Chiang Mai J. Sci. 2006; 33(1) : 45-52
www.science.cmu.ac.th/journal-science/josci.html
Contributed Paper

Effect of Admixing Ni and Cu Powders on Property of Sintered 316L Alloy

Nattaya Tosangthum*, Ornmanee Coovattanachai, Rungtip Krataitong, Monnapas Morakotjinda, Anan Daraphan, Bhanu Vetayanugul and Ruangdaj Tongsri
National Metal and Materials Technology Center (MTEC), Thailand Science Park, 114 Paholyothin Rd., Klong Luang, Pathum Thani 12120, Thailand.
*Author for correspondence, e-mail : nattayt@mtec.or.th

Received : 14 June 2005
Accepted : 23 September 2005

ABSTRACT

The 316L stainless steel powder was admixed with elemental Ni and Cu powders. The amounts of Ni and Cu powders, with particle sizes of less than 32 μm, were varied from 0 to 10 wt.%. The admixed powders were compacted into tensile test bars with green density of 6.58 g/cm^3. Sintering of the compacted test bars was carried out in pure hydrogen at 1300 °C for 45 minutes. It was observed that increasing Ni content in the 316L+Ni alloys resulted in improved tensile properties. In contrast, addition of Cu to the 316L+Ni alloys yielded inferior mechanical properties, compared to the 316L+Ni alloys. The Cu powders tended to compensate shrinkage regardless the amounts of Ni powders used for admixing.

Keywords: 316L stainless steel, powder admixing, property

1. INTRODUCTION

AISI 316L stainless steel powder has been used to replace P/M ferrous alloys due to its superior mechanical properties and corrosion resistance. P/M 316L stainless steel parts are used in several applications such as aerospace, agriculture, appliances, automotive, building and construction, chemical, electrical and electronic, hardware, industrial, jewelry, marine, medical office equipment, recreation and leisure [1]. Due to requirement for improved performance of P/M austenitic stainless steels, modifications of these materials may be performed either by using prealloying, premixing or admixing methods.

Admixing of austenitic stainless steel powder with some elemental powders has been employed to modify the material properties. Small amount of carbon added to 304L austenitic stainless steel powder acted as internal reducing element, which caused reduction of chromium oxides and concentration of non-metallic elements [2]. Silicon powder admixed to standard SAE 304L powder modified microstructures of the stainless steel after sintering, depending on silicon content [3]. It has been found that the corrosion resistance of the sintered mixture (316L stainless steel containing nickel base additives) increased substantially and proportionally to the brazing (nickel base) powder content in the range 1 wt.% to 5 wt.% [4]. Addition of nickel and aluminium powders to 316L stainless steel powder caused formation of a transient liquid phase during sintering [5]. The transient liquid phase reaction, between iron-nickel and aluminium to form an intermetallic $(Fe, Ni)_3Al$, modified densification of 316L stainless steel powder and resulted in change of its macrohardness and corrosion resistance. Boron powder was one of the additives admixed with 316L stainless steel powder [6]. It has been found that corrosion resistance of P/M 316L could be improved several-fold, to levels similar to those of wrought 316L, *via* addition of small amounts of boron, when combined with good sintering practice.

Nickel (Ni) and copper (Cu) powders are common elemental alloying additives admixed with iron powders [7]. Addition of nickel and copper powders to austenitic 316L stainless steel powder may modify densification behaviors and mechanical properties of the sintered tensile test bars made from the admixed 316L+Ni+Cu powders. Dimensional change, tensile property, hardness and microstructure of the sintered specimens of the admixed powders have been investigated in this study.

2. MATERIALS AND METHODS

Admixed powders were prepared by mixing of water atomized AISI 316L stainless steel powder, with varied amounts (0-10 wt.%) of fine nickel (Ni) powder with particle size < 32 μm and varied amounts (0-4 wt.%) of fine copper (Cu) powder with particle size < 32 μm. Tensile test bars were produced by compacting the admixed powders into standard tensile test bars (MPIF standard 10, ASTM B783) with green density of 6.58 g/cm^3. The green tensile test bars were sintered at 1300°C for 45 minutes in pure hydrogen atmosphere. Dimensions of the sintered tensile test bars (Figure 1) were measured. Dimensional changes at selected dimensions were calculated with respect to tooling component dimensions. Sintered density was measured by using MPIF standard 42. Microstructural observation was performed by using optical microscopy. Mechanical (tensile) properties of the sintered specimens were measured using a universal testing machine. Hardness of the sintered specimens was carried out using a hardness tester (Rockwell scale B).

