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Effect of induction hardening of Fe-C-Ni-Cu-Mo-B metal matrix composites by powder metallurgy for gear production

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ABSTRACT

Purpose: In this study, mechanical behavior of iron base (Fe-0.8 C-2.0 Cu-1.5 Ni-X Mo-Y B (%wt.), x=0.6, 1.2 and 1.8; Y=0.2, 0.6 and 1.0) metal matrix composite (MMC) by powder metallurgy was investigated for gear production. Effect of Mo and B elements on surface hardness, density and microstructure of the composite samples.

Design/methodology/approach: MMC has produced by warm compaction method followed by free sintering in controlled Ar gas atmosphere. Green composite has produced under 650 MPa pressure at 160°C temperature. The green products have been sintered at temperature of 1150°C and 60 min sintering time. Hardness test have been conducted before and after induction hardening. The microstructure of the samples have been examined before and after induction hardening under optical microscopy.

Findings: The results have showed that the highest surface hardness has been obtained X=1.8 and Y=1.0 composition. Addition of Mo and B elements does not affect on the density of the sample.

Research limitations/implications: The ability of induction hardening to composite material has been investigated.

Originality/value: The studies were carried out in experimental composition with warm compacting method.

Keywords: Powder metallurgy; Warm compaction; Induction hardening; Microstructure; Mechanical properties

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PROPERTIES

1. Introduction

The powder metallurgy PM technique is experiencing growth and replacing traditional metal-forming operations because of its low relative energy consumption, high material utilization. and low capital cost [1]. Therefore, some PM steels with high sintered density as well as high wear resistance have found wide application in the automotive industry, in engine and transmission systems. mainly for wear loaded components such as cam lobes etc [2].

Fe-Cu and Fe-Cu-C based PM parts are important to the industry. These parts are used in many applications that require high strength. hardness and wear resistance. Produced by powder metallurgy methods of Fe-based materials are used camshafts, connecting rods, sprockets, pulleys various valves, clutch adjustment rings, arm turbine converters. oil pump gears as many applications in the automotive industry [3].

The parts formed with the cold-pressing process in powder metallurgy method then different sintering methods are used for sintering (free sintering. hot press sintering. hot isostatic sintering. spark plasma sintering. microwave sintering etc.). In this study, the warm compaction method was used for performing of metal matrix composites. This technique consists in pressing a pre-heated powder in a heated die at a temperature typically ranging from 90 to 150°C. The green strength obtained from this approach is about two times higher than that provided by cold compaction [4-9]. By heating the powder mix and the press tool to 150°C an increase in density in the range 0.15-0.20 g/cm³ over conventional compaction was reported [10-11].

The aim of this study is to produce Fe-based (Fe-0.8C-2.0Cu-1.5Ni-XMo-YB (%)) metal matrix composite by warm compacting method for gear production. The effects of Mo (0.6-1.2-1.8%) and B (0.2-0.6-1.0%) additions were investigated on the hardness and the density.

2. Material and method

2.1. The powder preparation

The water atomized iron powder together with nickel, copper, molybdenum, boron and graphite with purity higher than 99%, were used for this experiment. The average diameters of particles were in the range of <68 μm for iron, <44 μm for copper, <37 μm for nickel, <88 μm for molybdenum, <15 μm for boron powder and graphite powder. The composition of powder mixture is 0.8 wt.% C, 2 wt.% Cu, 1.5 wt.% Ni, (0.6-1.2-1.8) wt.% Mo, (0.2-0.6-0.8) wt.% B, 0.6 wt.% zinc stearate and iron base. The chemical composition for different specimens is given in Table 1. In this study, effect of mechanical properties was investigated different amount of Mo and B powder. The powder mixtures were homogenized in a turbula mixer for 30 min.

