Metal Powder Concept Engineered to Facilitate Efficient Manufacturing of VVT components

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Abstract

Variable valve timing (VVT) systems have done much to improve fuel efficiency and to reduce emission levels of combustion engines. These factors are of increasing importance with stricter legislation and higher demands upon sustainable transportation. Components for VVT require a complex shape and make high demands on dimensional precision and machinability. Their complex geometry makes VVT components very suitable applications for PM. In addition, commercial manufacturing of VVT parts require high productivity and a minimized scrap rate. This paper describes a new powder mix concept that has been developed to meet the requirements of efficient manufacturing, and a trial of stator components under full production conditions validates the concept. Factors influencing the production efficiency and product precision such as die filling, compaction, and machinability have been investigated. Results from the tests show that this new concept enables improvement of dimensional precision and productivity, thus improving overall manufacturing effectiveness.

1. Introduction

VVT systems for combustion engines are becoming increasingly important due to increased demands upon fuel efficiency and reduction of emission levels. Complex shape and tight tolerances characterize the components used in VVT systems, and their manufacturing requires high precision and good machinability. Powder metallurgy has proven it can meet the requirements for cost-efficient production of high quality VVT parts. The material and process involved can be optimized to increase quality and reduce the total cost of production. The increasing demands on productivity and production economy have been the driving force behind developing an application-specific powder mix solution for the manufacturing of VVT PM parts. To meet the demands for consistent powder properties, dimensional stability and machinability, a new concept has been developed and evaluated. This concept was first described in a study on cylinders [1] and it showed that the concept enables a higher filling speed with a maintained quality level. This study presents results from a production trial at a VVT parts manufacturer. Weight scatter, compaction force variations, density distribution of sintered parts, and machinability data are analyzed. These are key factors that influence the productivity and precision of VVT parts.

2. Experiment

Two different Fe-Cu-C mixes, labelled “VVT” mix and “Reference” mix, were investigated in this study. Both mixes are based on Höganäs AB iron powder grade ASC100.29 and contain 2 % Cu, 0.80 % C and 0.6 % lubricant. In the VVT mix, copper is added using Distaloy ACu (diffusion bonded Cu) and elemental copper has been added as a -200 mesh powder in the Reference mix. The VVT mix is based on a novel mix concept engineered for improving productivity through enhanced filling, lubrication and machinability. Amide wax was the lubricant in the Reference mix.

Table 1 Powder mix compositions.

	Cu	**Lubricant**
Reference mix	Cu-200	Amide wax
VVT mix	Distaloy ACu (Diffusions bonded)	PEX*

* Productivity Enhancer X

Stator components as shown in Figure *1*~~Figure 1~~ were compacted under production conditions in a 500 ton Yoshizuka mechanical press at a VVT parts manufacturer. The parts were sintered at 1120 ºC for 30 minutes in 90/10 N_2/H_2. Data from 100 parts were then analyzed from the trial.

Weight: 201g
Green density: 6.95 g/cm^3
Outer diameter: 79.95±0.03 mm
Height: 16.5 ±0.05 mm
Circularity: 0.03

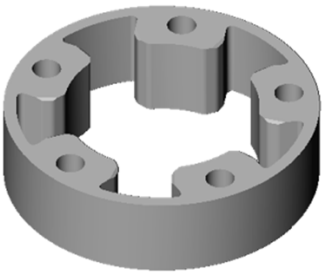


Figure 1. Investigated stator part.

The filling behavior was investigated by recording the weight of the parts and comparing the weight stability of the different mixes. The compaction force variations for two different mixes were also logged. The density distribution within the component was examined by dividing one sintered part into eight sectors and measuring the density according to Archimedes principle. This can be seen in Figure 2.

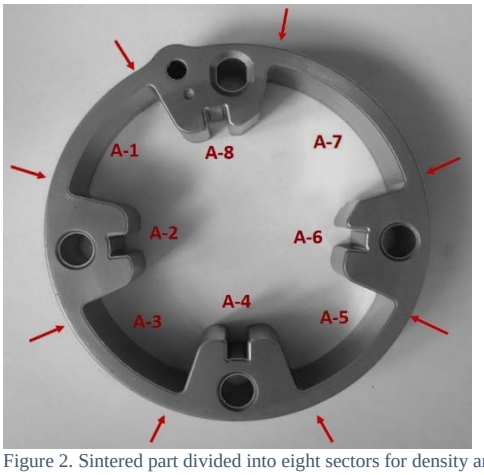


Figure 2. Sintered part divided into eight sectors for density analysis.

