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DETERMINATION OF THE EFFECTIVE LOAD-BEARING CROSS-SECTION OF SINTERED STEEL PRODUCTS

DOLOČANJE DELEŽA DUKTILNEGA PRELOMA SINTRANIH JEKLENIH IZDELKOV

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The mechanical properties of sintered steel products depend mostly on their porosity and the bonds between the steel powder particles. Increasing the cohesion interconnection significantly improves the mechanical properties. Using scanning electron microscopy (SEM) with its high depth resolution it is possible to determine the fraction of ductile fracture which is honeycomb-like in appearance and is effective load-bearing cross-section.

Key words: ductile fracture, sintered steel, warm pressed

Mehanske lastnosti sintranih jeklenih izdelkov so odvisne predvsem od njihove poroznosti in vezi med jeklenimi prašnimi delci. S povečanjem kohezivne povezave med njimi močno izboljšamo mehanske lastnosti. Uporaba vrstičnega elektronskega mikroskopa (SEM) zaradi velike globinske ločljivosti omogoča določitev deleža duktilnega preloma, ki je glede morfologije podoben čebeljemu satovju in je nosilni del v nekem prerezu.

Ključne besede: duktilni prelom, sintrano jeklo, toplo stiskanje

1 INTRODUCTION

Most of the steel products used in cars are manufactured by the classical powder metallurgy route of pressing and sintering. The products have a very good surface quality with excellent dimensional tolerances. The mechanical properties of these sintered steel products depend primarily on porosity. Higher porosity means lower density and correspondingly worse mechanical properties [1,2]. By influencing the volume fraction and the morphology of the pores better mechanical properties are obtained [2]. A reduction in the total porosity results not only in improved strength but also in better ductility [3]. The total porosity can be reduced, but not eliminated, by double pressing or using the newly developed technology of warm pressing [4]. Instead of using metallographic techniques, fractographic techniques were proposed for describing the porous microstructures [5]. The sintered products with low porosity show isolated pores while the high-porosity products show interconnected pores and isolated sintered contacts. Good mechanical properties correspond directly to the cohesion of sintered powder particles.

This paper deals with the method of load-bearing cross section determination according to the internal standards for sintered steel products used in the car industry. The fraction of ductile and brittle fracture at random places was measured by planimetry of SEM fractographs. Selected examples show how the method of sintered steel manufacture influences the load-bearing cross-section which indirectly controls the mechanical properties.

2 EXPERIMENTAL PROCEDURE

Two series of sintered steel products were industrially prepared using cold pressing and warm pressing on a Dorst 500 kN hydraulic press (**Figure 1**). The products were safety element of a servo system and were produced from Höganäs' Distaloy AB and Densmix [6] for cold and warm pressing, respectively. One can notice that two different materials were compared due to specific demand for cold and warm pressing. Both

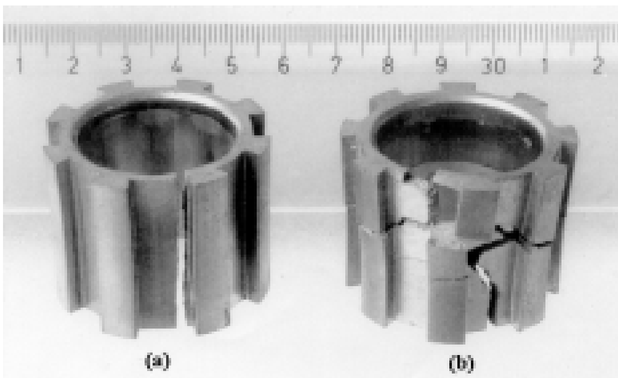

Figure 1: Sintered product of safety element of servo system fractured on different mode (a) cold pressed and (b) warm pressed

Slika 1: Sintran izdelek varnostnega elementa servosistema, zlomljen različno: (a) hladno stiskan in (b) toplo stiskan

Table 1: The pressing conditions and the compact performances, obtained by pressing on a Dorst 500 kN press. The characteristics of the sintered products using classical sintering powder metallurgy and warm pressing are compared.

Tabela 1: Pogoji stiskanja in lastnosti stiskanca, dobljeni na stiskalnici Dorst 500 kN. Podana je primerjava lastnosti sintranih izdelkov, dobljenih po klasični metodi sintranja prahov in s toplim stiskanjem.