Table 1.
Chemical compositions of materials

Material	Fe, wt.%	Ni, wt.%	Cu, wt.%	C, wt.%	Mo, wt.%	B, wt.%
1	94.9	1.5	2.0	0.8	0.6	0.2
2	94.5	1.5	2.0	0.8	0.6	0.6
3	94.1	1.5	2.0	0.8	0.6	1
4	94.3	1.5	2.0	0.8	1.2	0.2
5	93.9	1.5	2.0	0.8	1.2	0.6
6	93.5	1.5	2.0	0.8	1.2	1
7	93.7	1.5	2.0	0.8	1.8	0.2
8	93.3	1.5	2.0	0.8	1.8	0.6
9	92.9	1.5	2.0	0.8	1.8	1

2.2. Pressing

The pre-heated mixed powders were pressed in a steel mould (Fig. 1) at temperature from room temperature to 160°C. Compacting pressure was 650 MPa. Cylindrical specimens were obtained the dimension of 15x10 mm.

Fig. 1. The mould used in the pressing of the powder

2.3. Sintering

The re-pressed compacts were sintered with an argon atmosphere. The specimens were heated to 550°C at a heating rate 10°C/min and held at 550°C for 30 min in order to remove the lubricants. Then, continuously elevating the temperature to 1150°C and held for 60 min.

2.4. Induction hardening

High frequency current is applied to the metal for rapid surface heating. The heated part is rapidly cooled by using any cooling fluids. Parts were heated to 850°C temperature and parts rapidly cooled in high frequency induction bench. All compacts were welded by 2.5 kW, 900 kHz (high frequency) induction system for 10 second.

2.5. Microstructure

Metallographic sections were prepared by grinding, diamond polishing, and etching with 2% Nital for 5-10 s. The metallographic observations were conducted on a metal microscope Nikon Eclipse MA200. The microstructures of samples were examined both before and after hardening. Figures 2-4 shows the metallographic structure of the samples after nital etching.

2.6. Mechanical test

Hardness Test

Hardness tests were conducted in the INSTRON-WOLPERT macro hardness testers. HRA hardness values of the specimens were measured by using 60 kgf loads. Five hardness measurements were carried out for each sample and average value of hardness was presented (Fig. 8).

Density Test

Densities of samples were measured from 10x15mm pieces. The densities of the sintered samples were measured by Archimedes technique and the amount of porosity was calculated for each samples.

3. Description of results

3.1. Microstructure

Results of image analysis were obtained by Clemex Vision Pro. Figures 2-4 show microstructure previous of the material from hardening. When examined microstructures, it is observed that a homogenous dispersion. Regional gaps are not found.

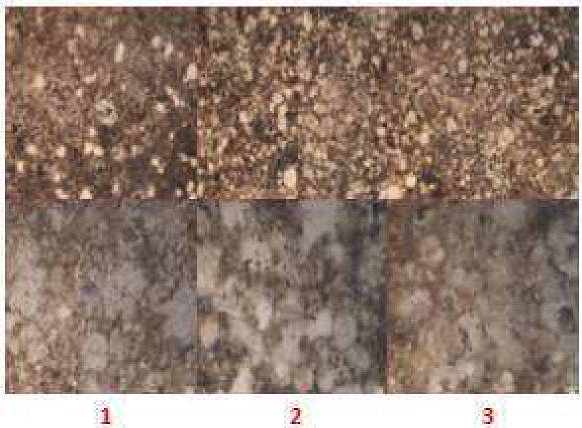

Fig. 2. Microstructure of samples number 1-3 before induction hardening (100x and 500x – 20 µm)

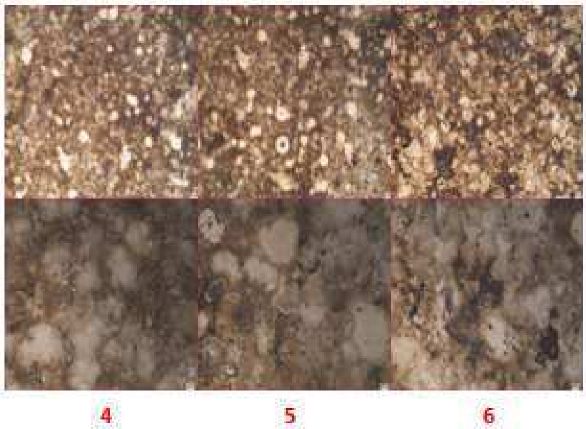

Fig. 3. Microstructure of samples number 4-6 before induction hardening (100x and 500x – 20 µm)