The inner and outer diameter of sintered stator components were measured and the scatter in dimensions evaluated. This can be seen in Figure 3. The dimensional change, from green to sintered state on the outer and inner diameter was also analyzed, and then the roundness calculated.

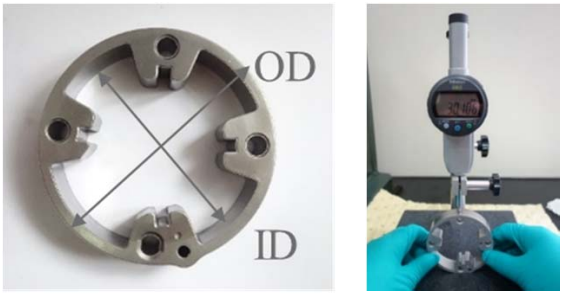


Figure 3. Measurement of outer and inner diameter of sintered stator.

The machinability was evaluated by a drilling test carried out on sintered test disc specimens, 80 mm in diameter and with a thickness of 12 mm. During the experiment, as many blind holes as possible were drilled before total drill failure (complete breakage or extreme heat release). Eight drills were used for each cutting speed and material. The drilling was carried out using Dormer Drill A002 (PVD TiN HSS), Ø3.5 mm under dry conditions.

3. Results

The robustness, including compaction consistency between components, filling consistency within one component, and stability of inner and outer dimensions were investigated. Figure 4~~Figure 4~~ shows the weight variations relative to the average weight value of the compacted stator parts. Figure 5~~Figure 5~~ shows the standard deviation of the weight. It can be seen that weight variations are 30 % lower for the VVT mix compared to the Reference mix. These results establish that the filling behavior is more robust for the VVT mix.

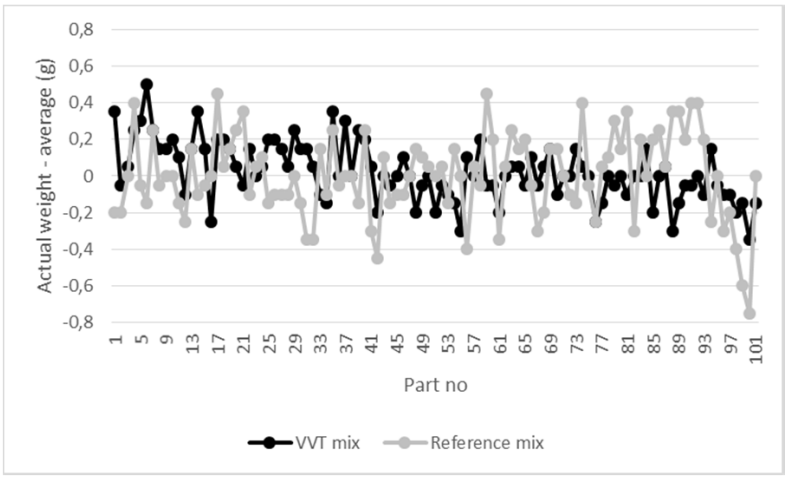


Figure 4. Relative weight of stator components after compaction.

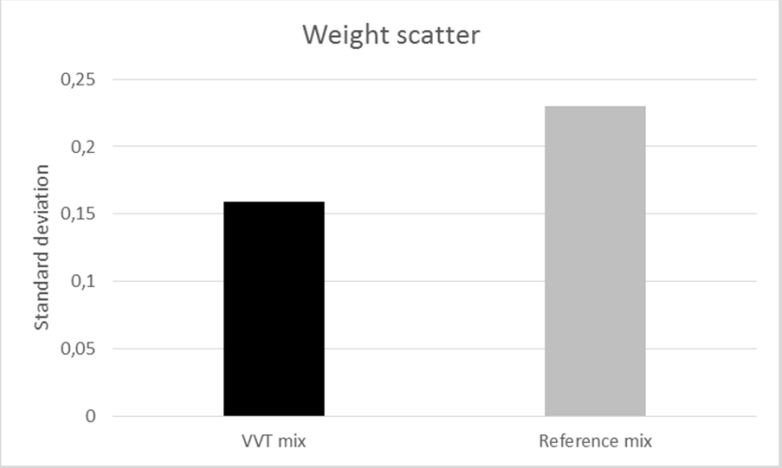


Figure 5. Standard deviation of weight scatted of compacted stator components.

