

Scatter in Sintered Component Strength Causes, Test Methods and Results

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Abstract

In the field of transmission construction, cost advantages can be achieved by using sintered steels to produce complex components which are subject to complex loads. Due to the complicated shape of these components and the lack of defined patterns, computer simulation proves exceedingly difficult. The material properties depend on the geometry involved and the manufacturing process used. Furthermore, certain components have poorer strength characteristics than the vast majority. This presentation describes defects in sintered components, the effect these defects have on material strength and the statistical scatter of strength values. In addition, it also looks at the influence of material density increases on the above variables.

1. Introduction

Some 5 % (by weight) of transmission components are currently made of sintered steels. The reason for using sintered steels is the cost advantage achieved in contrast to other mass production processes. Sintered transmission components are characterized by the following features:

- Complex form
- Resistance to several types of load
- High level of dimensional accuracy
- Good surface quality

The reliability of sintered materials depends greatly on manufacturing parameters and application conditions. Due to the forming process involved, both the geometry and the manufacturing parameters – such as powder, tooling configuration, pressing, sintering and calibration – have an effect on the strength characteristics. This process chain is susceptible both to isolated defects, which have a one-in-a-thousand chance of occurring, as well as to systematic defects.

2. Defects in sintered components

Two frequently occurring types of defects are described as examples in the following section. Breaking strength tests on synchronizer rings made from sintered steel regularly revealed parts with strength values lower than average. It was not possible to pinpoint the cause of this using the results of the standard material tests alone, i.e. there was nothing unusual about the data regarding density, core

hardness, pore distribution, etc.; however, by systematically analyzing the fractures in the SEM, it was proved that some zones in the fracture cross-section clearly had little binding between the powder grains. In other words, the occurrence of broken sinter bridges was not evenly distributed throughout the cross-section. Although some zones showed practically no signs of fractured sinter bridges (see Figure 1), the occurrence of fractured sinter bridges in other areas corresponded to the material density (see Figure 2).

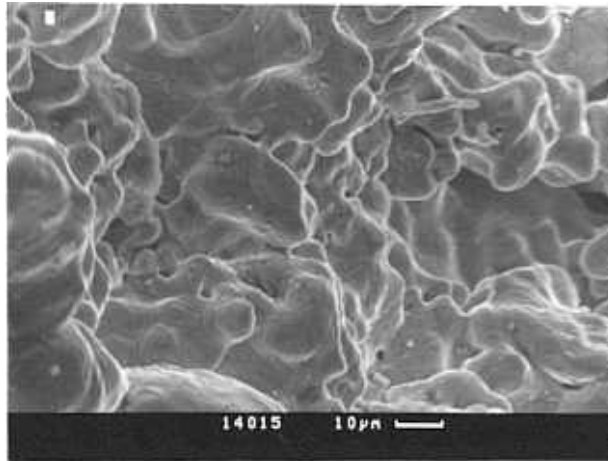


Figure 1 Fractured surface of a sintered synchronizer ring with low binding fraction and a small number of broken sinter stems.

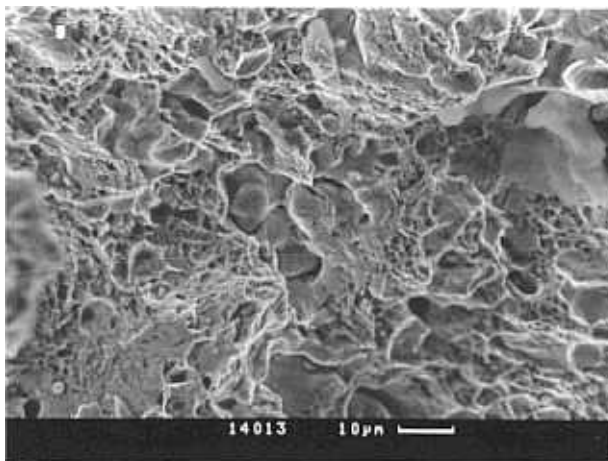


Figure 2: Fractured surface of a synchronizer ring with normal binding fraction and a normal number of broken sinter stems

Danninger [1] recorded similar findings in his analyses. The causes he cited included wax nests, impurities in the base material or liquid phase agglomerations during sintering.

