Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 20
ISSUES 1-2
January-February
2007

Sinter-hardening of Ni-Mo pre-alloyed powders with tungsten addition

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

Received 24.10.2006; accepted in revised form 15.11.2006

Manufacturing and processing

ABSTRACT

Purpose: Purpose of this paper was to present the benefits of powder metallurgy technology and development of sinter-hardening process. The mechanical properties, focusing in particular on hardness and wear resistance, of two different carbon levels pre-alloyed steel powders processed with sinter-hardening method, were described. Microstructure characteristic of produced sinter-hardened Ni-Mo steels with increasing amount of tungsten (from 0 to 0.3% wt.) was taken under consideration.
Design/methodology/approach: 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. Powders, with addition of 0.7% lubricant, were pressed in a 2000kN hydraulic press. 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 the temperature 1120ºC for 1 hour and rapidly cooled with a rate 2.5ºC/s.
Findings: The applied sinter-hardening process resulted with achievement of material characterized by good wear resistance. 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: Considering the achieved outcome, it was revealed that chemical composition and applied process of steels preparation, sinter-hardening with the cooling rate 2.5ºC/s, results in achieving materials with relatively high hardness and significant resistance to abrasion. Anyhow, further research should be performed.
Originality/value: Sinter-hardening of Ni-Mo pre-alloyed powders with the addition of different additions of tungsten, especially in terms of hardenability and wear resistance, was investigated.
Keywords: Powder metallurgy; Sintering; Low alloyed steels; Sinter-hardening

1. Introduction

Powder metallurgy is a processing technology which results with obtaining metal products, by compaction of metal powders into desired shapes and then sintered at the proper temperature. PM sintered parts can be made of a great range of materials and obtain wide choice of shape and accurate dimensions [1]. The development of powder metallurgy has increased in past years once its benefits were revealed. The strongest proficiencies that make PM applications competitive compared with other technologies, were recognized as self-lubrication, unique compositions that can be processed, cost and energy effectiveness, near-net shape products as an outcome, possibility of porosity controlling and materials flexibility. All these advantages, considered as very important, allowed powder metallurgy industry to break into new markets and fields of interest [2]. This alternative technology is beneficial because of no necessity of metal working processes such as machining, stamping and forging. The comparison of existing forging methods and powder metallurgy has been shown in the figure 1 [1].

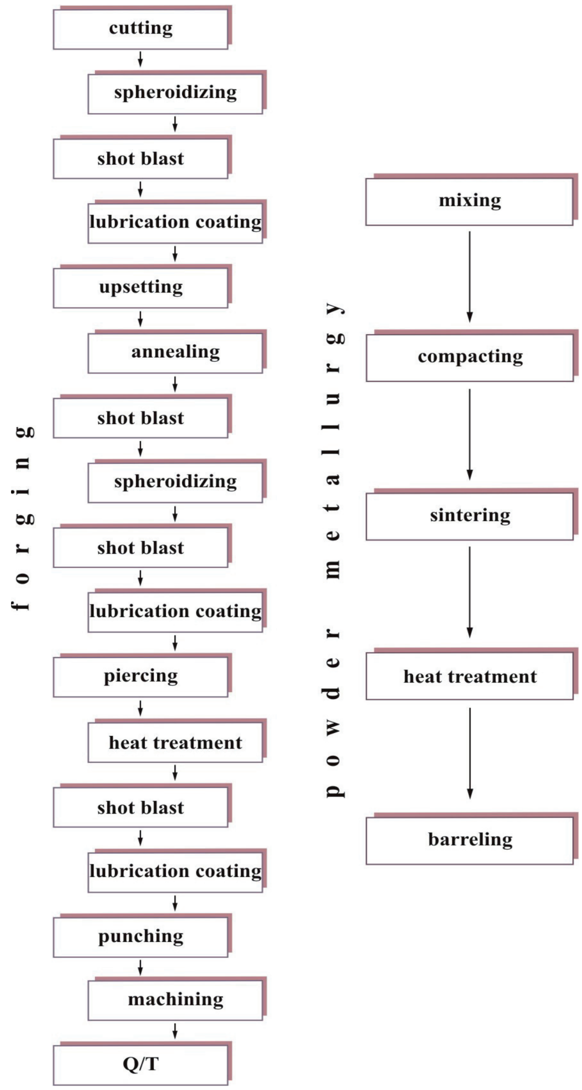

Fig. 1. The comparison of traditional forging method and powder metallurgy technology [1]

Powder metallurgy has continued to displace competing cast or wrought technologies in automotive applications [1, 3-5]. As far as size and production quantities are concerned, automotive components and among them, especially, transmission and car engine parts (fig. 2), have proved particularly attractive for powder metallurgy part applications [6].

