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Effect of Wheel Compliance on the Automatic Finishing Operation

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In the automotive die-mold finishing process, large mold surfaces such as bonnet, roof panel, side fender and door require highly skilled finishing work. Die mold manufacturers are confronting extreme shortage of skilled finishing workers. Hence, a robot finishing technology could be a crucial process for the auto-finishing of the automotive mold manufacturing. To accomplish robot finishing, the automatic measurement of surface roughness level as well as the precise machining control are required simultaneously. In the mold finishing process, several types of grinding wheel are used to produce smooth surface. Some of them have high rigidity for shape correction, others high flexibility for surface finishing. Cutting operation is repeatedly performed to remove the desired height. Hence, it has been considered as a highly complicate work for achieving full automation within a comparable time of the manned working. In this regard, the accumulated cutting depth, the generation of non-uniform cutting profile due to the flexibility of wheel and the change of wheel contact position due to the wheel rotation are introduced in this study. Upon overcoming those issues a positioning control regime based on the CAD model could be introduced.

NOMENCLATURE

mesh number of lapping wheel
C compliance
μ deflection factor (cutting width × cutting force / stiffness)
X_n : machined depth Y_n : residual
S : feed in depth

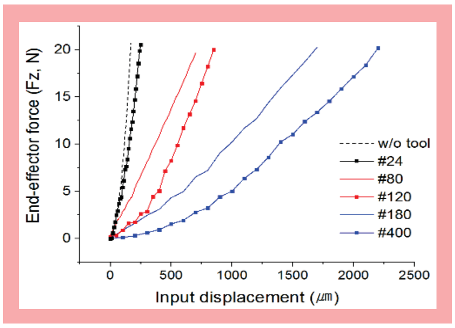
1. Introduction

In the press die-mold industry, the finishing works after having CNC milling are performed manually by the highly skilled workers. In the lapping process, the compliant wheels are used not only to maintain the original shape of the die-mold but also not to create undesirable scratch. Hence, many researchers have been relied on the force control methods to carry out the automatic lapping process. However, the lapping results only with relying on the force control method are unsatisfactory in terms of the machining accuracy and the processing time. In the lapping process, due to the flexibility of lapping wheel, the machining path should be repeated to remove the specified height. When the adverse effects of compliant wheel are predicted correctly, a positioning control based on the CAD model can be associated with the force control regime in the automatic lapping process. In this study, the effects of the wheel compliance on the finishing accuracy are investigated in terms of number of cutting path, lapping profile and wheel deformation.

2. Effect of wheel compliance

2.1 Machining accuracy

In the lapping process various type of wheel are used according to the desired surface roughness level. Hard and rough meshed wheels are used for grinding tool marks and shape correction while soft and fine meshed wheels for smoothing the contour surface. Those wheels have completely different compliance. Fig.1 depicts the typical relationship between force and displacement of the house-made



manipulator.

Fig.1 Compliance with clamping the lapping wheel

Due to the wheel compliance, the lapping paths should be repeated to achieve the desired height in the lapping process. The machined depth

$$X_n = nS - \mu S\left[1-\left(\frac{\mu}{1+\mu}\right)^n\right] \qquad Y_n = \mu S\left[1-\left(\frac{\mu}{1+\mu}\right)^n\right] \qquad (1)$$

and the residuals are obtained by Eq.(1). Fig.2 shows the machining accuracy according to the different compliance

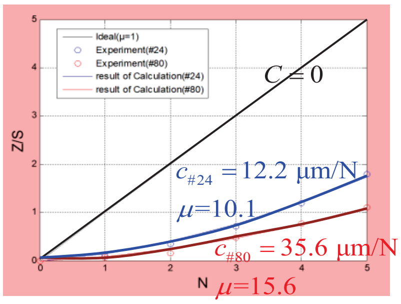


Fig. 2 Machined depth and residuals according to compliance

2.2 Lapping surface profile

The lapping wheel has large compliance, hence the transformation occurs when it approaches work surface until cutting force or position reaches the specified value. During this period, machining is accumulated, also in the disengaging process similarly accumulated. Namely, machined depths are significantly different at the stage of engaging, proceeding and disengaging. This behavior can be modified and improved by adopting speed profile considering the strain rate of the wheel on the basis of Kelvin's viscoelastic model.

