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Effect of copper on the mechanical properties of alloys formed by powder metallurgy

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ABSTRACT

Alloys formed by powder metallurgy are typically porous, which reduces their strength. In this study, we attempt to improve the mechanical properties of an alloy composed of 0.6 wt% C, 1.0 wt% Ni, 0.3 wt% Mo, 0.7 wt% Mn and the balance Fe by addition of 8 wt% Cu. To form the alloys, powders are blended and compacted in a dual-action hydraulic press and then sintered in a furnace at 1150 °C. Alloys with and without Cu are used in specific parts designed for impact testing. Stress analysis is performed using ANSYS, which validates the operation of the parts. The strength of the body geometry according to its design is determined by considering the manufactured material and the loads that it is subjected to during operation. SEM images revealed that the alloy without Cu contains martensite and bainite phases with large, irregular pores. In contrast, the alloy with Cu has a considerably lower pore concentration. During sintering, Cu forms a liquid phase that can fill the spaces between the particles of the alloying powders. The result is an alloy with increased density and toughness; the density of the alloy increases from 7.2 to 7.8 g/cm^3 upon addition of Cu, and its toughness increases from 22 to 34 J.

1. Introduction

With the growing demand for metallic components in the metalworking industry, powder metallurgy (PM) can be used to produce components with complex geometries, reduce machining costs and compete with other forming processes for large-scale production [1]. PM can be used to form multiple compositions by blending pre-alloyed or elemental powders [2]. However, the elements obtained using PM are porous. Generally, components that are subjected to impact loads during their operation are manufactured from steels produced by a continuous caster. Components produced by PM with the ability to tolerate high stresses can be obtained by sinter hardening, which yields a microstructure such as tempered martensite or bainite.

To produce good-quality components using PM, the porosity distribution must be homogeneous because heterogeneity has a negative effect on mechanical properties [3,4]. The porosity of components produced by PM is usually in the range of 5–15% depending on the compressibility of the alloying powders, carbon content and added lubricant. The pores are potential crack initiation sites, and can also guide and propagate cracks through the material. According to Bergmark and Alzati [5], a strong microstructure may be obtained by incorporating small amounts of alloying elements to compensate for the microcracks formed by pores.

Copper (Cu) is the most common alloying element added in powder form because of its low cost, availability and ability to improve the properties of alloys. Cu powder is blended with the master alloy, alloying element(s), lubricant and graphite. Cu can have a large effect on the mechanical performance of the resulting material. Copper melts at 1083 °C [6] and disperses well in the master alloy because of the capillary forces present as a result of the transition to a liquid phase during the sintering process. As a result, Cu helps to increase the toughness and density of the resulting alloys by filling pores [7]. The ability of Cu to improve the properties of alloys has been demonstrated. For example, Sanderow and Rivest [8] found that Cu infiltration provided a mix of phases that improved the mechanical properties and tempered hardness of prealloyed steel powders. Chawla et al. [9] determined that addition of 1.5 wt% Cu to an alloy containing Fe, Mo and graphite resulted in an increase in proportional limit stress, ultimate tensile

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Table 1
Chemical compositions and properties of alloys.

	Fe (%)	C (%)	Ni (%)	Mo (%)	Mn (%)	Cu (%)	Apparent density (g/cm^3)	Flow rate (s/100 g)
Alloy 1 (without Cu)	97.42	0.6	1	0.86[a]	0.12[a]	–	3.13	58.2
Alloy 2 (with Cu)	89.42	0.6	1	0.86[a]	0.12[a]	8	3.5	56.8
Particle size (μm)	<10	45	40	25	45	33		

[a] Prealloyed.

Table 2
Mechanical properties of the alloys following sinter hardening.

Material	Elastic limit (MPa)	Tensile strength (MPa)	Young's modulus	Poisson's ratio	Hardness (HRc)	Toughness (J)	Density (g/cm^3)
Alloy 1 (without Cu)	520	1600	160	0.28	30	22	7.2
Alloy 2 (with Cu)	480	690	155	0.28	35	34	7.8

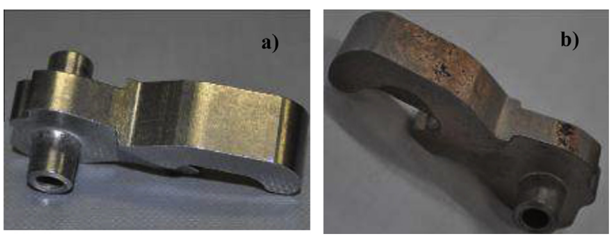

Fig. 1. Photographs of parts composed of (a) Alloy 1 without Cu and (b) Alloy 2 with Cu.