Pressing conditions	Temperature (°C) (tool/ powder)	Pressing device	Density ρ (g/cm^3) [6]		Load bearing cross-section (%)		Fracture strength (kN) [8]		Hardness HB
			green	sintered	ductile	brittle	green	sintered	
cold pressing	Room temperature	Dorst 500 kN	7.05	7.11–7.13	24-29	0	0.40-0.45	12.2-12.5	106/117
warm pressing	110/110	Dorst 500 kN	7.33	7.32–7.34	31-45	1-4	0.50-0.54	14.9-15.3	125/132

materials consists of iron particles, but for warm pressing a lubricant is added. The pressing conditions are shown in **Table 1**. Some physical properties were compared and analysed. The fraction of ductile fracture area – the effective load-bearing cross-section – on both series of samples was determined using a SEM Jeol JSM-35 and image analysing software analySIS-PRO 3.1 from Soft Imaging System, Germany.

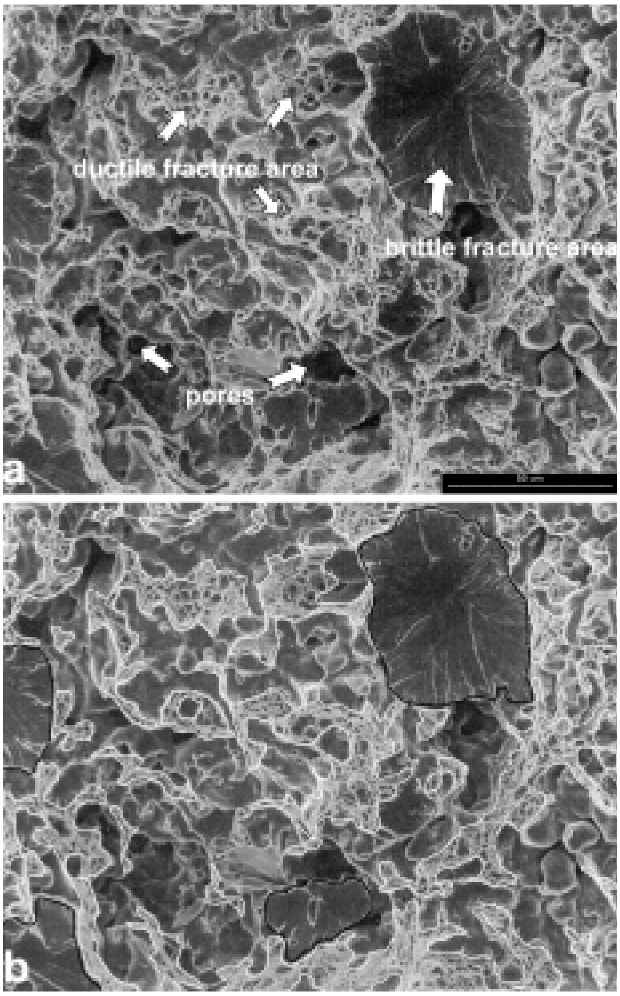

Figure 2: (a) Typical fracture surface of a sintered sample showing areas of porosity as well as ductile and brittle regions. (b) The area of the ductile and brittle fracture surface is determined by a planimetric technique using manual mode in analySIS-PRO software. The ductile and brittle areas are 31 % and 14 %, respectively.

Slika 2: (a) Tipična prelomna površina sintranega vzorca, na kateri so poleg duktilne in krhke prelomne površine prikazane tudi pore. (b) Ploščino duktilnega in krhkega dela preloma smo določili z ročnim planimetriranjem ob uporabi računalniškega programa analySIS-PRO. Delež duktilnega preloma je 31-odstoten in delež krhkega preloma 14-odstoten.

2.1. Method for the determination of the load-bearing cross-section

For detecting the sintered material performances different static as well as dynamic mechanical parameters can be measured. The procedure for determining the porosity of sintered steel products is standardised [7,8]. Additionally to all this parameters the car industry also check the load-bearing cross- section which is a very good indicator of the mechanical properties. The procedure to determine the load-bearing cross-section which

