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DIMENSIONAL CHANGES IN SOME IRON-BASED POWDER METALLURGY ALLOYS

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ABSTRACT

The purpose of this paper is to present the dimensional changes in some iron-based (P/M) alloys. The specimens produced from atomized iron powder and alloyed powder with different sizes (< 45, 45-63, 63-100, 100-150, >150 μm) were subjected to compaction at 400 and 600 MPa. After compaction, the specimens were sintered at 1150 ºC for 1 h. The density of green and sintered iron and iron-based alloys, the mechanical properties (hardness) and dimensional changes were evaluated.

KEYWORDS: powder metallurgy, sintering, density, dimensional changes

1. Introduction

Powder metallurgy (P/M) has rapidly increased in past years as a suitable alternative technology because of its low cost and the near-net-shape components.

The applications of powder metallurgy are continuously extended in different areas and included: components that are difficult to obtain by any other technology, such as molybdenum, tungsten or tungsten carbide, filters, porous bearings, magnetic components, connecting rods, camshafts, automotive clutch plates, and planetary gear carriers.

The main advantages of PM technology are: low unit cost, easy formability, near net shape components, components with high tolerance, use of 100% of raw materials [1-4].

Dimensional precision is an important factor in manufacturing of PM parts, especially for components with near-net-shape. The dimensional change of sintered compacts is influenced by many factors which affect the hardness of the produced part. The most important parameters are: chemical composition, particle size, powder density, sintering time and temperature, cooling rate and microstructure [5, 6]. The parameters like sintering temperature and time have effect in the specimen's shrinkage. Other parameters like cooling rate have an important effect on the microstructural changes. Concerning the chemical composition of the powders, especially the alloying elements, has an important role in improving the mechanical properties of the sintered parts. In principle, the alloying elements have the same effect on the sintered steels as on conventional steels. In general, all alloying elements improve the hardenability. Molybdenum (Mo), one of the main pre-alloyed and highly effective elements used in powder metallurgy industry due to its relative small impact on compressibility has a good response in hardenability [7, 8]. Copper (Cu) is one of the widely used elements in P/M increasing the strength and hardness. The usual amounts of copper used as alloying element are 1.5-3 wt.%, after this percentage can causes swelling to iron. Copper is an advantageous alloying elements due to its melting point at 1083 °C, thus at the typical temperatures used to sinter ferrous alloys, Cu forms a liquid phase which promotes sintering and enhances the strength of the sintered part. During the melting of Cu particles, they are leaving from their original positions and are creating very small pores in their initial place, so called secondary porosity because the pores are much smaller than the larger primary pores [9-12].

Nickel (Ni), another usual alloying element, increases the sintered density. Nickel, during sintering is in solid state and is forming in the sintered microstructure the Ni-rich areas which have a positive influence on hardness and strength by providing a local ductility [13].

In this paper, the dimensional changes in some iron-based P/M alloys were studied.

2. Experimental details

2.1. Raw materials

The analyzed specimens in this research are represented by two types of metal powders obtained by water amortization with different particle sizes (< 45, 45-63, 63-100, 100-150, >150 μm):

- atomized pure iron (Fe) powder and
- atomized iron-based alloyed powder with Cu, Ni and Mo. This powder has wide application in automobile PM parts such as gears.

The chemical composition of the powders is shown in Table 1. Tables 2 presents the basic characteristics of elemental iron and alloyed powder, such as flow rate, apparent density and in Table 3 and 4 are represented the sieve size analysis of analyzed powders.

2.2. Mixing

The required mass of powders was weighed and blended with 1% zinc stearate (ZnSt) in a mixer device for 10 minutes at a constant speed (30 rpm) in order to achieve the homogenization of the powder mix. Zinc stearate is a lubricant and was added to ensure that the mixture was completely homogenous and to prior to add the extraction after compaction.

