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Experimental investigation of machining error in elastomer endmilling

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This paper deals with fundamental investigation for machining error in elastomer endmilling. In the conventional metal machining, cutting force during endmilling is one of the most important factors to machining error. Because of low-rigidity of elastomers, influence of cutting force may be more important. Therefore, relationship between the cutting force and machining error is investigated. From the experimental results, it becomes clear that cutting forces affect to the machining error only in the down cut machining.

Keywords : Elastomer, Machining error, End milling, Cutting force, Error modeling

1 INTRODUCTION

Elastomers are widely used in various applications because of their excellent characteristics such as low elasticity, insulation performance and flexibility. Because usual elastomer parts are mass production consumables, molding is adapted to fabricate elastomer parts. However, small lot fabrication of elastomer parts are required to realize variational products development like personalized products, innovative products development and so on. In order to achieve agile fabrication of elastomer parts, endmilling of elastomer recently begins to attract much attention.

In the former researches for elastomers machining, machining error is one of the most important problem [(1)-(3)]. Therefore, error modeling of elastomer endmilling is expected to be a basic knowledge for accurate parts fabrication of elastomer parts.

In the conventional metal endmilling, cutting force during the endmilling is one of the dominant factors to machining error. Cutting force causes workpiece deformation and machine tool deflection. Because most elastomers have low rigidity, relationships between the cutting force and machining error are considered as fundamental characteristics. In this research, two-dimensional endmilling with straight edge endmills are investigated as an elementary step to model the relationship. Machining experiments are designed and executed to investigate how the cutting force affects the machining error.

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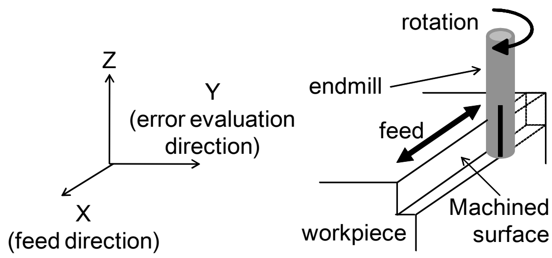

Fig. 1 Side-milling

2 MACHINING ERROR IN ELASTOMER ENDMILLING

Figure 1 shows an example of standard endmilling process. As illustrated in Fig. 1, a trajectory of endmill is copied to the workpiece as a machined surface. Therefore, macroscopic workpiece deformation during the machining process affects machining error directly. Low rigidity workpiece like elastomers are easy to deform. In this way, workpiece deformation during the machining process is an important phenomenon. Because of this reason, workpiece deformation during the machining process has been investigated.

In order to investigate the effect of workpiece deformation, cutting forces in error evaluation direction are measured. Then, correlation between measured cutting forces and machining error has been evaluated.

Because workpiece deformation is caused by both of fixturing force and cutting force, it is desirable to separate the effects by fixturing and the effects by cutting force individually. In order to reduce influences of workholding and to clarify the datum plane, the elastomers are attached to the metallic base. We handle both of the elastomers and the base as a unit workpiece.

3 MACHINING EXPERIMENT

In order to investigate the machining error of elastomer endmilling, 16 cases of machining conditions are designed as listed in Table.1. Because it is well known that a feed rate of endmill affects cutting force significantly, four levels of feed rate are determined for machining experiments. Furthermore, workpiece deformation is significantly affected by the workpiece rigidity. Therefore, two levels of work thickness are prepared in order to evaluate the effect of workpiece deformation. Finally, both of up cut machining and down cut machining are evaluated because it is also well-known that there are big differences between up cut machining and down cut machining.

In this experiment, we conducted machining with straight edge end-mill for urethane rubber (hardness: 90 degree). Figure 2 illustrates schematic diagram of the machining experiments. Urethane workpiece is glued to the metallic base and the bases are fixed to the dynamometer.

After the machining experiments, workpiece as a unit is released from the dynamometer and set on measuring equipment. Then, machined elastomers are measured by scanning laser displacement sensor. The surface of the base is used as the reference surface of measurement. From the height data of machined surface, machining error is estimated.