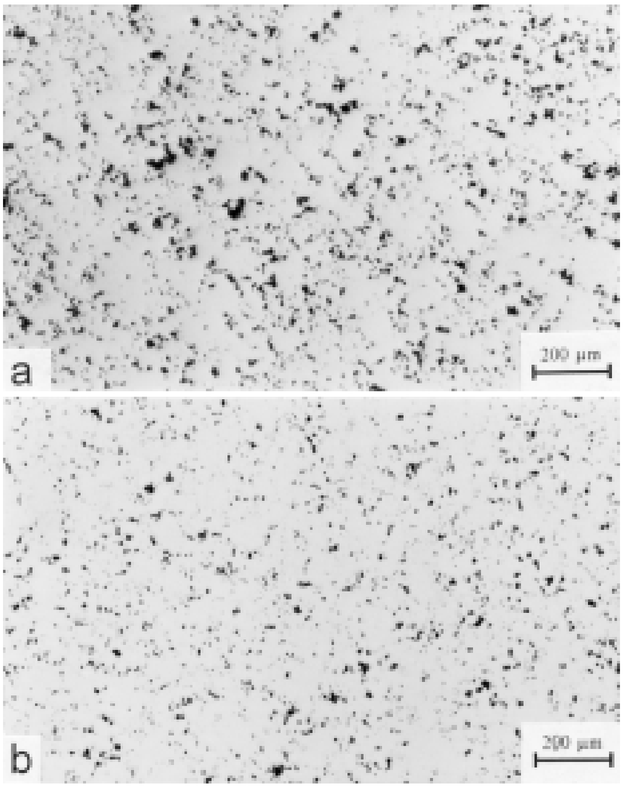

Figure 3: Porosity of (a) the cold-pressed and sintered sample is 9.0 % and (b) the warm- pressed and sintered product is 3.6 %

Slika 3: Poroznost (a) hladno stiskanega in sintranega vzorca je 9-odstotna in (b) toplo stiskanega in sintranega vzorca 3,6-odstotna

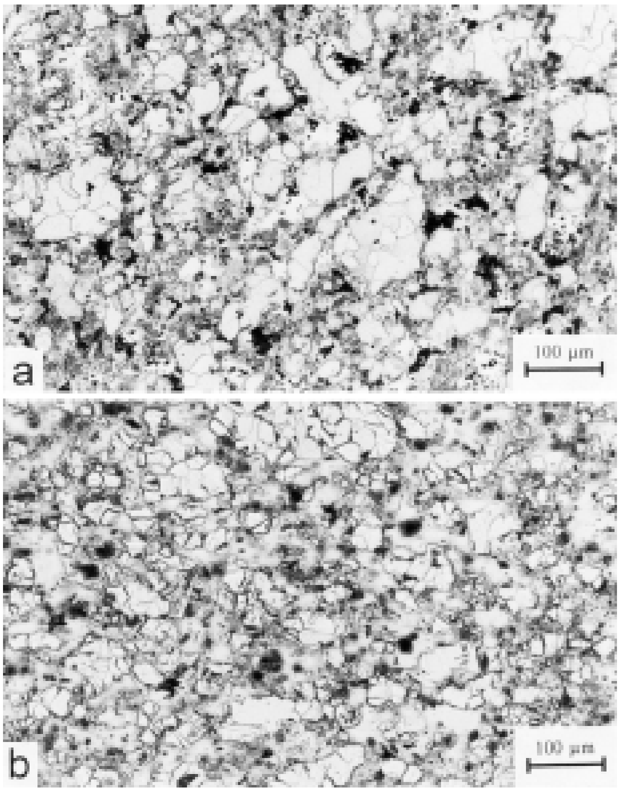

Figure 4: Microstructure of (a) the cold-pressed sintered product and (b) the warm- pressed sintered sample (etched in 2 % Nital)

Slika 4: Mikrostruktura (a) hladno stiskanega sintranega izdelka in (b) toplo stiskanega sintranega izdelka (jedkano v 2-odstotnem nitalu)

has been used in our research and is very similar to those used in car industry is described as follows:

- Sintered steel products are fractured always by pressuring or bending at the same ordered critical place, performed in the same way.
- The fractured area is observed under the SEM at magnification 400-times.
- The number of examined places should be at least 25, which have to be randomly chosen and uniformly distributed on the fractured surface, 15 of them must be selected from the border area.
- The observed area is photographed. The ductile area can be measured directly in the SEM or with photographs.
- The area of the ductile fracture surface – the load-bearing cross-section – is determined by a planimetric technique. This can be done by the application of image-analysing software in automatic mode or manual mode.
- 30 % of the fracture surface area must be of a ductile nature.