Figure 6~~Figure 6~~ show the compaction force variations from the compaction trials, and Figure 7~~Figure 7~~ shows the standard deviation values from these data. It can be seen in these diagrams that compaction force variations are reduced by 12 % using the VVT mix when compared to the Reference mix.

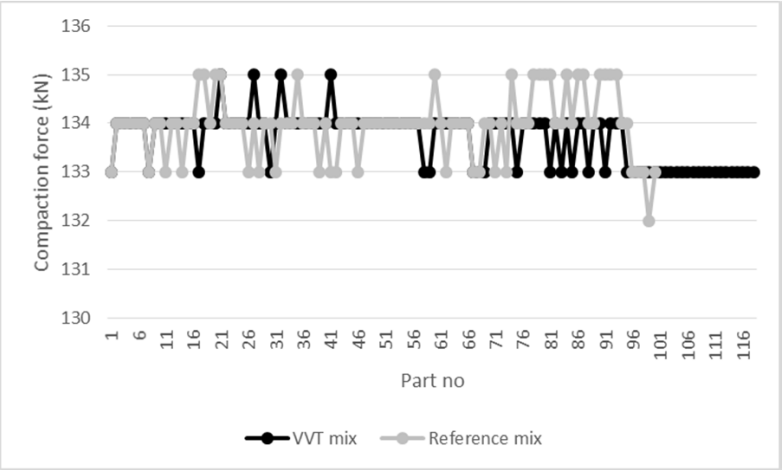


Figure 6. Compaction force profile.

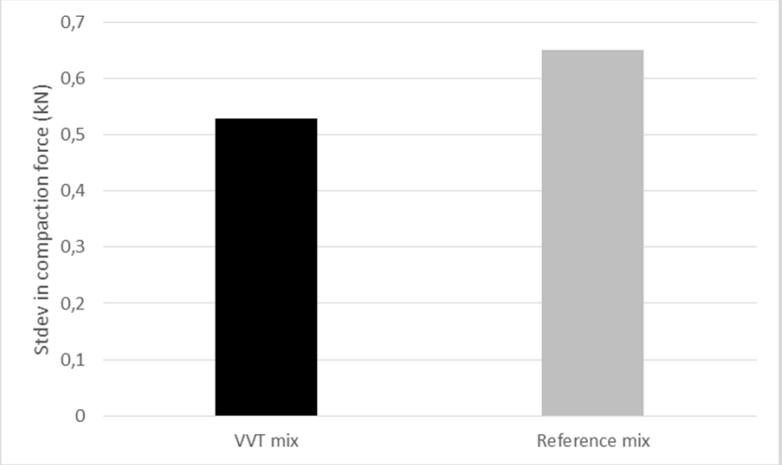


Figure 7. Standard deviation in compactions force.

Figure 8~~Figure 8~~ shows the density range for eight sectors of a sintered stator component. It can be seen that the density variations are 40 % lower in the stator made of the VVT mix when compared to the Reference mix.

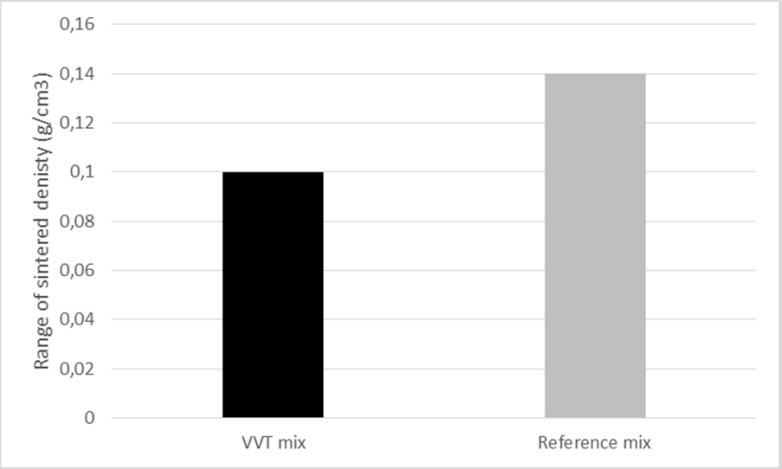


Figure 8. Sintered density range.

Figure 9~~Figure 9~~ shows the standard deviation for the inner and outer diameter measurements of the sintered stator components. The chart shows that the scatter is 33 % lower on the outer diameter, and 63 % lower on the inner diameter for the VVT mix when compared to the Reference mix.