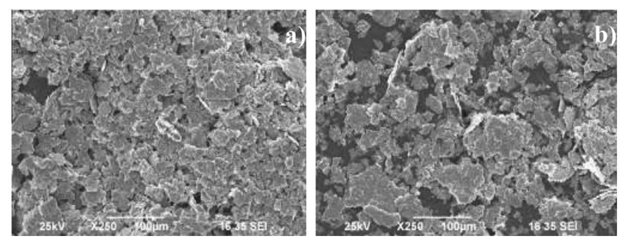

Fig. 3. SEM micrographs of the alloys after 10 h: (a) Alloy 1 without Cu and (b) Alloy 2 with Cu.

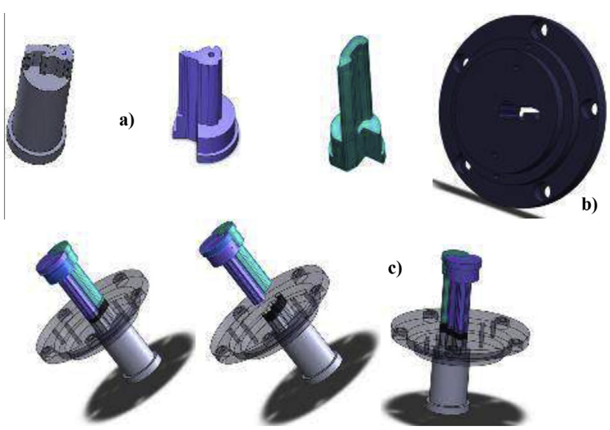

Fig. 2. (a) Compaction punches, (b) compaction matrix, and (c) the compaction tool ensemble used to produce parts.

strength, and fatigue strength over those of the Cu-free alloy. Takaki et al. [10] investigated the tensile properties and grain size of alloys containing 0–4 wt% Cu. They found that an increased proportion of martensite, which increased with Cu content, improved the strength-ductility balance of the alloys. Lowhaphandu and Lewandowski [11] examined the effect of infiltration of 10 vol% Cu on the monotonic fracture resistance and fracture crack growth behavior of PM-processed porous plan carbon steels exposed to different heat treatment conditions. They found that the Cu-infiltration samples possessed superior fracture toughness and fatigue properties compared with the porous matrix material lacking Cu. Bernier et al. [12] helped to improve our understanding of the role of Cu in strengthening sintered steel parts through detailed characterization of the microstructure, hardness and transverse rupture strength of Cu-infiltrated steel samples. They quantified the strengthening effect of Cu in pearlite and martensite and observed nanometer-sized copper precipitates in the doped steel

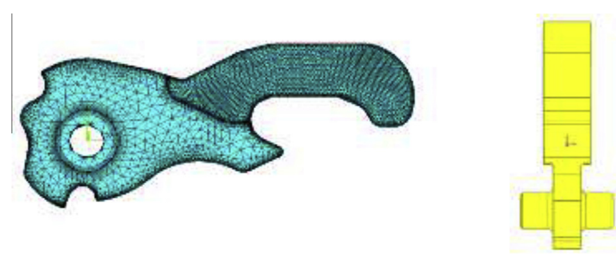
Fig. 4. Center of mass of the analyzed part.

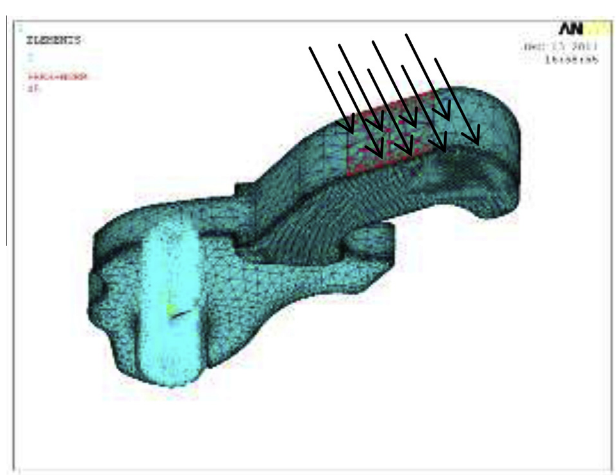

Fig. 5. Direction and placement of impact on part.