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Sintered Properties of 409L Powder Compacts Influenced by Metal Powder Additives

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Abstract

Sintering of powder compacts, prepared by admixing of 409L powder with 2-6 wt.% of copper and nickel powders was investigated. It was observed that the strength of the 409L-Cu specimens increased with increasing Cu content. In contrast, sintered density and elongation decreased with increasing Cu content due to swelling effect. When 2 wt.% of Ni powders were added, sintered density and strengths were maximized. When Ni contents higher than 2 wt.% , the decrease of sintered density and strengths were attributed to the number of pores left by the original sites of Ni powder particles.

Key Words : sintering, stainless steel, 409L, copper additive, nickel additive

Introduction

Elemental Cu and Ni powders are usually employed as additives for making alloys via conventional 'press and sinter' powder metallurgy (P/M). In industrial practice, copper powder is added to iron (Fe) powders to make the Metal Powder Industries Federation (MPIF) alloy grade FC-XXXX whereas Ni addition is for making FN-XXXX.(1) Alloying element powders used for producing P/M ferrous alloys should be sintered without difficulty in the same atmosphere normally used for iron.(2)

Previous studies revealed that sintered density of the 409L stainless steel was strongly dependent on densification methods.(3) The Cu-infiltrated 409L stainless steel showed higher density when Cu content is increased. In contrast, the sintered parts made from the admixed 409L-Cu powder exhibited lower density when Cu content is increased. Studies had been extended to investigate on the effects of Cu powder particle size and composition on densification behavior of 409L-Cu powder compacts.(4) It was observed that the strength of the sintered specimens increased with increasing Cu content. In contrast, sintered density and elongation decreased with increasing Cu content. Addition of Cu powder of up to 2 wt. % provided optimum density and mechanical properties. Admixing of smaller Cu powder particles (<32 μm) yielded higher sintered density than that of larger Cu powder particles (as-received and 63-90 μm). Pure and infiltrated grade Cu powders caused similar effects on mechanical properties of sintered specimens.

In this article, the effects of Ni powder addition on densification and mechanical properties of the sintered 409L-Ni compacts has been studied. Experimental results were compared to those of the sintered 409L-Cu materials.(4)

Experimental Procedures

Water atomized 409L stainless steel powder ($D[4,3]$ = 91 μm) was either admixed with 2, 4, or 6 wt.% of copper and nickel powders. The copper and nickel powders had an average particle size ($D[4,3]$) of 28 and 32 μm, respectively. The admixed powders were uniaxially compacted at 600 MPa into 7 tensile test bars (ASTM E 8-96) for each condition. The green test bars were delubricated at 600°C for 1 hour under argon atmosphere and sintered at 1350°C for 45 minutes under pure hydrogen atmosphere. Sintered density and mechanical properties of the sintered test bars were measured. Microstructures of the sintered samples were also observed using optical microscopy.

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Results & Discussion

Sintered Density

Sintered density of the sintered 409L-Cu materials decreased with increasing Cu powder content (Figure.1) Decrease of sintered density is directly caused by swelling phenomenon.[2, 3] Swelling is mainly the result of penetrating, wetting of the grain boundaries and pushing the 409L grains apart by molten Cu. Decrease of sintered density of the sintered 409L-Cu materials is also attributed to pore size expansion (see the microstructure in #(3.3)).

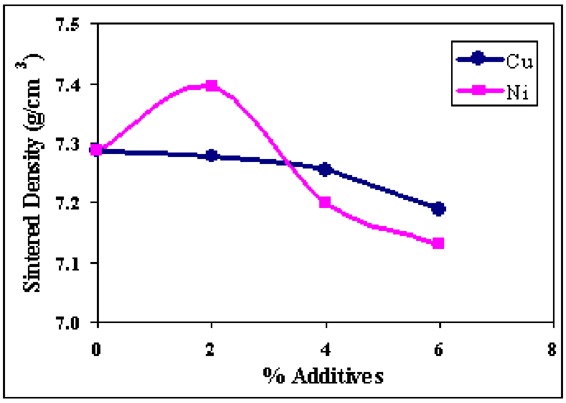


Figure 1. Sintered density of 409L.