3 RESULTS AND DISCUSSION

In **Figure 2 a** the fractured surface area of a sintered steel product is shown. There are three different types of area:

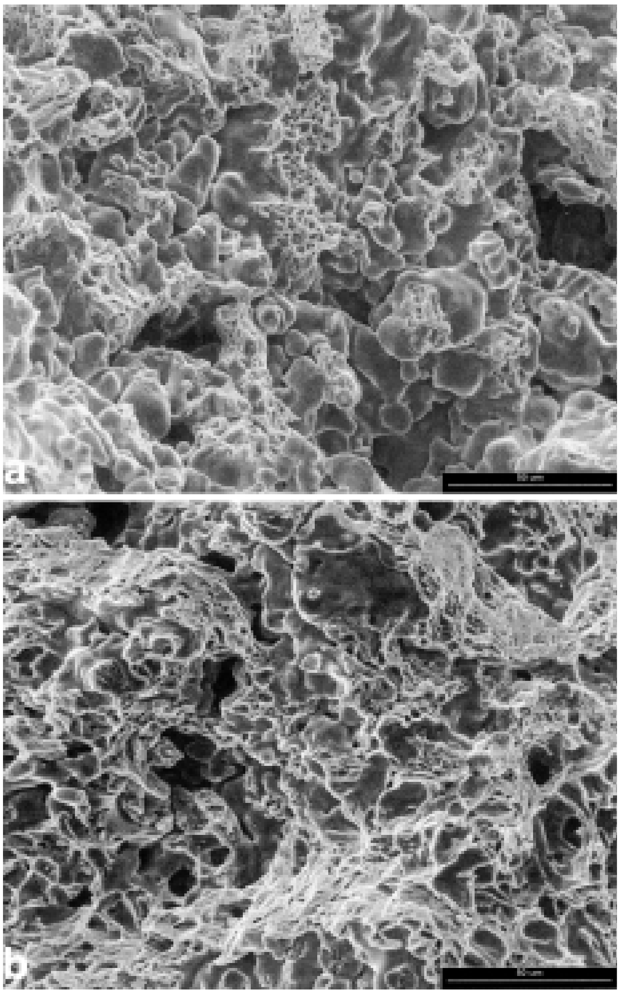

Figure 5: SEM image of the fracture surface of (a) the cold-pressed and sintered sample. The ductile area is 25 % and (b) the warm-pressed sintered sample. The ductile area is 45 %

Slika 5: SEM-posnetek prelomne površine (a) hladno stiskanega in sintranega vzorca, kjer je delež duktilnega preloma 25 % in (b) toplo stiskanega sintranega vzorca, kjer je delež duktilnega preloma 45 %

1. Ductile, which is honeycomb-like in appearance and acts as an actual effective load- bearing cross-section;
2. Brittle, which has cleavage lines and is flat;
3. Pores.

For exact measurement, the ductile areas are measured in the manual mode, that means every ductile fracture area is marked by hand and the marked areas are measured (**Figure 2 b**). The automatic mode can be used, and this is much faster, but the correct thresholding of gray scale image must be applied. Sometimes this is not possible, because the ductile area are not always within a specific defined gray value range.

Sintered steel products manufactured by warm pressing have a higher density and a lower porosity. By decreasing the porosity level the static as well as the dynamic mechanical performance (hardness, strength, ductility and fatigue life) is improved. In **Table 1** a comparison of some mechanical properties is summarised for sintered steel products manufactured by classical sintering powder metallurgy and warm pressing. It is clear that the ductile fracture area increases with increasing density or decreasing porosity of the sintered steel product. In **Figure 3** the porosity of cold and warm-pressed samples is shown. The porosity of these cold- and warm-pressed samples are 9.0 % and 3.6 %, respectively. **Figure 4** shows the microstructure of samples after etching with 2 % nital. The ferrite-perlite grains are smaller and the microstructure is more homogeneous compared to the cold-pressed samples. Both porosity and microstructure are improved by warm pressing. The mechanical properties can be directly compared to the fraction of ductile fracture area. As a consequence, the car industry have introduced the measuring of load-bearing cross-sections as an additional test method for controlling the quality of sintered products. **Figure 5** shows the fracture surface of cold- and warm-pressed samples. The difference in ductile fracture area is obvious.

4 CONCLUSIONS

A method for the determining the load-bearing cross-section is described. It is an appropriate additional method for controlling mechanical properties, particularly useful because sintered steel products are very small and have complicated shapes which make them unsuitable for standard mechanical test procedures. The results have shown that warm-pressed sintered products have a much higher area of ductile fracture surface and smaller porosity resulting in a better microstructure and mechanical properties.

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