Table 1 Machining conditions

Cutting direction	Up cut		Down cut	
Revolution[rpm]	4000			
Feed rate[mm/min]	40	80	120	160
Depth of cut[mm]	5			
Width of cut[mm]	1			
Work thickness(WT)[mm]	WT=10		WT=20	

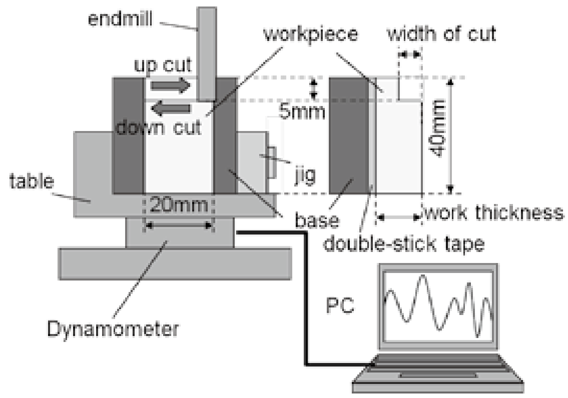

Fig. 2 Machining experiments

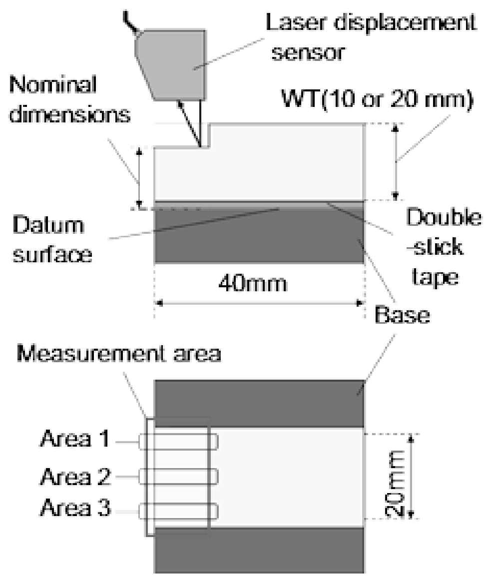

Fig. 3 Measurement of workpiece

4 RESULTS AND DISCUSSION

4.1 Results

As representing values of cutting force and machining error, three areas of machined surfaces are picked up (Area 1 and Area 3: about 2mm from the edge of workpiece, Area 2: center of workpiece). Maximum values of machining error and cutting force at selected areas are summarized. Concerning the cutting force, only normal direction(Y direction) of machined surface is evaluated.

Figure 4 and Fig.5 show cutting force of each feed rate. Average value, maximum value and minimum value of Y direction cutting force for ten times rotation at selected areas are illustrated. Cutting forces in down cut machining is more influenced by feed rate than up cut machining. There is no clear tendency about the change of work thickness.

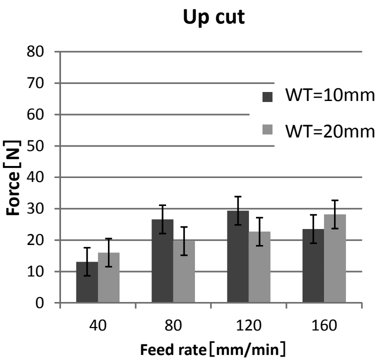

Fig. 4 Cutting force in up cut machining

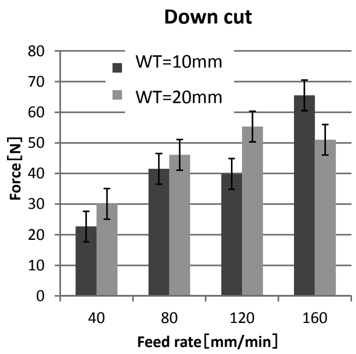

Fig. 5 Cutting force in down cut machining

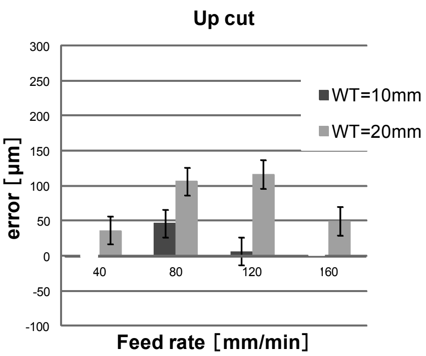

Fig. 6 Measured machining error (Up cut)

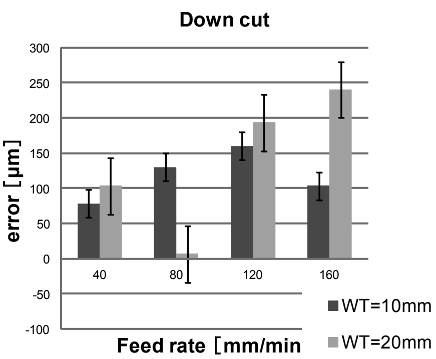

Fig. 7 Measured machining error (Down cut)