Alongside these randomly distributed defects which can occur anywhere in the component cross-section, there have also been cases of defects which tend to occur at certain points in the component due to the manufacturing process used and the shape of the component. The manufacture of synchronizer hubs using multi-platen technique can give rise to cracks or binding defects due to the fact that no binding occurs between the powder columns which are displaced during the pressing process. The diagram in Figure 3 shows a conventional pressing sequence incorporating machining contrasted with a multi-platen pressing process. The effect of these defects on component performance is shown in Figure 4. This is a comparison between the S/N-curves obtained from torsion tests on conventionally produced components and on components using the multi-platen press technique, both with and without defects.

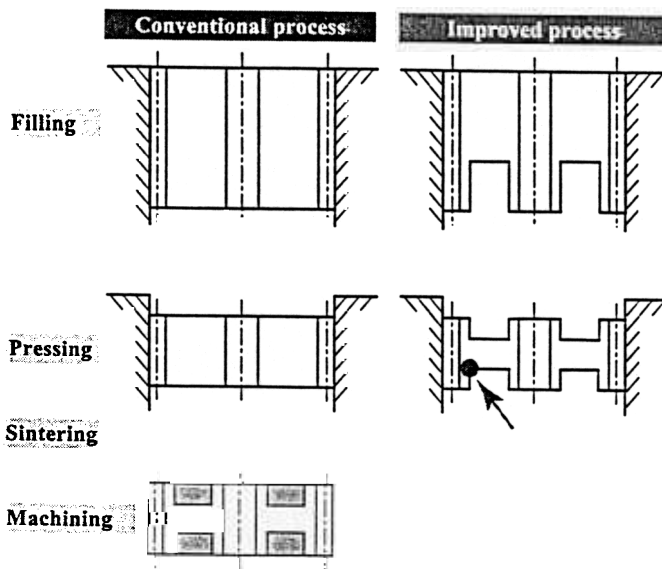


Figure 3: Diagram comparing synchronizer hub manufacturing processes.
 Old: Conventional technology with machining.
 New: Multi-platen technique press process without machining [2].

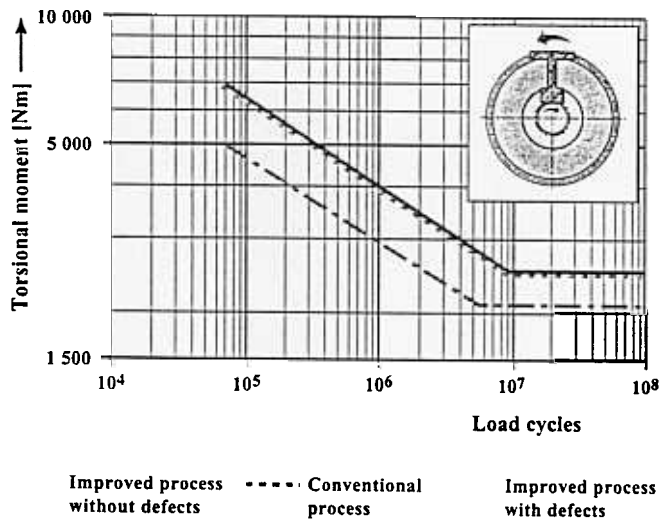


Figure 4: Comparison of stress cycle diagrams (cyclic torsion) for synchronizer hubs made using conventional manufacturing methods, new press processes with defects and optimized press processes without defects [2].

The defects involved only showed up as chains of pores on the metallographic cross-sections; however, the fracture test showed that there was no binding between the powder grains in these areas. There are currently no reliable, economical, non-destructive testing methods available for detecting either of these defects.

3. Test methods and results

The strength characteristics of sintered components cannot be assessed by means of stress calculations such as FEM or classical strength parameters from single-axis tests. This is due to the complex geometry of the components as well as to the different types of load and stress to which the components are subjected. In addition, the defects described in section 2 effect the components to different degrees. The

effect of random defects – such as insufficient binding caused by wax nests or the like – on component strength can only be gauged by employing extensive tests involving a sizeable number of samples and statistical evaluation. In contrast, the effect of systematic, localized errors can be proved by performing conventional comparisons and fracture tests.

