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Microstructural characteristic and mechanical properties of Ni-Mo-(W) steels

L.A. Dobrzański [a,*], J. Otręba [a], M. Actis Grande [b], M. Rosso [b]
[a] Division of Materials Processing Technology and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
[b] Politecnico di Torino – Alessandria Campus, Viale T. Michel 5- 15100 Alessandria, Italy
* Corresponding author: E-mail address: leszek.dobrzanski@posl.pl

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ABSTRACT

Purpose: Purpose of this paper was to examine the role of tungsten on properties of two different carbon levels pre-alloyed steel powders. Microstructural characteristic and mechanical properties of sinter-hardened Ni-Mo steels with increasing amount of tungsten (from 0 to 0.3% wt.) were taken under consideration.
Design/methodology/approach: Powder mixes (Ni-Mo, Ni-Mo-W) have been compacted at 700MPa and sintered in a vacuum furnace with argon backfilling at 1120°C for 60 minutes. Rapid cooling has been applied with an average cooling rate of 2.5°C/s. Obtained samples were analyzed by scanning microscopy with energy dispersive spectroscopy (EDS) for phase distribution and mapping and light optical microscopy for observations of the microstructure. Charpy impact test, three-point bending, microhardness and pin-on-disk tests were used.
Findings: The effect of chemical composition and applied vacuum sintering with rapid cooling were studied in terms of mechanical properties, focusing in particular on impact energy, hardness and wear resistance. The results achieved after the investigation of Ni-Mo and Ni-Mo-W sinter-hardened steels with low and high carbon content proved that applied process of sintering under vacuum and rapid cooling brought expected outcome.
Research limitations/implications: According to the powders characteristic, the applied cooling rate seems to be a good compromise for mechanical properties and microstructures, nevertheless further tests should be carried out in order to examine different cooling rates and parameters of tempering process.
Originality/value: The effect of small additions of W and WC to low alloyed steels, especially in terms of hardenability and wear resistance, was investigated.
Keywords: Powder metallurgy; Sintering; Low alloyed steels; Sinter-hardening

1. Introduction

Powder metallurgy development has rapidly increased in past years as an alternative technology profitable because of low cost and no need of metal working processes such as machining, stamping and forging. It has continued to displace competing cast or wrought technologies in automotive applications. One of the main advantages of the technology is the easiness of mixing different metal powders and composing new materials with unique physical and mechanical properties that cannot be obtained by standard melting-casting processes. Growth of powder metallurgy processes using sintering is followed by all technological advancements through development of new processes to obtain powders, lubricants and near net-shaped products widely used in the production of automobile parts [1-4].

Sinter-hardening is an increasingly popular technique, which requires to cool parts from the sintering temperature at a rate sufficient to transform a significant portion of the material matrix into martensite. Application of that process allows avoiding secondary heat treatment, contamination of pores in the sintered

Table 1.
Chemical composition of studied powder mixes

Grade powders	Composition designation	Elements concentration (wt.%)				
		Ni	Mo	W	C	Fe
W0-AC	0A	2.00	1.50	-	0.60	95.9
W0-BC	0B	2.00	1.50	-	0.40	96.1
W1-AC	1A	2.00	1.50	0.10	0.60	95.8
W1-BC	1B	2.00	1.50	0.10	0.40	96.0
W2-AC	2A	2.00	1.50	0.20	0.60	95.7
W2-BC	2B	2.00	1.50	0.20	0.40	95.9
W3-AC	3A	2.00	1.50	0.30	0.60	95.6
W3-BC	3B	2.00	1.50	0.30	0.40	95.8

steels with quench oil and helps in subsequent surface treatment improving the environment of working place. Cost reducing, technical and manufacturing economy, improved process efficiency, densities and mechanical properties, make PM products more appealing, especially in case of applications where high wear resistance is required [5-10].