Table 1. *The chemical composition of analyzed powders*

Powder type	C	Cu	Ni	Mo
P_1	<0.01	0.10	0.05	0.05
P_2	<0.01	1.50	1.75	0.50

Table 2. *The physical properties of analyzed powders*

Powder type	Apparent density, g/cm^3	Flow rate, s/50 g
P_1	3.14	24.11
P_2	3.10	25.07

2.3. Compaction

The blended powders mass was then uniaxial compacted in a mold into cylindrical discs of 8 mm diameter and 6 mm height using a universal mechanical testing machine. The applied pressure was 400 and 600 MPa at the ambient temperature. The compaction process involves the flow of the powder particles past one another, the interaction between particles and with the mold walls. Also, a deformation of the particles it occurs. An increased in the applied pressure will conduct at an increased in density of the powder compact while the porosity decreased.

2.4. Sintering

After compacting, the green samples were subjected to sintering. Sintering of all samples was carried out in a laboratory furnace. The sintering cycle applied to the samples involves heating at temperature approximately of 1,150 °C and then holding at that temperature for 1h and then air-cooled to room temperature.

2.5. Density measurement

The density of all samples was measured. The green and sintered densities of the samples were determined from weight and dimensional measurements, which were accurate to within ± 0.01 g and ± 0.001 mm, respectively (Table 5).

Table 3. *Sieve analysis of iron powder*

Sieve size (μ)	+150	+100	+63	+45	-45
Weight retained (%)	2.78	17.73	27.01	20.19	32.22
Cumulative weight retained (%)	2.78	20.51	47.52	67.71	99.93

Table 4. *Sieve analysis of iron-based alloyed powder*

Sieve size (μ)	+150	+100	+63	+45	-45
Weight retained (%)	3.72	20.88	30.54	20.80	23.82
Cumulative weight retained (%)	3.72	24.60	55.14	75.94	99.76

2.6. Mechanical tests

The hardness measurements were made using a Vickers hardness tester with a load of 5 kg and a time of 30 s. All the mechanical tests were done at ambient temperature and the test results were the average of three experiments.

3. Results and discussion

3.1. Microstructure analysis

The sintered specimens were analyzed according to their microstructure using an optical microscope (Olympus BX 50M).

In Fig. 1 are represented the optical microscope images for the sintered samples. From the image analysis of the specimen's porosity, it can conclude that the sample P_1 has a higher porosity compared with sample P_2, in accordance with a lower density and mechanical properties values. Porosity in sintered P/M alloys had a negative effect because it may conduct to areas of stress concentration or stress raisers, affecting the mechanical properties by cracks propagation. Even after sintering, it is very difficult to obtain a component without a certain percent of porosity, excepting the situation when the porosity is deliberately desired into the component to satisfy the imposed requirements, such as filters and bearings. The alloying elements are dissolved in the base metal, leading to the formation of various microstructures and increasing the materials resistance. The influence of alloying elements on the sintered steels is having the same effects as on the conventional steels but not all elements commonly alloyed with conventional steels can be used on the sintered steels.

3.2. Green and sintered density

The conventional compaction and the sintering were used to obtain the sintered densities between 6.81 g/cm^3 and 7.10 g/cm^3. As expected, green and sintered density increase with an increase in the compaction pressure (Table 5).

3.3. Mechanical results

In Table 6 is presented the Vickers hardness of the green and sintered specimens. The highest value of micro hardness was achieved for specimen P_2 due to the presence of alloying element Ni which will form the so call Ni-rich areas, who had a positive influence on hardness and strength of the sintered materials. Also, by pressing with a compaction pressure of 600 MPa is ensuring an optimal compaction of the samples. In Table 7 is presented the dimensional change of samples in the green state, pressed at 400 and 600 MPa and in the sintered state.