The sintered 409L-Ni materials also exhibited a decrease of sintered density with increasing Ni powder amounts. Sintering of the 409L-Ni powder compacts occurred via solid state type. No liquid phase was formed during sintering process. The microstructure of the sintered 409L-Ni material (see the microstructure in #(3.3)) indicates that Ni atoms diffused into 409L particle matrix. Solid state transportation of Ni atoms is speculated to result in pore formation at the original sites of Ni powder particles.

Mechanical Properties

Increases of tensile strengths and hardness with increasing additive powder contents were observed both in the sintered 409L-Cu and 409L-Ni materials (Figures.2, 3 and 5). Improved tensile strengths and hardness are probably caused by solid solution strengthening, which is the result of Cu or Ni atom diffusion into the 409L matrix during sintering process. Precipitation hardening may be another reason for the increase of strength and hardness, which will be further studied in the near future.

The sintered 409L-2%Ni exhibited maximum tensile strengths and hardness. The tensile strengths of the sintered 409L-Ni materials are increased by solid solution strengthening. However, diffusion of Ni particles leaves pores behind. The pores cause detrimental effect on strengths.

Elongation of the sintered 409L-Cu and 409L-Ni materials decreased drastically with increasing Cu or Ni powder contents (Figure. 4) Ductility of the sintered materials depends on several factors such as the number of sintered necks between 409L particles, pore size and shape, strengthening effect from Cu or Ni atoms and the presence of new phase. It was hard to compare the number of sintered necks in the microstructures of the sintered materials (#(3.3)). However, the pore size and shape in the sintered 409L-Cu and 409L-Ni materials were seemingly responsible for decreased ductility. In the sintered 409L-Cu materials, some irregular-shape brownish seams, which were saturated solid solution of Cu in 409L, were also responsible for decreased ductility.

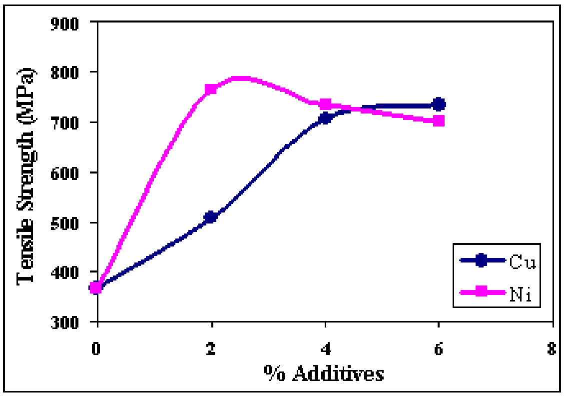


Figure 2. Ultimate tensile strength of 409L.

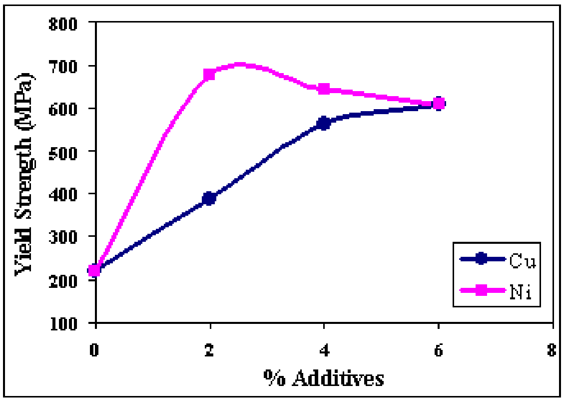


Figure 3. Yield strength of 409L.

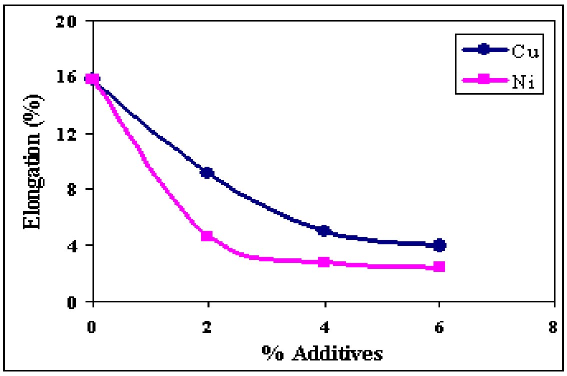


Figure 4. Elongation of 409L.