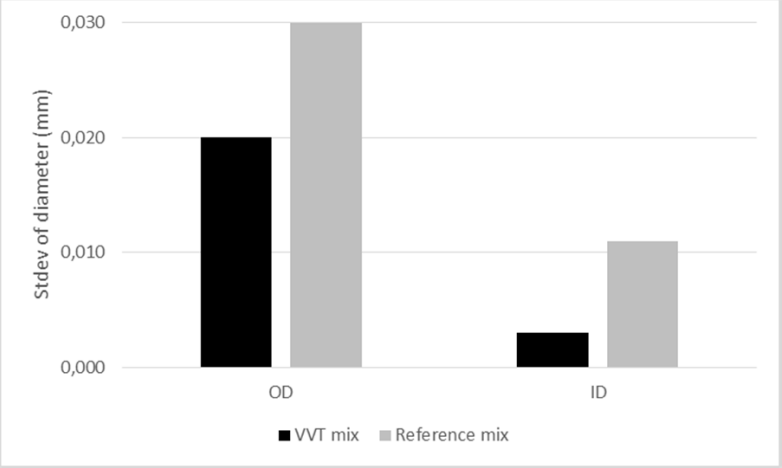


Figure 9. Standard deviation of inner and outer diameter measurements.

The results from the drilling test are presented in Figure 10~~Figure 10~~. This shows the life of the tool, which is the total number of holes that can be drilled before tool failure or a high heat release, plotted against the feed rate of the drill. It makes clear that the life of the drill is increased by at least three times using the VVT mix system due to the tailor-made productivity enhancer.

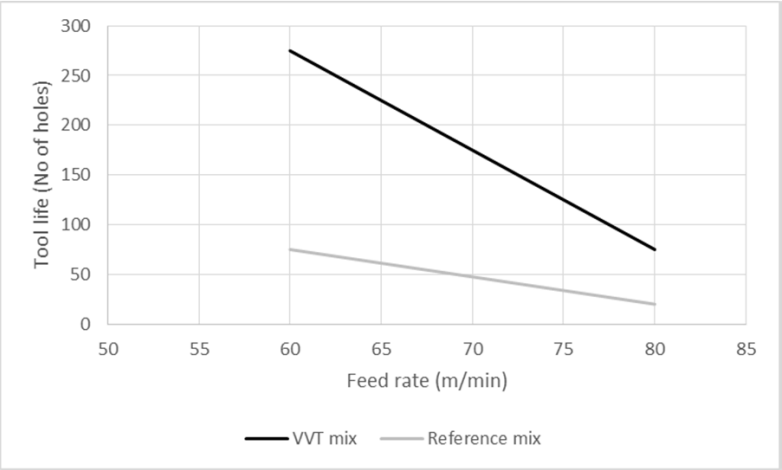


Figure 10. Machining performance and drill life at different feed rates.

4. Discussion

Improved weight stability of parts can lead to a reduction in process variations, better tolerances and a lower scrap rate. Reduced variations in compaction force contribute to higher productivity since it leads to fewer adjustments of the press. Lower density variations within the component will result in a more stable dimensional change between green to sintered state. In the tests, the measurements on the inner and outer diameter show that the dimensional stability is improved by better filling and a more even density distribution. For high precision parts, this is very important since a stable dimensional change leads to better tolerances and reduces the need for post-sintering operations such as sizing. All these factors can contribute to higher quality VVT parts that can be also be produced more cost-effectively since productivity can be increased, and the scrap rate and adjustment time is reduced.

5. Conclusions

A powder mix concept tailor-made for VVT parts has been evaluated under production conditions and the key conclusions are listed below.

- Improved filling and reduced part-to-part weight scatter.
- Reduced density variations within the component.
- Decreased scatter in inner and outer diameter dimensions.
- Improved machinability.

These conclusions are all important factors for producing complex parts with high tolerance requirements. With good filling, the weight scatter between components is reduced and the density distribution within the component is improved and leading to parts with better precision and quality. At the same time, the above characteristics also lead to a more stable production process with less waste in terms of press adjustments, scrapped components and additional machining operations. In summary, it can be seen that VVT parts can be manufactured with improved quality and reduced cost. A powder mix with a productivity enhancer, tailor-made to meet the requirement of parts producers can facilitate filling, lubrication and machining to greatly enhance productivity.

6. Acknowledgment

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7. References

[1] U. Engström and Z. Tan, Mix Concept Engineered for High Precision VVT Components. Proceedings of the 4th International Conference on Powder Metallurgy in Asia, 2017.