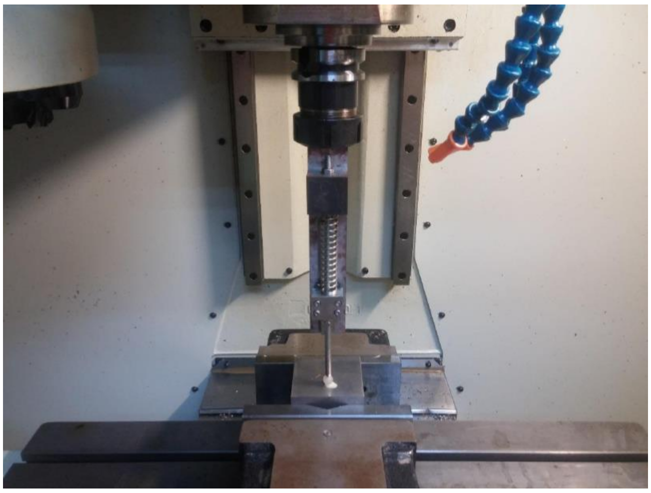

Figure 2. Installation of lapping tool on VMC machine

3. Results and Discussion

Before the experiment, prediction on the critical / limit surface roughness is conducted using Vickers hardness theory with assumption that the work surface is in perfectly plastic condition. The critical / limit surface roughness is the processing surface roughness that cannot be improved even by increasing the friction distance. In this research, the material of lapping head involved is polypropylene. The Vickers Hardness of polypropylene is 9.0. With the same size of mesh grain and work piece, surface roughness limit was examined in order to produce good surface roughness. Table 2 shows the limit surface roughness for polypropylene lapping head. It can be predicted by equation. (1).

$$Rz(lim) = 0.768 \frac{1}{tan\propto} \sqrt{\frac{P}{HV\ work\ x\ Ne}} \quad (1)$$

Where P is the lapping force, α is the angle of tip of the grain, *HV work* is the Vickers hardness of the work piece and *Ne* is the (active) effective number of grain on the lapping head. Three grain sizes are predicted in the study, namely #320, #1200 and #2500. Table 2 shows the predicted limit surface roughness at lapping pressure of 25 MPa.

Table 2. Limit surface roughness for Polypropylene ball [9]

Material of work piece	SKD1		
HV of work piece	330		
Material of lapping head	Polypropylene		
HV of lapping head	9.0		
Lapping pressure (MPa)	25		
Grain size	#320	#1200	#2500
Average angle of tip, α (°)	118	117	114
Effective number of grain (Ne)	116	214	490
Predicted limit surface roughness (μm)	0.50	0.35	0.18

Based on the result in table 2, polypropylene shows good quality in producing good surface roughness. This is because polypropylene has small wear effect and can hold the grains strongly. In fact, Yahya et al. [9] have made the comparison between the polypropylene and nylon lapping head and found that polypropylene lapping head gave less wear effect and can strongly hold the grains compared to nylon.

Surface roughness identification based on different lapping pressure is conducted experimentally on the newly designed lapping tool. Although the critical surface roughness can be calculated theoretically, there are other factors that affect the lapping process in reality such as plastic deformation, wearing and chemical reaction. In the present study, four lapping pressures (25, 35, 45 and 55 MPa) are tested for comparison. Table 3 shows the limit surface roughness for grain size of #320 at lapping time of 24 minutes. It is found that higher lapping pressure produces better surface finishing because more grains are matched on the surface of lapping head as larger lapping pressure is applied. Hence, the effective grain number received on the lapping ball increases and the removal rate is more effective. However, at lapping pressure 55 MPa, higher surface roughness is found because it already reaches its pressure limit, thus the limit surface roughness will not decrease any further if the lapping process is continued.

Table 3. Limit surface roughness of grain size #320 at 24 minutes

Lapping speed (mm/min)	Lapping pressure (MPa)	Limit surface roughness (μm)
3500	25	0.87
	35	0.76
	45	0.61
	55	0.73

In the next process, finer grain sizes are used to improve the surface roughness. In the study, #2500 grain is used as the final grain size as it produces finer surface finishing due to the smaller cutting edge. Figure 3 shows the refinement on the surface roughness by lapping the surface using new lapping tool with grain size of #1200 and followed by #2500 at 25 MPa. After the refinement process, the surface roughness achieves the mirror-like finishing surface which is below 0.1 μm. Compare the experimental data with the predicted values in table 2, it is obvious that the new lapping tool produces finer surface roughness. Besides, the reported value is also lower than the commercial lapping tool, which is around 1μm [10]. Therefore, it can be concluded that the new lapping tool is able to produce better surface roughness compare to the conventional tool.

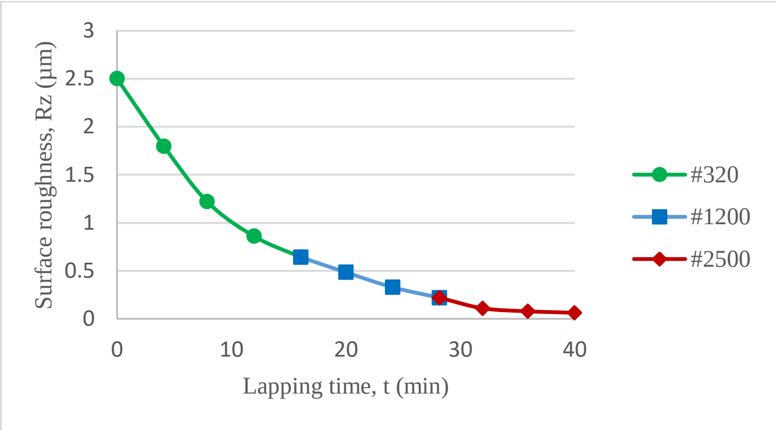

Figure 3. Improvement of surface roughness from grain size of #320 to #2500

4. Conclusion

A new lapping tool is designed for lapping machine where polypropylene is used as the lapping head. The purpose of the present study is to identify the performance of this lapping tool in improving the surface roughness of a block. Four different lapping pressures are tested on this new lapping tool and it is found that pressure of 45 MPa is more appropriate to be used for the lapping process. Polypropylene is found to produce good quality surface with fine surface roughness. Besides, the new lapping tool is found to perform better than the theoretical prediction and the commercial lapping tool.

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