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Prevention of Crack Formation by Changing Tool Shapes in Powder Compaction Process

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Abstract

In a multi-action tooling system, which is usually used for the powder compaction process to fabricate the complex multi-level parts, crack formation is crucially detrimental and should be avoided. Among various process factors, tool shape is an important factor to prevent the crack formation during powder compaction process. In this work, the effects of different tool shapes were investigated through the experimental oberservation of pore distribution in real products and the finite element analysis of residual stresses. The results were interpreted based on non-uniform powder density in the compacted parts.

Keywords: Powder compaction, Tool shapes, Cracks

1. Introduction

The retained-end clutch (REC) in the automatic transmission of cars, which transmits the power of the engine to the planetary carrier, has a complex shape of multiple levels. In powder metallurgical process, it can be produced by a complicated powder compaction system, *i.e.*, the so-called multi-action tooling system. In contrast to the single-action tooling system where only a upper punch moves up and down and the other components are kept stationary, this system consists of a die and many sets of punches moving simultaneously in the process so as to obtain uniform powder density at each level. Although it has a superior performance over the single-action tooling system, it usually results in weak green compacts of non-uniform density with cracks or voids due to the complex multi-level structures of the parts such as REC.

There has not been so much efforts to study the crack formation behaviors in the green compacts of multi-level P/M products. Bradbury [1] reported the patterns of cracks formed in various compaction systems and Cai *et al* [2] showed that cracks are generated by the spring-back effect of green compacts during ejection stage based on actual data. Although the tool shape has a significant effect on crack formation in multi-level P/M products, it has not been studied sufficiently. Therefore, in this work, we attempted to prevent crack formation in the compaction process of multi-level-structured REC by changing the tool shape. The effect of tool shape was analyzed based on the pore distributions of real products and the results of finite element analyses.

2. Experimental and Results

Tools were designed into two shapes and then the compacts were fabricated by three stage compaction process. One compact has a conventional cylindrical shape with sharp edges between levels (shape A in Table 1) and the other is a similar one but possesses a tapered boss on the center of the bottom face and a rounded edge between the boss and the bottom face (shape B in Table B). Two shapes of the compacts are shown in the following.

Table 1. Comparison of two tool shapes

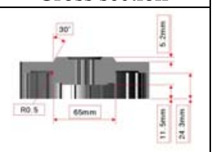
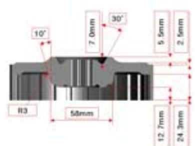
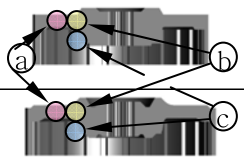
	Top	Bottom	Cross section
Shape A			
Shape B			

Table 2 shows the pore distributions after sintering at 1120^{O}C for 30min. in hydrogen atomosphere.. The sintered product of shape A revealed the highest pore fraction of approximately 8% at the arm region near the boss. The difference in pore fractions among regions marked in the figure showed 3.5% at most. But the sintered product of shape B showed the highest pore fraction of 5% at the edge between the arm and the boss. The pores in shape B, showed distinctly smaller fractions and uniform distribution compared to those in shape A.

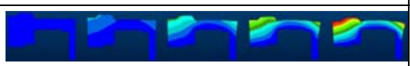
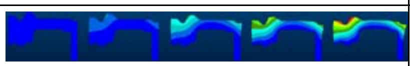
Stress distribution when the pressure of 550 tons was

Table 2. Pore distributions of sintered products of two shapes

	Cross section	Pore distribution		
		a	b	c
Shape A		 8%	 6%	 4.5%
Shape B		 4.5%	 5%	 4%

applied to the top side from the bottom of the product was analyzed by using the computer software, Pro-Engineering ver. 2001. The results are shown in Table 3 where a red color indicates the region of high stress and a blue the region of low stress. The result of shape A shows steeper stress profile at the edge between the boss and the arm in the fifth pictures than that of shape B. In the analysis, this steeper stress profile generated cracks. In addition, the result of shape A shows stress concentration on the outer edge, which can cause a distortion during the sintering process.

Table 3. Stress distributions in compaction process

	Stress distribution	Remarks
Shape A		Cracks
Shape B		No cracks

The above analyses show clearly that the tools (or green compacts) with sharp edges and corners between levels usually exhibit stress concentrations on these regions. The high density of pores at these regions in sintered specimens indicates that stresses were concentrated here during a pressing and relaxed rapidly when the specimens were ejected. Notice that the stress concentrations on edges and corners were relieved effectively by slight changes in these geometries such as tapering or rounding. These results illustrate that more attensions should be paid to the design of tool shapes in order to prevent crack formation in the powder compaction. Finally, in this work, the product of shape B has a smaller volume than that of shape A so that it consumes less raw material (Table 4) and the cost is reduced.

Table 4. Volumes and weights of two sintered products

	Volume	Density	Weight
Shape A	245.7 cm^3	6.8 g/cm^3	1670.8 g
Shape B	216.3 cm^3	6.8 g/cm^3	1470.8 g

3. Summary

In this work, two tool shapes were compared in view of crack formation during compaction and sintering process. By means of pore distribution measurement of sintered REC parts and finite element analysis, a slight shape change such as tapering a boss and rounding edges were found to be distinctively effective in reducing stresses and preventing crack formation. Through this tool shape change, the crack formation was reduced by 300ppm in the boss and by 600 ppm in the teeth in real production of REC parts.

4. References

[1] S. Bradbury, Powder Metallurgy Equipment Manual, 3rd ed., Metal Powder Industries Federation, Princeton, New Jersey (1999).

[2] H. Cai, Inelligent Tooling Design for Rigid Die P/M Compaction (Manufacturing Engineering Department, WPI, Ms thesis, 1995).