Sinter-hardening permits the production of powder metallurgy components having high apparent hardness and high strength and is applied for components difficult to be quenched because of their shape or dimensions. Fe-Mo pre-alloyed powders, in part with addition of Ni through admixing or diffusion bonding, can be successfully used in the sinter-hardening process. They are characterized by high density, homogenous or heterogeneous microstructures (the degree of heterogeneity varies with the carbon concentration), which promote tensile and fatigue strength. High compressibility of Ni-Mo powders allows producing powder metallurgy steel compacts with green density reaching $7.3 Mg/m^3$, promotes sintering density and improves pore morphology without the need of applying double pressing and double sintering processes [11, 12].

In pre-alloyed powders the selection of type and amount of alloying elements additions has to be considered and focused, in particular, on compressibility, sinterability of green compacts and on the transformation of austenite in order to achieve the desired microstructure. The way chosen for alloying, distribution of powders and green density clearly affect porosity of sintered parts. All processing variables, sintering temperature, time of the process and post sintering cooling rate have to be well defined with the aim of modeling final properties required in specific field application [12, 13, 15].

Molybdenum, due to its relative small impact on compressibility if compared to other alloying elements, good response in hardenability, is one of the main pre-alloyed elements used in powder metallurgy industry. It has been proved that the addition of nickel to iron-molybdenum powders increases sintered density, hardenability and reduces sintering activation energy. Ni-rich areas provide local ductility and influence positively hardness and strength of sintered materials. Both elements, Ni and Mo form highly stable oxides determining the sintering atmosphere to be utilized and allowing for development of bainitic-martensitic microstructure when standard conditions of cooling are used. Products prepared from Fe-Mo pre-alloyed powders with presence of heterogeneous microstructure, high densification and better fatigue properties show many advantages in number of applications [12-15].

The effect of W and/or WC additions to highly alloyed steels is well known, especially in the case of hardenability and wear resistance [16, 17], but there is no recollection of literature of W additions in small amounts into low alloyed products. The goal of this work was also to investigate the role of tungsten on the properties of two different carbon levels pre-alloyed steel powders.

2. Experimental procedure

Different compositions have been tested in order to investigate the influence of various tungsten additions into low (0.4%) and high (0.6%) carbon content of pre-alloyed steel powders. The chemical composition of powders used in this study and their designation are listed in Table 1.

Powders, with addition of 0.7% lubricant, were pressed in a 2000kN hydraulic press applying pressure of 700MPa, using rectangular (10x55) and a disk shaped mould (40mm diameter) in order to prepare samples for Charpy, three-point bending and both pin on disk and disk on disk tests.

De-waxing process at 550ºC for 60 minutes in a fully nitrogen atmosphere was performed before the sintering. Sintering was carried out in vacuum furnace with argon backfilling. The furnace was equipped with a cooling zone to provide accelerated cooling from the sintering temperature. Green compacts were sintered at 1120ºC for 1h and rapidly cooled with a rate 2.5ºC/s.

In order to evaluate the densities of sintered samples, water displacement method was used. Microstructure was investigated using LEICA MEF4A light microscope after polishing samples and metallographic etching with Nital 2%.

Microhardness in the scale HV0.1 performed on studied materials was measured in every direction, starting from 20µm from a border and continuing each 30µm up to the centre on Vickers hardness intender.

Room temperature unnotched Charpy impact test was performed on all materials. In order to determine wear resistance both pin on disk and disk on disk tests were introduced.

Zwick Z100 machine was used to perform three-point bending test. Initial load applied was equal 10N and the speed 1.5mm/min. The mode of the probe was set for continuous controlling the crossbeam's position.

Pin-on-disk test was carried out through a tribometer with discs prepared from analyzed materials and the abrasive media - counterpin with 3 mm diameter made of WC-Co. The loads applied during experiment were 15 and 25N; the rotation speed of the disc was 0.26 m/s. Samples were tested on both sides and weighted several times up to 1000 meters of sliding distance.