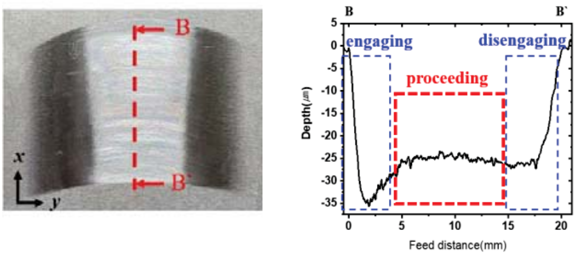
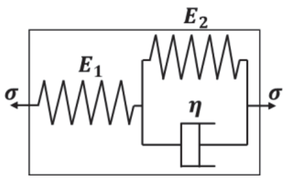


Fig. 3 Machined surface profile along the feed direction



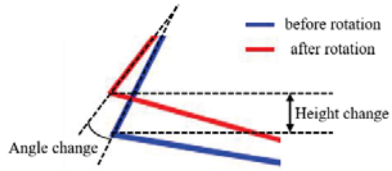
	E_1	E_2	η
#120	33.56	237.85	497.52
#180	13.26	76.51	228.9
#320	5.64	32.7	83.48
#400	8.38	46.07	409.16

Fig. 4 Viscoelastic model of wheel deformation

2.3 Wheel deformation due to rotation

When the wheel rotates, wheel expands and shape changes due to the flexibility. Although the rotation speed is applied, the speed decreases as load increases. Hence the wheel contact position changes.

Fig. 5 compares the wheel shape before and after the rotation. This deviation can be estimated easily when density and stiffness are given.



	Air cutting	Machining
Revolution[RPM]	8200	6100
Height change[mm]	1.22	0.78
Angle change[Deg]	2.0	

Fig. 5 Wheel shape change before and after rotation (# 120, ϕ 90 mm)

3. Conclusions

In the lapping process, due to the flexibility of lapping wheel, the machining path should be repeated to remove the specified height. When the adverse effects of compliant wheel are predicted correctly, a positioning control based on the CAD model can be associated with the automatic lapping process. In this study, the effects of the wheel compliance on the finishing accuracy were investigated.

1) The number of cutting path and the residuals for the specified height can be exactly predicted if the wheel compliance given.
2) The cutting profile is not uniform in the direction of wheel path since the transformation behaviors of the wheel are different when the engaging and the disengaging speeds are same. The lapping surface profile can be modified and improved by designing the wheel approaching speed on the basis of Maxwell model.
3) When the wheel rotates, the wheel expands and the shape changes from the stationary state due to the centrifugal force. The expansion and the contact position of the wheel can be predicted precisely when the density and the compliance are given.

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REFERENCES

1. S. Park, D. Koh, J. Shim, J.-J. Kim, and S.-K. Lee, "Gantry type Lapping Manipulator toward Unmanned Lapping Process for a Large Work Surface, *International Journal of Precision Engineering and Manufacturing-Green Technology*, vol. 7, pp. 547-557, 2020.
2. A. P. S. Arunachalam and S. Idapalapati, "Material removal analysis for compliant polishing tool using adaptive meshing technique and Archard wear model," *Wear,* vol. 418, pp. 140-150, 2019

3. V. T. Thien, Z. B. A. Halil, S. Yajuan, Y. S. Hock, and A. Wee, "Surface Finishing: Experimental Study of Pressure Distribution by Compliant Contact Wheels," in *Proceedings of the 3rd International Conference on Mechatronics and Robotics Engineering*, pp. 88-94, 2017.