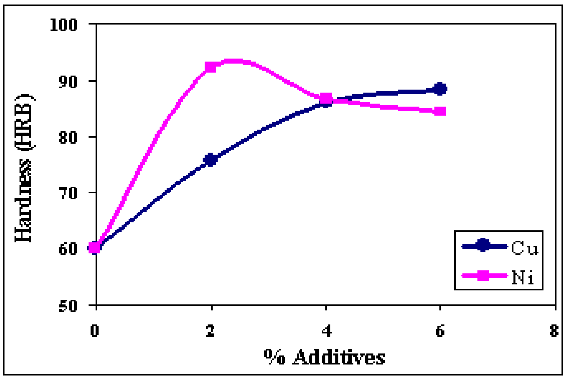
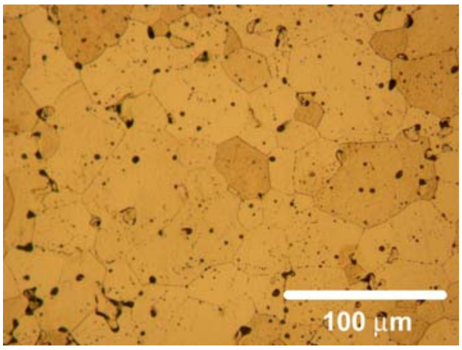


Figure 5. Hardness of 409L.

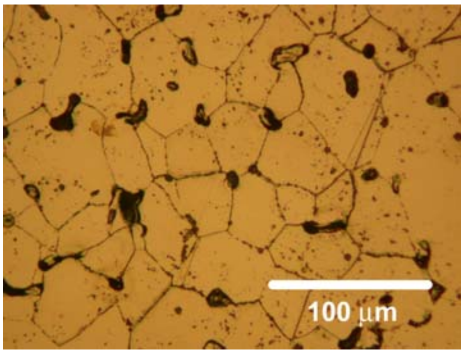
Microstructure

Examples of microstructures of the sintered 409L are shown in Figure 6. The microstructure of the sintered 409L material (Figure. 6(a-c)) showed equiaxed ferritic grains surrounded by grain boundaries and small pores. Sintering of the Cu-added 409L powder compacts (with ≥ 4 wt.% Cu powder) resulted in inhomogeneous distribution of Cu in the 409L matrix (Figure.6(d-f)). Regions of high copper concentration appeared as irregular-shape brownish seams along grain boundaries and on former 409L particle surfaces. The irregular-shape brownish seams were speculated to be saturated solid solution of Cu in 409L matrix. This type of microstructure was similar to that of the sintered Cu-added Fe materials (with Cu powder contents of up to 4 wt. %)[5]

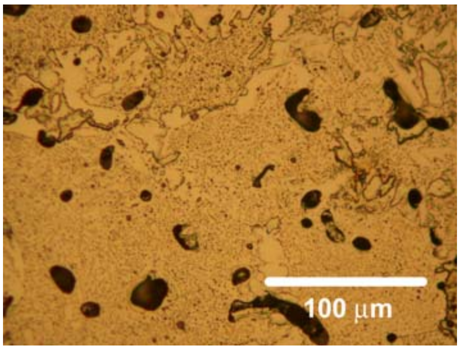
The microstructure of the sintered 409L-Ni material (Figure.6(g)) showed similar features to that of the sintered 409L material. Only the pore size in the sintered 409L-Ni material was larger. The bigger pores were created by disappearance of Ni particles due to Ni atoms diffusion into 409L grains during sintering process.