Fig. 2. Powder metallurgy transmission and engine parts

One of the main advantages of the PM 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 [1, 3-5].

Introduction of PM steels with a success into new applications requires meeting the needs and expectations of end users for improved performance and superior efficiency than current systems. Even though every application has individual necessities, several common features and market requirements for PM steels can be listed: lower cost, closer tolerances, higher tensile and fatigue strength, higher yield strength and improved ductility [5].

Powder metallurgy technology, as any other, has its weaknesses which have the most potential to impede new PM applications. The critical areas of vulnerability were recognized in achieved material properties, such as poor ductility and toughness, green cracks and limited fatigue strength [2].

Anyhow, the growth of powder metallurgy processes using sintering is followed by all technological advancements throughout development of material systems with higher and more reliable performances than previously available, new processes of obtaining powders, lubricants, near-net-shaped products and heat treatment techniques [1, 3-5].

Sinter-hardening is an increasingly popular technique, which offers an alternative method through hardening the powder metal components without the application of traditional austenitisation, oil quench and tempering cycle. The sinter-hardening process requires the compaction of PM component, sintering and tempering cycle, that needs to cool parts from the sintering temperature at a rate sufficient to transform a significant portion of the material matrix into martensite. Each of these steps must be optimized in order to ensure the consistent production of sinter-hardened parts [6-18].

Application of sinter-hardening process allows avoiding secondary heat treatment, contamination of pores in the sintered steels with quench oil and helps in subsequent surface treatment improving the environment of working place. Ultimate tensile strength and hardness of sinter-hardened parts are equivalent and even superior to those conventionally heat treated powder metallurgy steels obtained by double pressing and sintering. Cost reducing, technical and manufacturing economy, improved efficiency of process, densities and mechanical properties, make PM products more appealing, especially in case of applications where high wear resistance is required. 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 [6-18].

Sinter-hardening can be achieved in a variety of ways, also with the use of standard sintering furnaces and those equipped with accelerated cooling zones, processing modified ferrous powder metallurgy admixed alloy systems. Some of the powder metallurgy materials have been developed especially for sinter-hardening process. These steel powders are generally characterized by higher hardenability when compared to conventional PM steels. There are few ways of introducing the powders preparation, including usual admixture where additions are mixed into pure iron powder and diffusion-alloying [19].

2. Experimental procedure

The materials used for the present study were pre-alloyed steel powders differed with the addition of tungsten and amount of carbon. The 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 (table 1).

Table 1.
Chemical composition of studied powder mixes

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

Ni-Mo and Ni-Mo-W steel powders, with addition of 0.7% lubricant, were pressed in a 2000kN hydraulic press applying pressure of 700MPa in rectangular (10x55) and a disk shaped mould (40mm diameter) in order to prepare samples for hardness, pin-on-disk and disk-on-disk tests. Before the sintering process de-waxing was performed at 550ºC for 60 minutes in a fully nitrogen atmosphere. 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. The temperature of sintering of green compacts was equal 1120ºC and the time 1 hour. After the sintering the samples were cooled with a rate 2.5ºC/s. In order to evaluate the densities of studied Ni-Mo-(W) sinter-hardened steels, water displacement method was used. Microstructure was investigated using LEICA MEF4A light microscope after polishing samples and metallographic etching with Nital 2%.

Hardness in the HRB scale of studied materials was performed on Rockwell hardness intender.

The investigation of wear resistance of tested materials was performed through pin-on-disk and then on disk-on-disk tests. In the case of pin-on-disk, the abrasive media was a 3mm diameter pin machined from WC-Co and the discs were prepared from analyzed materials. According to the wear resistance of achieved steels, 15N and 25N loads were applied during experiment; the rotation speed of the disc was 0.26m/s. Samples were tested on both sides and weighted several times up to 1000 meters of total sliding distance. Disk on disk test was done on device with 500N and 1000N of load (for samples with low and high concentration of carbon, respectively). Analyzed disc ran against the abrasive disk machined from WC-Co with the 10% of difference between their rotation speeds. The speed selected for driver was 0.2m/s and 0.18m/s for driven disc. During the test, the weight change of samples was measured using weight with the sensibility of 10^{-4}g. The measurements were done after each 100m up to 500m of the total sliding distance.