Standard test methods for sintered steels – such as density measurements, metallography, etc. – have a limited ability to characterize component strength. This is why ZF has developed methods for testing synchronizer rings which simulate the individual component test of the complex loads one by one. Figure 5 highlights the three major tests employed: the mandrel test, the radial tensile test and the impact test. These tests allow the following properties to be determined:

- Mandrel test: Static force at rupture and deformation when the synchronizer ring is pushed onto the clutch body
- Radial tensile test: Static and dynamic load capacity of the ring cross-section
- Impact test: Resistance to impact stress during synchronizer engagement/grating in the event of incorrect operation

The impact test delivered the most reliable proof regarding the suitability of sintered synchronizer rings for transmissions. It was shown that there were correlations between the synchronizer ring fractures in test transmissions and the impact test. It was also verified that each synchronizer ring must fulfill minimum impact resistance requirements to ensure that it does not fail in the transmission. By statistically evaluating the measured impact resistance of a sizeable number of samples the performance of a technology or material can be assessed.

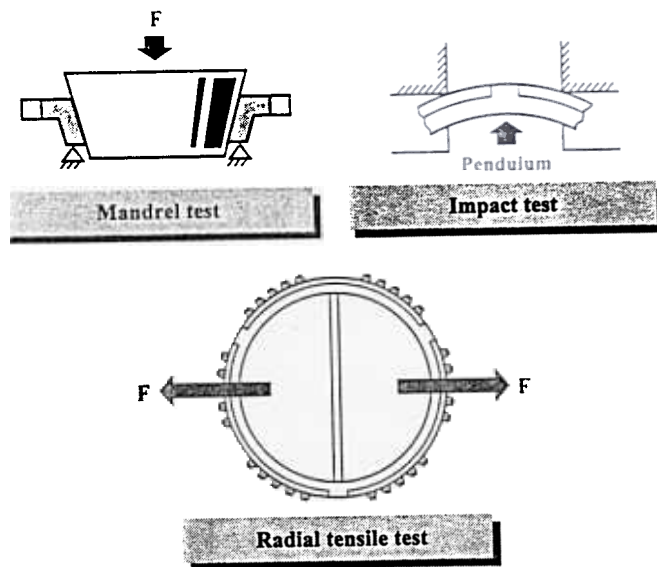


Figure 5: Model tests for strength analysis of sintered synchronizer rings

Figure 6 shows the distribution of impact resistance values for various synchronizer rings and the necessary minimum impact resistance for each application. The distribution of measured values compared to the minimum impact resistance gives a theoretical failure rate, see area „A“. The reason for this is internal defects in the component fracture cross-sections. SEM analyses were employed to prove that these were binding defects, i.e. missing sinter stems between the sinter particles. Figure 7 shows a comparison between the mean binding content and the measured impact resistance. As the binding occurrences increase so does the impact energy. This diagram shows that density alone does not determine characteristics since different densities can produce similar binding occurrences.

