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COMPARATIVE ANALYSIS OF MECHANICAL PROPERTIES OF PM MANGANESE STEEL AFTER DIFFERENT POWDER PROCESSING

СРАВНИТЕЛЕН АНАЛИЗ НА МЕХАНИЧНИТЕ СВОЙСТВА НА ПРАХОВО МЕТАЛУРГИЧНИ МАНГАНОВИ СТОМАНИ СЛЕД РАЗЛИЧНИ ОБРАБОТКИ НА ПРАХОВЕТЕ

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Abstract The purpose of this research was to evaluate the effect of powder processing on the structure and mechanical properties of Fe-Mn-C PM steels. The steels were based on Höganäs pre-alloyed powder NC 100.24 and ELKEM II ferromanganese admixed with graphite powder grade C-UF. Base powders were mixed in two ways: in Turbula mixer and by preparing ferromanganese master alloy in a ball mill. Chemical composition in % mass was Fe + 2% Mn + 0.8% C. Samples were single pressed into a "dog bone" shape according to PN-EN ISO standard under pressure of 660 MPa. Sintering of compacts was carried out in a laboratory tube furnace at 1250°C for 60 minutes in an atmosphere consisting of a mixture of 95%N_2 and 5%H_2. After sintering sinterhardening treatment was used. Cooling rate was 60℃/min.

Density measured by geometrical method was similar: 6.68g/cm^3 after ball milling, 6.64 g.cm^3 after Turbula mixing. Yield strength was slightly higher after ball milling – 448 MPa, and after mixing 430 MPa. Microstructures were mainly ferritic-pearlitic with rare bainitic areas.
Keywords: powder metallurgy, sintering, sinter-hardening, ball mill, master alloy, mechanical properties

1. *Introduction*

Manganese is widely used for sintered materials instead of carcinogenic nickel or non-recyclable copper. Because of its high strengthening and hardenability this element can be added to construction parts produced by powder metallurgy. The influence of manganese on mechanical properties of sintered steel is presented on Fig.1.

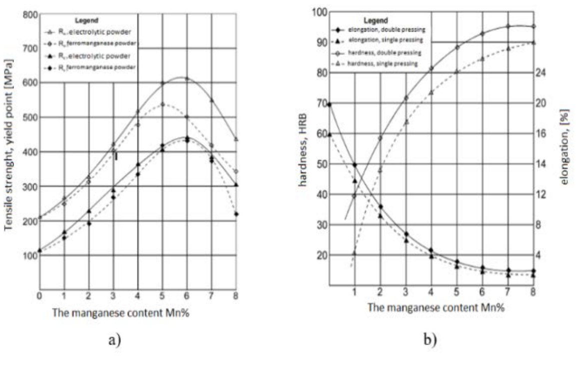


Fig. 1.The effect of Mn content on: a) mechanical properties of single pressed steels, b) hardness and elongation [3,4 z SIM]

Main problem with addition of manganese is its high affinity to oxygen and intergranular decohesion. To limit the formation of oxides during sintering, manganese is added as ferromanganese. Mitchell and Ciaś also proposed to use semiclosed container to create an active microclimate inside [1-2].

Mechanical milling was developed for aerospace industry. Initially materials were designed as oxide-dispersion strengthened (ODS) nickel and iron-base superalloys. The main advantages of using MM are: creation of fine dispersion of second phase, possibility of alloying of difficult to alloy elements at low temperatures and increasing strain hardening [3-5]. However MM involves repeated processes such as: welding, fracturing and rewelding of powder particles and requires using high energy or planetary ball mills, so its makes this process more expensive than classical mixing in Turbula mixer [6-7]

2. *Material and preparation of test samples*

The powders were Höganäs pure iron powder NC 100.24 and ferromanganese master alloy admixed with carbon in the form of graphite powder grade C-UF (ultra fine - 0.8 mass %)

Preparation of master alloy was conducted using CDI-EM60 frequency inverter for 50 hours. Rotational speed was 70% of critical rotational speed of the jar. Ball milling was performed on 100 g mixture consist of 50g/50g NC 100.24 and Elkem II ferromanganese, respectively.

Two mixtures were prepared based on different powder processing – traditional mixing powders in Turbula mixer and making master alloy in the ball mill. Chemical composition of the mixtures was Fe + 2% mass Mn + 0.8% mass C. Table 2 contains designation, chemical composition and type of preparation of powders mixtures. Following the mixing/milling, green compacts were single pressed at 660 MPa according to PN-EN ISO 2740 standard. Sintering was carried out in a laboratory horizontal furnace at 1250°C for 60 minutes in 5%H_2 – 95%N_2 atmosphere and dew point -60°C. Cooling from sintering temperature was performed using sinter-hardening technique (fast). Heating rate was 75°C/min and for sinter-hardening technique cooling rate was 60°C/min.

Table 1. Designation, chemical composition and type of preparation of powders mixtures

Designation	Chemical composition, % mass	Type of preparation of powders, h
T	Fe + 2% Mn + 0.8% C	Mixing in Turbula mixer, 0,5 h
B		Ball milling, 50h

3. *Scope of the research*

To evaluate effect of processing powders on the structure and mechanical properties of PM steels followed investigations were made:

- measurement of density by the geometric method,
- assignation of tensile strength and hardness on section examined steels,
- evaluation of structure on micrographs.