3. Results and discussion

The sintering density for steels obtained from powders without addition of tungsten and 0.4%C was 7.25Mg/m^3, while with 0.6%C – 7.26Mg/m^3. Among steels with different amounts of tungsten the highest sintered density equal 7.23Mg/m^3 was achieved for steel marked as 2B, containing 0.4% of carbon and 0.2% of tungsten. Figure 1 presents sintered and green density of investigated powder mixes.

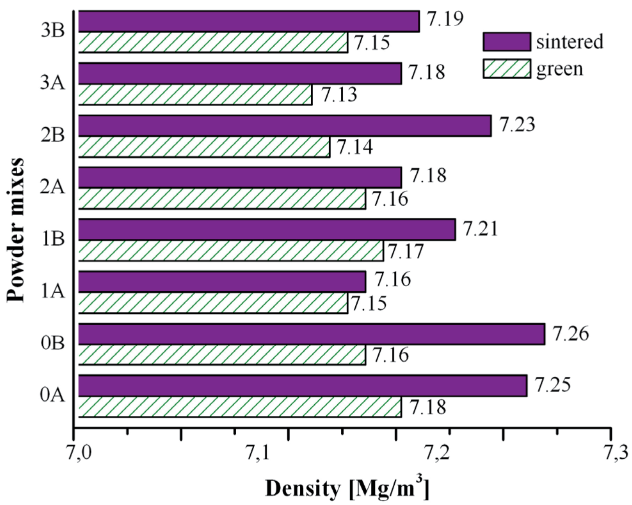

Fig. 1. Green and sintered density of studied compositions

Metallographic observations of samples were carried out after their polishing and etching with nital 2%. All tested materials after the applied process of sintering and rapid cooling, proved to have microstructure mainly composed of martensite.

Microstructure of composition without addition of tungsten and with low carbon content (0B) consisted of low carbon martensite, some retained austenite and lower bainite. The average microhardness of that steel was approximately equal 278HV0.1. Respectively higher microhardness (377HV0.1) was noted when increasing the amount of carbon to 0.6% (0A). Microstructure of that composition apart from martensite and retained austenite contained also finer martensite. The microstructure of materials containing various additions of tungsten and 0.6%C consisted of martensite, lower bainite and smaller amount of retained austenite, especially when comparing to material 0A without added tungsten. Among these steels, the highest value of microhardness was achieved for material composed of 0.2%W. Its microstructure is shown on figure 2.

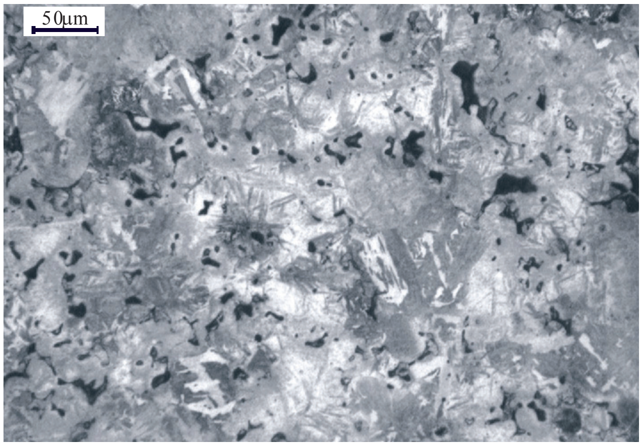

Fig. 2. Microstructure of composition 2A

Distribution of W into the matrix has been evaluated with SEM analysis applying Back Scattered Electrons. Figure 3 refers to steel with higher content of W – 0.3% and lower amount of carbon. The studies of image indicate that tungsten was observed preferentially accumulated in the proximity of pores. The dimension of agglomerates can be presented as a function of the amount of added tungsten.