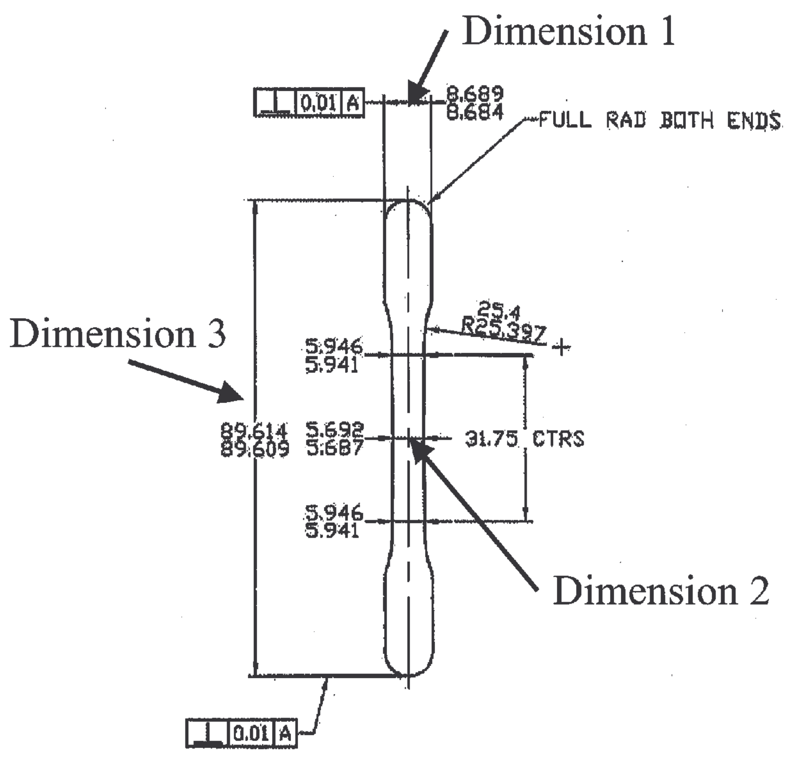


Figure 1. Selected dimensions for shrinkage measurement on the sintered tensile test bar.

3. Results and Discussion

3.1 Effect of Ni and Cu Powders on Sintered Density

Density of the sintered 316L+Ni tensile test bars increased with increasing Ni powder content (Figure 2). Increase of sintered density with increasing Ni amount may be attributed to diffusion of Ni atoms into the austenitic matrix [4]. Elemental or Ni alloy powders activate sintering of the Ni-containing admixed powder compacts.

When Cu powders (up to 4 wt.%) were added, densification behavior of the 316L+Ni+Cu compacts was affected by Cu content. Sintered densities of the 316L+Ni+Cu tensile test bars were significantly lower than those of the 316L+Ni (Figure 2). Generally, increasing Cu content in the 316L+Ni+Cu compacts resulted in lower sintered density. However, experimental errors could be observed for the 316L+2 wt.%Ni+2wt.%Cu and 316L+4wt.%Ni+2wt.%Cu. Cause of the error was not understood. Lower sintered density of the 316L+Ni+Cu tensile test bars may be attributed to liquid phase sintering. Some phenomena caused by formation of the liquid Cu phase and interaction between the liquid Cu and Ni powder may occur. Some of the liquid phase may fill the pores or penetrate, due to capillary effect, along the boundaries between the 316L stainless steel powder particles. Some may diffuse into the austenitic matrix to from solid solution and/or precipitation. The possible reason for low sintered density is a typical swelling effect caused by Cu powder. Swelling effect has been reported in P/M iron-copper alloys [7]. Swelling in iron-copper alloys is mainly the result of molten copper penetration, wetting of the grain boundaries and pushing the iron grains apart.

Shrinkage of the sintered tensile test bars at different dimensions was lowered when higher Cu powder content was added to the admixed 316L+Ni powders (Figure 3). Reduction of shrinkage by Cu addition is also resulted from swelling effect. Pushing the 316L grains apart would reduce material volume change from green to sintered parts.