Tensile strength test was carried out on endurance machine MTS. Parameters of tensile test were defined in accordance with standard PN-EN 10002-1. Speed of traverse was 1 mm/min. Transverse rupture strength was measured on an endurance machine ZD10 with 28.6 mm span.

Hardness tests were made on durometer Innovatest. Loading measurement was 50 G and performed on sample for 10 seconds. Microhardness test was carried on the overall width every 0,5 mm.

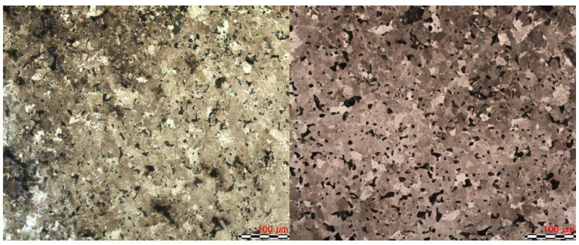
Metallographic sections were prepared according to procedure [8]. To reveal microstructures, crosssections were etched by 3% Nital. Observations of microstructure were made on Leica DM4000M optical microscope using bright field (**BF**) technique. Metallographic observations were performed with magnifications 200x and 500x.

1. *Results of research*

Table 2 contains mean values of density before, in the range 6.62 to 6.63 g/cm^3,'and after sintering, when it slightly increased - maximum increase of density was +0.86%. Results of mechanical properties are recorded in Table 3 and on Figure 1 microstructures and on Figure 2 fractographs are presented.

T B

200x Mark 100 µm



500x Mark 50 µm

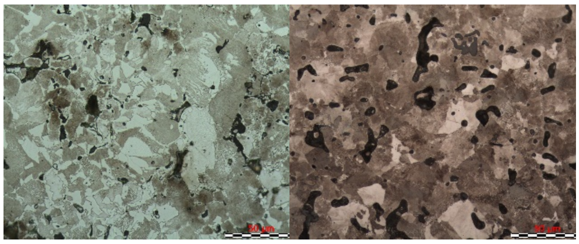


Figure 1. The microstructures of steels based on Fe + 2% Mn + 0.8% C sintered at 1250°C

T B

1500x

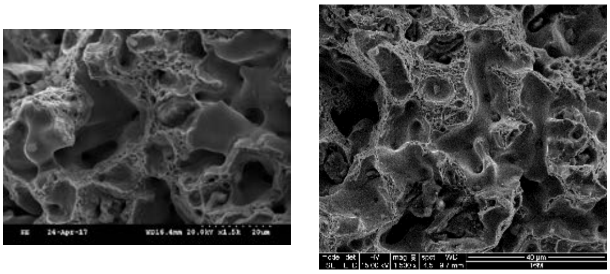


Figure 2. The fracture surfaces of steels based on Fe + 2% Mn + 0.8% C sintered at 1250°C (SEM)

Table 2. Density (16 samples) – geometric method

Steel variant	1250°C		
	Mean density, g/cm^3		Density changes, %
	Green	Sintered	
T	6.63±0.01	6.64±0.01	0.15
B	6.62±0.01	6.68±0.01	0.86

Table 3. Mechanical properties of investigated PM steels – mean values (16 samples)

Steel variant	1250°C				
	UTS MPa	$YS_{0.2}$, MPa	TRS, MPa	A, %	HV 0.05
T	713±52	430±31	1200±85	2.98±0,98	249±21
B	722±38	488±87	1161±110	2.73±0,39	286±26
Properties changes, %	+1.26	+13.49	-3.25	-8.39	14.86

2. *Discussion of results*

Table 2 shows that sintering at 1250°C for 60 minutes caused slight densification, up to +0.86%.. Higher densification was obtained for ball milled specimens. During milling of powders, particles broke and revealed areas with higher chemical activity which intensifies changes during sintering.

Processing powders in a ball mill affected the mechanical properties slightly. Table 3 shows that steel based on powder processed ina ball mill has higher tensile strength but lower plastic properties (UTS from 713 to 722 MPa, $R_{0.2}$ from 430 to 488 MPa and A from 2.98 to 2.73 %). However, these changes are in the range of standard deviation. Hardness increased from 249 to 286 HV 0.05, which corresponds well with decrease of plastic properties. As the result of ball milling (plastic deformation) powder particles strain hardened.

Ball milling conducted for 50 hours caused strong grinding of particles.

Microstructures were characterized by mainly pearlitic structure with small ferritic areas.

Failures were characterized by shallow dimples filled with oxides, which is characteristic for brittle character of fractures in the researched samples.

3. Conclusions

The studies allow the following conclusions:

1. Processing powder in ball mill did not affect significantly mechanical properties of sintered steels.
2. Addition of strain hardened particles caused increase of hardness of examined PM steels.
3. Presence of oxides in researched steels promoted brittle character of failures.
4. Presence of ball milled particles in green compacts intensified the sintering processes.

Acknowledgments

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