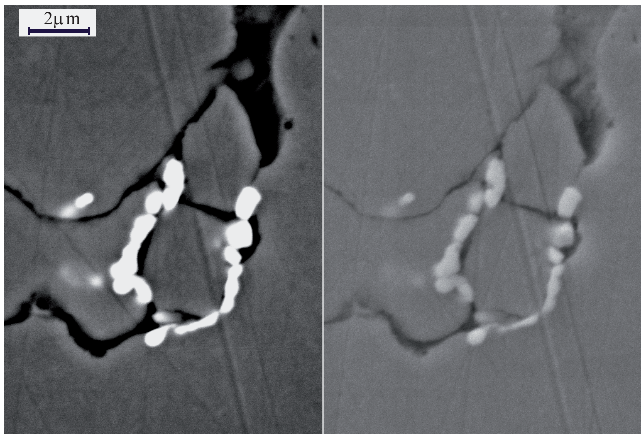

Fig. 3. Detail of the distribution of W in mix 3B

The values of impact energy for investigated steels were in the range 21J to 27.2J. The highest impact energy was noted for steels produced with 0.4%C (set of compositions B). The tungsten addition shows minor influence on impact energy for steels containing high carbon content and reaches the average of 21.7 J/cm^2. Material 0B containing 0.4%C without addition of tungsten shows the best result of impact energy equal 27.2 J/cm^2. Equivalent values of impact energy (24.8J/cm^2) was noted for mix 1B (0.1%W) and 3B (0.3%W).

According to three-point bending test it was shown that the highest value σ_{max}=1713MPa of maximum stress was achieved for steel designated as 0A, containing no addition of tungsten and high amount of carbon. Tungsten addition decreased σ_{max} and for steels 1A, 2A and 3A reached the average value of 1630MPa. A definite decrease in strength was observed when reducing carbon content to 0.4%. Within materials with lower concentration of carbon the highest value of σ_{max} was noted for steel 1B composed with addition of 0.1%W. During the test also deformation was noted. It differed for each set of steels. For materials with 0.6% of carbon (A) average ε was equal 1.9 % (the lowest value obtained for material marked as 3A), for materials with 0.4%C (B) deformation reached the average of 2.23 %. Maximum stress and deformation as a function of different amounts of tungsten, low and high carbon content are shown on Fig. 4.

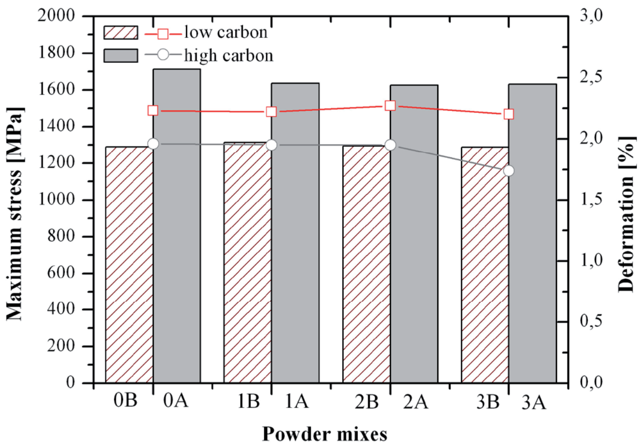

Fig. 4. Maximum stress and deformation as a function of different amounts of tungsten, low and high carbon content

The subsequent step of investigation was the wear resistance evaluation for all studied materials. Results of performed pin on disk wear test presented the highest relative mass loss for steels without addition of tungsten and low carbon content, while the most resistant to abrasion was composition 2A where mass loss noted was only 0.0001%.

4. Conclusions

Investigation of Ni-Mo-W sintered steel alloys proved that the application of an average cooling rate of 2.5ºC/s determined the formation of mainly martensitic microstructures, characterized by relatively high hardness values.

According to the steels' characteristics, the applied cooling rate seems to be a good compromise for mechanical properties and microstructures. Studied materials show good resistance to abrasion which could place them among materials in the specific field of application, especially where that feature is desired and determines their use.

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