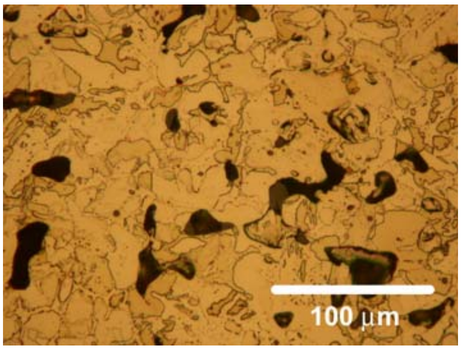
(a) 409L



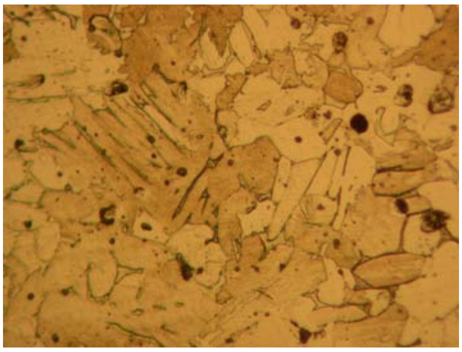
(b) 409L-2%Cu



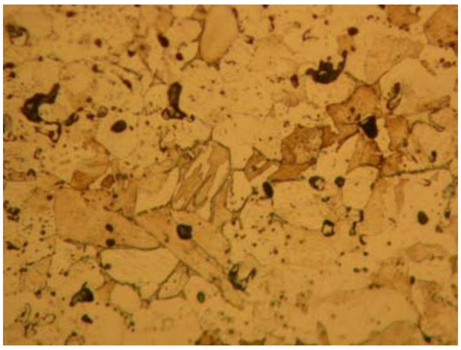
(c) 409L-4%Cu



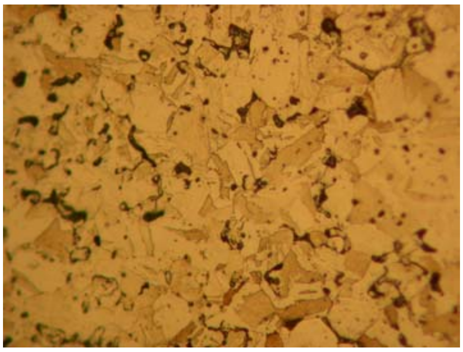
(d) 409L-6%Cu



(e) 409L-2%Ni



(f) 409L-4%Ni



(g) 409L-6%Ni

Figure 6. Microstructures of the sintered 409L, 409L-Cu and 409L-Ni materials at the same resolution (Glyceregia etched).

Conclusions

When 2-6 wt. % of Cu powder were added to 409L powder, tensile strengths and hardness of the sintered 409L-Cu materials increased with increasing Cu powder content, while sintered density and elongation decreased. Sintered density decrease was due to swelling effect and pore size expansion. Reduction of ductility of the sintered 409L-Cu was due to the presence of irregular-shape brownish seams along grain boundaries and on former 409L particle surfaces.

When 2 wt. % of Ni powders were added to 409L powder, sintered density and strengths were maximized. But when Ni contents higher than 2 wt. % were added, sintered density and strengths were decreased. These were attributed to the number of pores left by the original sites of Ni powder particles.

Acknowledgement

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References

1. German, R.M. 1998. *Powder Metallurgy of Iron and Steel.*New York : John Wiley & Sons.

2. Engstrom, U. 2003. Copper in P/M Steels. *Int. J. Powder Metall.* **39(4)** : 29-39.

3. Coovattanachai, O. 2002. *Infiltration and Liquid Phase Sintering of Stainless Steel Powder Type 409L with Copper.* Master Thesis, Chulalongkorn University, Bangkok, Thailand.

4. Coovattanachai, O., Tosangthum, N. and Tongsri, R. 2004. Densification Behavior of 409L+Cu Powders Compacts. In : *Advances in Powder Metallurgy and Particulate Materials.* Princeton. N.J. : Metal Powder Industries Federation. (7-137) - (7-147).

5. Hoganas, A.B. 1997. *Hoganas Handbook for Sintered Components, Handbook* **3** : 9.15-9.30.