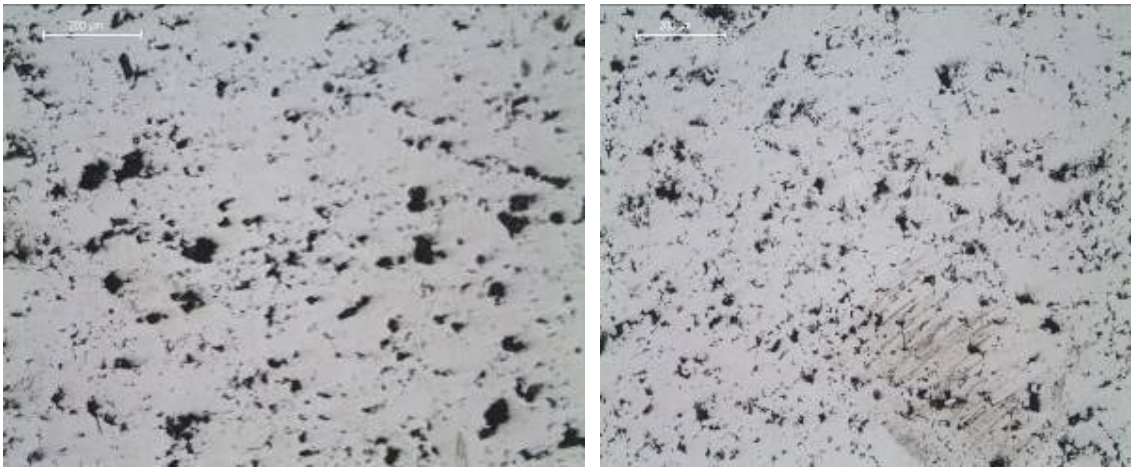

Fig. 1. *Optical image analysis for the sintered specimens: a) P_1, b) P_2*

Table 5. *Green and sintered density of analyzed alloys*

Powder type	Pressure applied, MPa	Green density, (g/cm^3) – ρg	Sintered density, (g/cm^3) - ρs
P_1	400 MPa	6.71	6.81
	600 MPa	6.93	6.98
P_2	400 MPa	6.78	6.83
	600 MPa	6.97	7.10

Table 6. *Vickers hardness in green and sintered state of analyzed alloys*

Powder type	Pressure applied, MPa	Vickers hardness, HV_5, (MPa) in green state	Vickers hardness, HV_5, (MPa) in sintered state
P_1	400 MPa	790	910
	600 MPa	870	1050
P_2	400 MPa	830	990
	600 MPa	960	1130

Table 7. *Dimensional changes of analyzed samples*

Powder type	Pressure applied, MPa	Dimensional change (%)
P_1	400 MPa	-0.06
	600 MPa	-0.03
P_2	400 MPa	-0.05
	600 MPa	-0.02

The dimensions of the pressed and sintered samples were measured with a micrometer with digital display. The dimensional change (ΔLDG) in % was determined using the following relation:

$$\Delta LDG = [(LS - LP) / LP] \times 100\%$$

where: LS is the length of sintered sample and LP is the length of pressed sample.

The dimensional change analysis that is presented in Table 7 indicated that the sample P_2 have a smaller dimensional change from die size as compared to the pure iron base P_1. The powder type and pressure applied are the major contributors to the final dimensional change values that were observed in this case. In powder metallurgy, it is important that the dimensional changes of the structural parts during sintering are as small as possible.

4. Conclusions

- The addition of alloying elements to the base materials is observed to improve the density.
- By pressing with a compaction pressure of 600 MPa is ensure an optimal compaction of the samples.
- The alloyed sample with Cu, Ni and Mo, P_2 can improve mechanical properties of sintered P/M alloys.
- The alloy compositions of the sintered steels for structural parts have to be carefully chosen not only with respect to the desire strength, but also with respect to the dimensional stability during sintering.
- The alloying elements distribution in the green compact can play a large role on the dimensional stability of a sintered part. As can be seen, the sample P_2 (pressed at 600 MPa) is having a dimensional stability higher compared with sample P_1.
- The shrinkage after sintering is the highest for the unalloyed sample P_1 -0.006% at 400 MPa and -0.03% at 600 MPa.

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