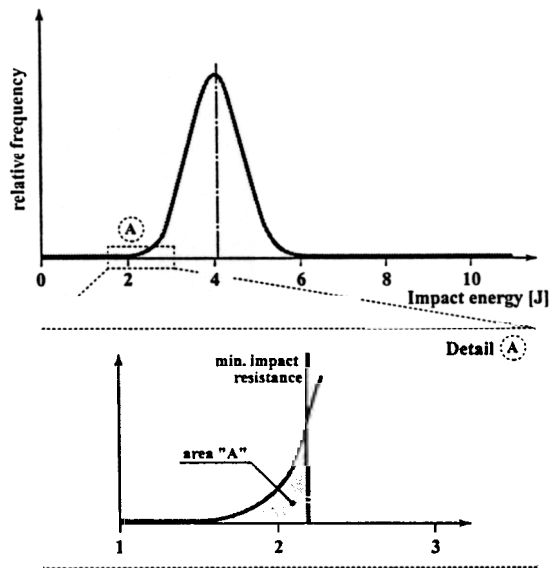


Figure 6 : Distribution of impact resistance values on synchronizer rings

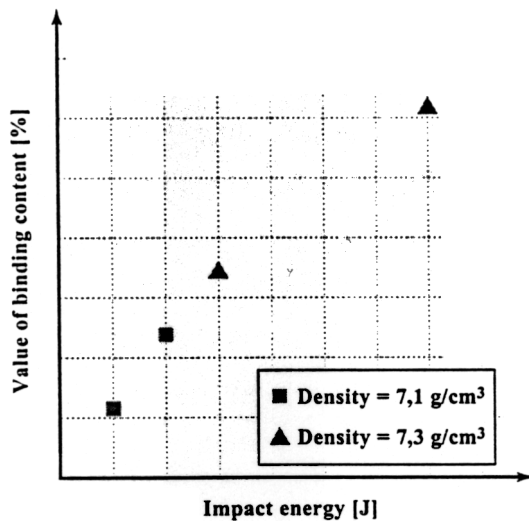


Figure 7: Impact resistance as a function of sinter stem surface area and binding occurrences in the fracture cross-section

4. Optimizing synchronizer rings

A conventional method used to improve the strength of sintered steels is to increase the density. Optimization of the pressing process has made it possible to economically produce synchronizer rings with a density of 7.4 g/cm^3 using single pressing processes [3]. These rings were also analyzed in the model tests previously described and evaluated statistically as shown in Figure 8. It was shown that, although the mean impact resistance values clearly improved, the scatter also increased, i.e. the distribution curve became wider and flatter. The number of parts which did not fulfill the minimum requirement was reduced, see area „B“.

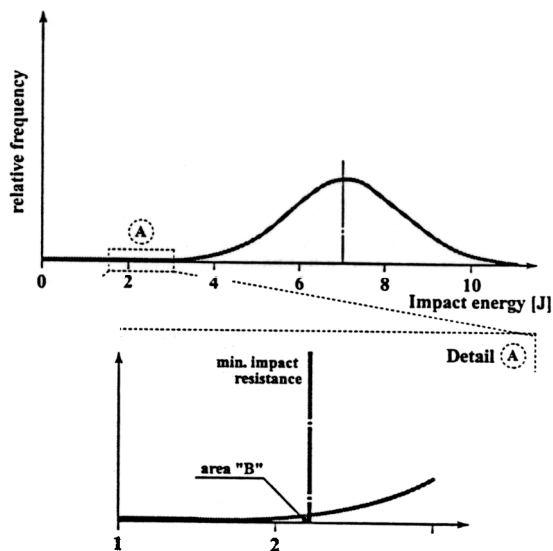


Figure 8: Distribution of impact resistance values on synchronizer rings with enhanced density

5. Summary:

These findings show that standard parameters such as density and hardness are insufficient for accurately determining the performance of sintered steels. Reasons for this include the relationship between material properties and geometry as well as fluctuating strength values due to internal defects. In this particular instance, impact tests made it possible to describe the strength characteristics of synchronizer rings in practice. It was shown that all the components which failed these tests had internal binding defects, i.e. missing sinter bridges between the powder grains. Causes or remedies for this problem are unknown and systematic research is still required. Simple model tests using a sizeable number of samples and statistical evaluation have been developed and verified. Using these tests, it is possible to evaluate component load capacity with regard to specific application requirements and to compare different batches, processes and technologies. Although it was possible to clearly improve the mean impact energy by increasing density, the scatter was increased at the same time.

- [1] Herbert Danninger, D. Spoljaric, B. Weiss: "Microstructural Features Limiting the Performance of P/M Steels". The International Journal of Powder Metallurgy, Vol. 33, No.4, p. 43 - 53.
- [2] Ulrich Baum, St. Hock, F. Kolzarek: "Einsatz von Sinterbauteilen im Getriebebau". Pulvermetallurgie in Wissenschaft und Praxis, Band 10, ed by: Hans Kolaska, Hagen, 1994, p. 84 - 102.
- [3] Pierre Blanchard: "High Density under Cold Single Pressing Operation: New Applications". Proceedings of the 1997 European Conference on Advances in Structural PM Component Production München, 1997, p. 44 - 50.