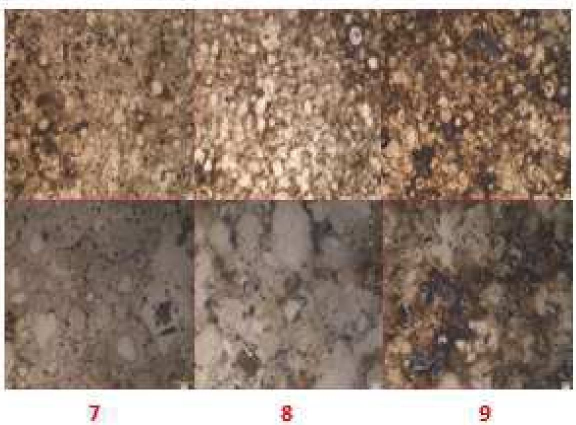

Fig. 4. Microstructure of samples material number 7-9 before induction hardening (100x and 500x – 20 µm)

In samples 1, 2 and 3, it was kept constant at 0.6% Mo, 1.5% Ni, 2.0% Cu, 0.8% C. Three different rates (%0.2-0.6-1.2) of addition of boron are made. Light colour regions indicate the grain of molybdenum. There are areas darker regions where is ferrite. It shows grey colour spots element boron. It is observed that the copper deposited at the grain boundaries in 500x magnification. It does not appear to cause major changes in the microstructure when amount of boron is increased. This is because of addition of low quantities of boron.

In samples 4, 5 and 6 it was kept constant at 1.2 % Mo, 1.5% Ni, 2.0% Cu, 0.8% C. Three different rates (%0.2-0.6-1.2) of addition of boron are made. It has increased the amount of pearlite with the increase of the amount of molybdenum in microstructure.

In samples 7, 8 and 9, it was kept constant at 1.2 % Mo, 1.5% Ni, 2.0% Cu, 0.8% C. Three different rates (%0.2-0.6-1.2) of addition of boron are made. It is seen that the amount of pearlite most in %1.2 boron addition. Molybdenum spread evenly provided due to the increase of the sintering temperature and time in the matrix.

3.2. Induction hardening microstructure results

After induction hardening the martensite phase is seen as intense in microstructure. Samples were hardened by the center as a small section of material. It leads to grain thinning with the increasing addition of boron.

Molybdenum is a strong carbide and nitride-forming element. It increased the hardenability it is used in conjunction with nickel. Martensite and regional bainite structure are increasing with the increase of the amount of molybdenum in the composition (Figs. 5-7).

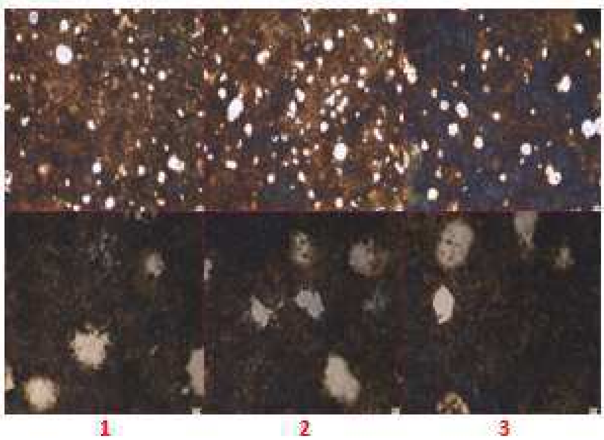

Fig. 5. Microstructure of samples material number 1-3 after induction hardening (100x and 500x – 20 µm)