3. Results and discussion

The sintering densities for steels obtained from powders were included in the range from 7.16 to 7.26Mg/m^3. For steels without addition of tungsten, 0,6 and 0,4% C, the density was equal 7.25 and 7.26Mg/m^3, respectively. Amongst materials with different additions of tungsten, the highest density equal 7,23Mg/m^3 obtained the steel marked as 2B containing 0,2%W and low carbon content. The sinter-hardening process determined the formation of mainly martensitic microstructures with small amounts of lower bainite and retained austenite.

The hardness of studied materials differed according to the level of carbon. The average hardness of materials with addition of 0.4%C was approximately 89.8HRB, whilst for those with 0.6% of carbon the hardness rose to 101HRB. No significant changes were observed when comparing steels with different amounts of tungsten. The evaluation of performed pin-on-disk results revealed that, apart from higher carbon content, addition of tungsten leads to significant improvement of wear resistance of investigated Ni-Mo-W steels.

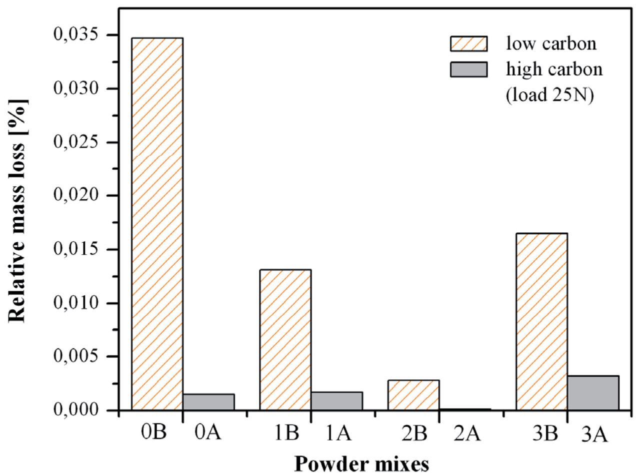

Fig. 3. Wear resistance as a function of different amounts of W for investigated compositions tested with pin-on-disk

The most resistant to abrasion was composition designed as 2A composed with 0.6% C and 0.2%W where mass loss noted was only 0.0001% while the highest relative mass loss achieved the steel without addition of tungsten and low carbon content. High resistance to abrasion of investigated materials, especially those with high carbon concentration, forced the change of applied load to 25N whilst initially applied was equal 15N. Figure 3 presents the wear resistance as a function of different amounts of tungsten for investigated compositions tested with pin-on-disk.

The following step of the study was the analysis of disk-on-disk test. It allowed to confirm that the Ni-Mo-W sinter-hardened steel with addition of 0.3%W and 0.4%C is less resistant to abrasion when comparing to the other containing lower tungsten. For steel 3B after 500m of sliding distance and load 50N the relative weight loss was equal 0.59%. In case of steels composed with higher carbon content the load applied had been changed to 100N. The composition of high addition of carbon, 0.2% and 0.3% of tungsten results with great improvement of wear resistance (relative mass loss noted was 0.25 and 0.21%, respectively).

4. Conclusions

The results evaluation of performed hardness, pin-on-disk and disk-on-disk tests revealed that, apart from higher carbon content, addition of tungsten in proper amount leads to significant improvement of wear resistance of investigated Ni-Mo-W steels. Steels with high carbon and addition of 0.2%W shows slight relative mass loss and is most resistant to abrasion, which was confirmed by pin-on-disk and disk-on-disk tests.

Considering the achieved outcome, it was revealed that chemical composition and applied process of steels preparation, sinter-hardening with the cooling rate 2.5ºC/s, results in achieving materials formed of mainly martensitic microstructures with small amounts of lower bainite and retained austenite, with relatively high hardness and significant resistance to abrasion.

Acknowledgements

The researches were partially realized within the framework of the Socrates Erasmus Programme, in Politecnico di Torino, Campus Alessandria, Italy.

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