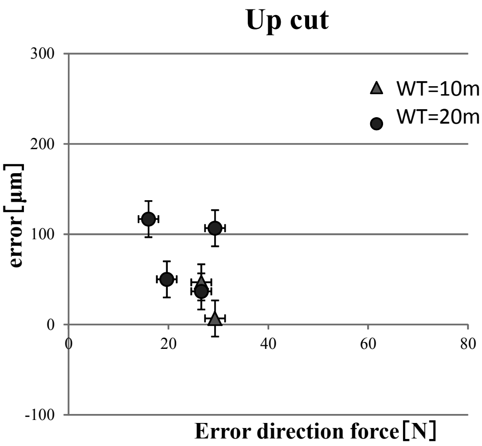

Fig. 8 Relationship between cutting force and

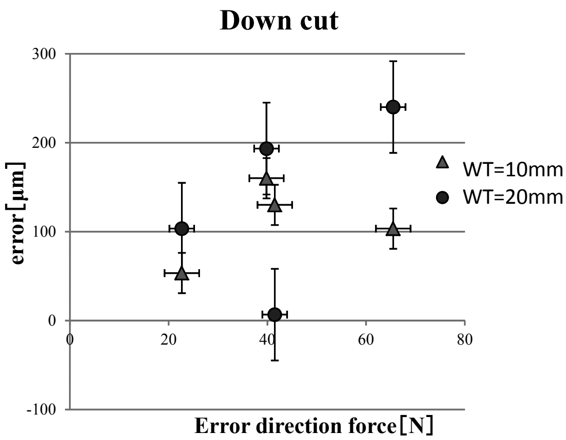

Fig. 9 Relationship between cutting force and

Figure 6 and Fig.7 show measured machining error by up cut machining and down cut machining respectively. At cases of work thickness 10mm of up cut machining, some machined workpiece slipped from the base. Therefore, the data of feed rate 40 mm/min and 160mm/ min are eliminated. Figure 6 shows machining error with up cut machining. The results do not show clear tendency. On the contrary, Fig.7 shows weak linearity is observed. Because of the limitation of data quantity, it is hard to induce influence of work thickness to the machining error.

Because the deformation of the workpiece in Y direction is a simple model of machining error directly, relationships between the maximum machining error and maximum cutting force of Y components at selected areas are summarized in Fig. 8 and Fig.9. These figures illustrate the results of up cut machining and down cut machining, respectively.

4.2Discussions

Different tendencies are obtained between down cut machining and up cut machining. In down cut machining, positive correlations between the machining error and maximum cutting force are observed except the several cases. On the other hand, no correlation between cutting force and machining is observed in up cut machining. These results indicate the workpiece deformation caused by Y component cutting force could be a dominant factor of machining error only in down cut machining.

Furthermore, it has become clear that there are different error generation mechanisms between up cut machining and down cut machining.

A possible reason is effects of X component cutting force. As shown in the Fig.10, in the down cut machining, maximum cutting force is generated at the beginning of the cutting which may cause less X component cutting force. On the contrary, maximum cutting force in the up cut machining is generated at the end of cutting which may cause larger X component cutting force. This difference may affect the workpiece behaviors.

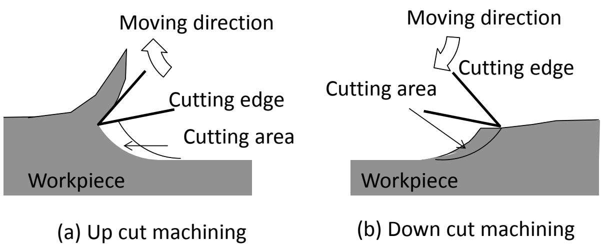

Fig. 10 Cutting situations at maximum cutting force

Finally, there is an error that cannot be explained because of machining error from static global elastic deformation. Irregular chip separation and / or effects dynamic vibration should be investigated in order to predict the machining error of up cut machining.

5 CONCLUSION

By using the straight edge endmill, basic tendencies of machining error in elastomer endmilling have been observed. From the experiment, it has become clear there are different error generation mechanisms between up cut machining and down cut machining.

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