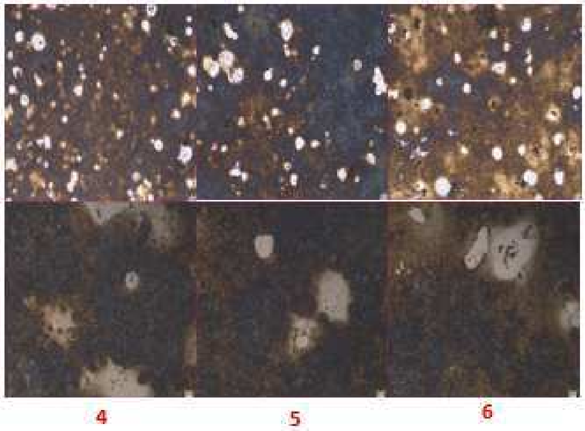

Fig. 6. Microstructure of samples number 4-6 after induction hardening (100x and 500x – 20 µm)

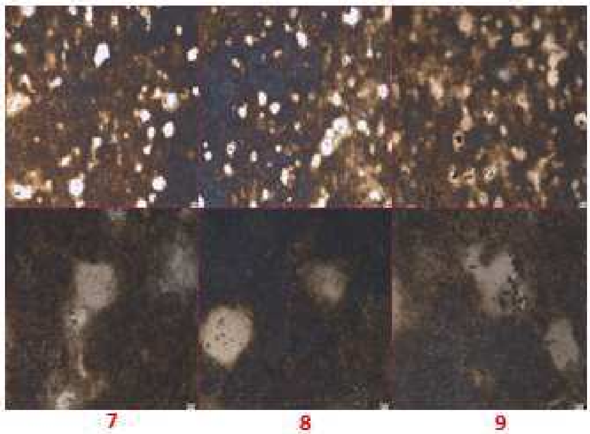

Fig. 7. Microstructure of samples material number7-8 after induction hardening (100x and 500x – 20 µm)

3.3. Density

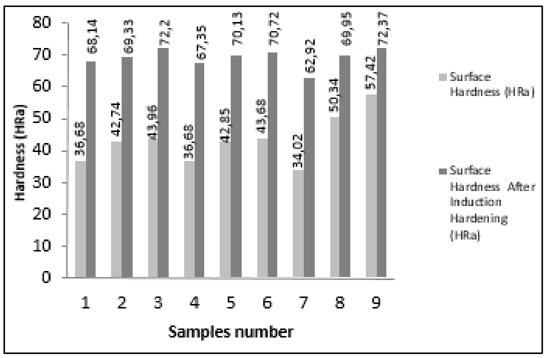

Fig. 8. Hardness measurement results

The densities of sintered samples were measured by Archimedes technique and the porosities in the samples were calculated. The results are shown in Table 2.

Table 2.
Sintered density and porosity samples

Sample	ρ_{theo}, g/cm^3	ρ_{exp}, g/cm^3	%Porosity
1	7.86	6.97	11.28
2	7.83	7.07	9.75
3	7.81	6.98	10.65
4	7.87	6.98	11.38
5	7.85	7.05	10.23
6	7.83	6.94	11.32
7	7.89	6.97	11.67
8	7.86	7.00	10.98
9	7.84	6.90	12.07

4. Conclusions

Another contribution of alloying elements in ferrous P/M parts results in improving of hardenability. Hardenability is increased in powder due to increased amounts of copper and nickel in alloy P/M parts. Lower molybdenum addition is influenced the solid solution hardening in ferrous P/M parts. Molybdenum is improving the hardenability when dissolved carbon [12].

The warm compaction parameters (P, T and t) were kept constant in this study. So the effect of the density has not been of composite materials. The average ranges from 10-12% porosity ratio of the material. It is necessary to increase the sintering temperature and time to reduce the amount of porosity.

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