SILESIAN UNIVERSITY OF TECHNOLOGY

Faculty of Mechanical Engineering

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DOCTORAL THESIS

Effect of the chemical composition of iron-based powder materials on the properties of sintered components

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Discipline: Material engineering

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Extended Abstract

SUBJECT

Effects of the chemical composition of iron-based powder materials on the properties of sintered components

THESIS STATEMENT

The chemical composition of powder material, the density of the moulded parts and the type of material from various technological processes has an impact on the properties of sintered components include hardness and compression, tensile strength values.

GOAL

The scientific objective of the doctoral dissertation is examination of the impact of the influence of the chemical composition of iron-based powder materials, as Fe-C, Fe-C-Cu on the properties of sintered components.

Based on the formulated research postulate, the following implementation goals of the dissertation were determined:

1. selection of powder material to determine the strength properties of sintered components
2. reduction of large research amounts under laboratory conditions by the development of an appropriate scientific knowledge base and verification of the implementation of new powder metallurgy products
3. the Digital Twin concept - a comparison of real and literature parameters used for the finite element analysis (FEA)
4. design and construction of a suitable test stand to study the density of sintered components.

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SCOPE

The thematic scope of the dissertation, including the definition of the research topic, includes defining the relationship between copper and carbon content and the density parameter for sintered components that are components of vehicle suspension. Using the right chemical composition and a technological process, it is possible to find relationships among the chemical composition, density and mechanical properties of the components (tensile and compression strength, yield strength, elongation and hardness).

Metallographic studies carry information about the effects of a crack in a sintered component on a potential failure in the entire car suspension system. Production costs may be reduced by the calculation and determination of carbon losses in the production process.

The scope of scientific studies requires verification of the following issues:

1. the properties of powder materials
2. the structures of manufactured sintered components
3. the mechanical properties of sintered components

For that purpose, an optical microscope, a scanning and a transmission electron microscope were used. Studies of mechanical properties require hardness, tensile and compressive strength tests and density.

The scope included a comprehensive study of a compact structure, built from FC-0208 material (22). Tensile and compressive strengths were tested for various combinations. The test data yielded compression and tensile test results for the tests conducted at 23°C and 120°C, for sintered components of different densities, and for the sintering process, either with or without additional heat treatment. The breakthroughs were analysed, using SEM and TEM microscopy. A Drucker-Prager mathematical model was developed to simulate the behaviour of the compacts during compression and tension tests and the appearance of potential cracks.

The scope of the dissertation included checks of the behaviour of sintered components produced from Fe-C iron-based powder material and from Fe-C-Cu copper-doped and iron-based powder material. Their compression and tensile strengths were tested. Their microstructure was also tested for different density samples of the sintered component.

CONCLUSIONS

1.

The tests in the study were carried out on six different types of powder materials. Each material demonstrated a specific chemical composition, derived directly from the powder supplier. Those materials were subjected to a conventional sintering method. Half of the mouldings were additionally treated with oxidation. The aim of the study was to check the influence of the chemical composition on the mechanical properties of the moulded parts produced. Due to the large number of samples to be tested, it was assumed that the strength tests could be affected by:

- the type of sintered powder,
- the segregation of copper, which was a component of the powder mixture,
- powder storage time period before it was used in the densification/sintering processes,
- the quality of production process,
- the grain size of powder material,
- porosity,
- ferrite/perlite microstructure.

The results of the compression and tensile tests were scattered due to material porosity. In order to determine the relationship of data and results, the tests were separated into the analysis of sintered components from powder material 22 (FC – 0208) and the analysis of sintered components from the other powder materials, i.e. Fe-C-Cu and Fe-C.

2.

Comprehensive tests were carried out on FC-0208 (Fe-C-Cu), as this was a new material used in that particular conventional manufacturing process. It was also noted that many mouldings, produced from this material, had cracking in their application use. The sintered components were subjected to compression and tensile strength tests. It was noted that the samples had been cracking around the jaws during the tensile tests, rather than in the middle of the sample length, beyond the gauge length. The repeated tests - using the same sample but a different apparatus - confirmed that the tests had been carried out correctly.

Sample buckling occurred during the compression test, which is a normal occurrence during compression strength tests. Due to the porosity of the test sample, it was noted that the yield strength had differed in compression and tensile tests.

A tensile test of the powder 22 moulding showed that temperature had no effect on the tensile strength parameters of the tensile strength, i.e. the ability of the test sample to resist fracture when a pulling force is applied in the direction parallel to its longitudinal axis. Neither did temperature have any effects on the value of Young's Modulus, a parameter that determines the material elasticity level during tensile tests. Differences in results were not apparent for the samples either with or without additional oxidation A relationship was observed, namely that tensile strength and Young's modulus values had both increased together with density.

The compression test also demonstrated that temperature differences, either 23°C or 120°C, had no effect on differences in test results. As density increased, hardness of the sintered components increased as well. Density and hardness increase were also associated with increased compression strength, yield strength and Young's modulus values.

The Drucker Prager model was used to model the behaviour of a sintered component in the study. The results differed among literature data, standards and the results from real tests. It was also found that there was no information in the standards about the type of powder material, i.e. by which manufacturing process the material had been produced.

A prototype model of a sintered component was developed, based on the finite element analysis in the Abaqus program. The model indicated further research directions regarding the properties of sintered components.

Strength test simulations and a wide range of tests made it possible to establish a material base. The knowledge gained from the research will facilitate the standardization of the materials used to produce sintered components.

The porosity of the sintered components tested was in the range of 0.02-25%. For the same material type porosity varied by approximately 10 per cent.

Fractography of fractures after the test showed that copper segregation and an exaggerated amount of oxides had appeared in those areas. Purity of the tested components did not show the required quality, either; many impurities were observed on the structure surface.

3.

Sintered components, manufactured from Fe-C-Cu material (FC-0205 and Fc-0208) of 18.4.26 sample and Fe-C (F-0005) of 2.17 sample, were also subjected to strength tests. However, no such comprehensive tests (as for sample 22) were carried out on those materials.

Observations with an optical microscope revealed ferrite and pearlite structures. It was a typical phase component for the components under study. Those structures did not depend on the density of the compact under study.

The tensile test for the Fe-C-Cu samples showed no yield strength. However, as density increased, tensile strength increased as well. For a density of 5.9 g/cm^3 tensile strength is in the range of 150-250 MPa, with a density of 6.9 g/cm^3 in the range of 260-480 MPa.

For samples 4 and 18, the tensile strength was within the range of 150-500 MPa, while for sample 26, it was within the range of 150-350 MPa (the results occur in a smaller range). Neither room temperature nor an elevated temperature changed the material properties. It did not affect the test results, either. The data of tests of the samples with an additional coating were more cumulative, occurring over a narrower range of values.

The compression strength test for the Fe-C-Cu samples showed that, as the density increased, the parameters of compression strength increased as well. The range for PN 26 was the narrowest, with the compression strength within the range of 580-910 MPa, while the other PN samples demonstrated results within the range of 270-780 MPa.

Compression strength was higher for the samples without additional heat treatment. By contrast, Young's modulus was higher for the samples with additional heat treatment.

For the samples, produced from Fe-C powder material (F-0005), similarly as for the Fe-C-Cu samples, the tensile test did not show any yield strength. The test, carried out at an elevated temperature of 120°C, did not induce any difference in the results. In contrast, together with an increase in density, the tensile strength increased by up to twofold. The oxidation-treated samples generated results with a narrower range.

A compression test of the samples, produced from Fe-C powder material (F-0005), also showed an increase, both in Young's Modulus and in the compression strength with additional heat treatment. The process with additional heat treatment demonstrated significantly higher values than the process without such treatment. The samples, produced from material 17, provided more consistent results within a series of repetitions (trial) than the samples produced from powder material 2.

It was noted in the course of the study that the type of powder material (sponge or atomised) had demonstrated the highest influence on the results of the strength tests carried out. This fact is confirmed by a number of literature sources, as well as by the behaviour of sintered components produced from sponge powder 2 and 26. Those samples did not break before the end of the test and were able to retain most of the parameters from the compression and tensile tests.

4.

As part of the implementation works, a workstation was set up to determine density and porosity by means of the Archimedes method. These tests are performed when approving a sintered component for mass production. Microscopic studies enabled a data base to be created with the knowledge on the structure of sintered components, produced from various powder materials. An analysis of carbon loss during the production process was also implemented. The studies showed carbon loss in the tested conventional process at the level of 0.1%, which was in compliance with the ASTM E1019 test. The percentage of carbon supplied in the powder material should be equal to the percentage of carbon in the sintered part produced. Lost carbon is converted into costs and losses in the production process.

As part of the implementation works, a model was designed and developed to simulate sintered components. An initial study, carried out by the finite element method, illustrated the status quo and revealed further possible research directions. They should focus on creating the FEA (Finite Element Method) models of densification and of moulded part formation processes.

A prior analysis of the manufacturing stage enables the potential areas of later cracking to be revealed much earlier than any analysis of the finished sintered parts.

The study showed that the most suitable type of material for the conventional sintering process studied had, in that case been the sponge material. The chemical composition and density of the sintered component had less influence and importance with regards to the properties of sintered components.

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Key words: powder metallurgy, conventional sintering process, hardness, mechanical properties