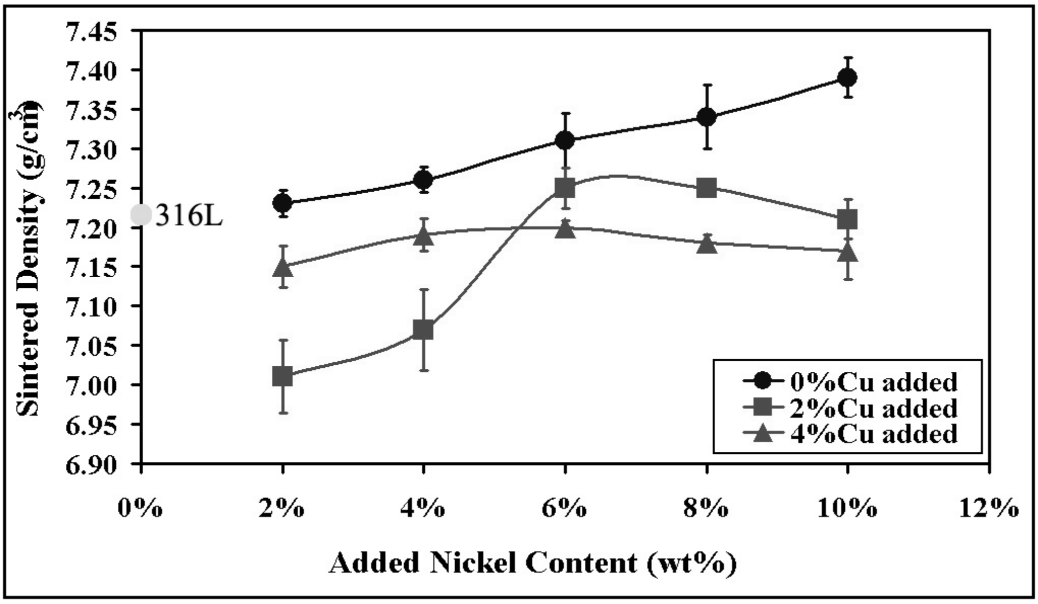


Figure 2. Effect of alloying powders on density of the sintered specimens.

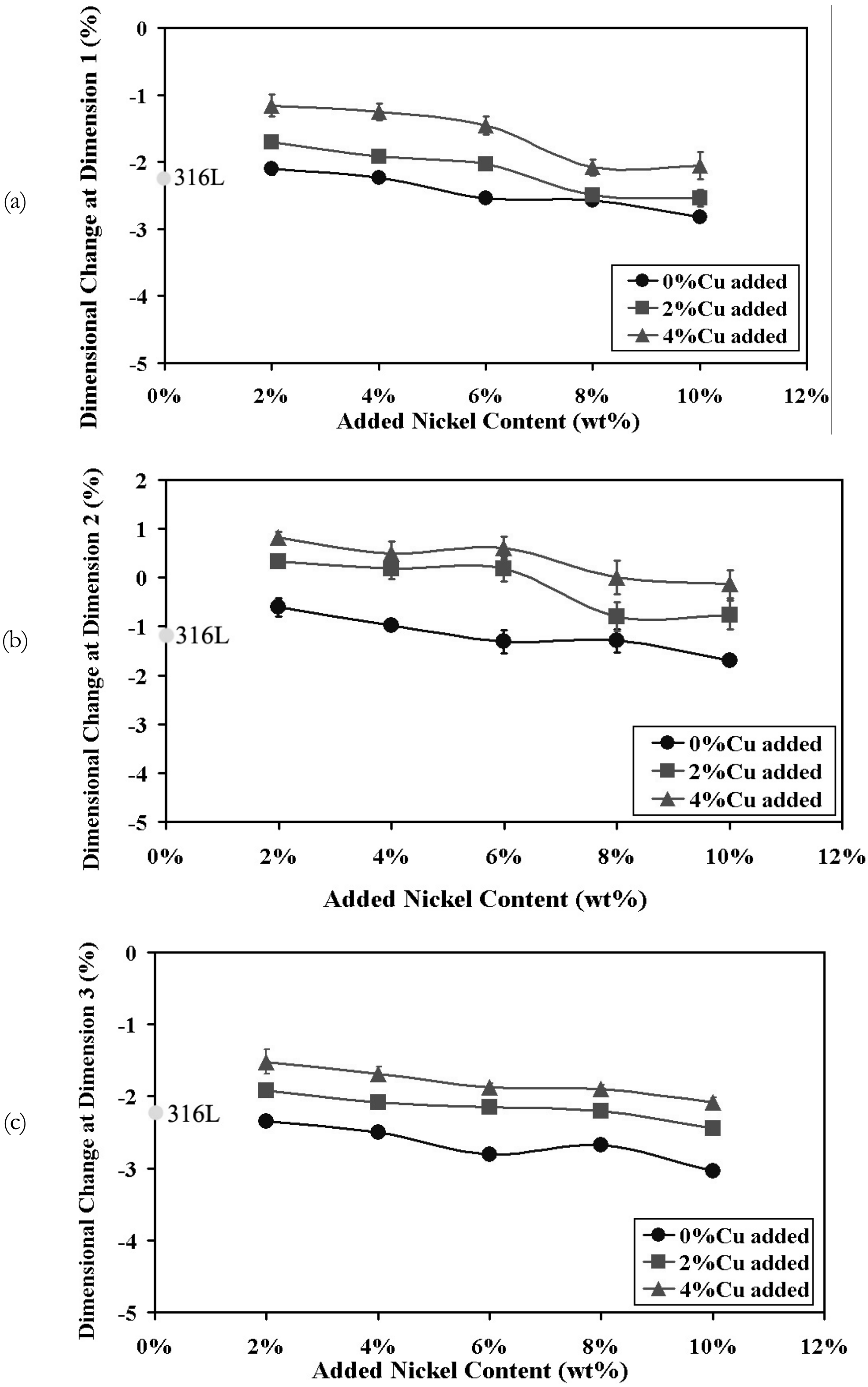
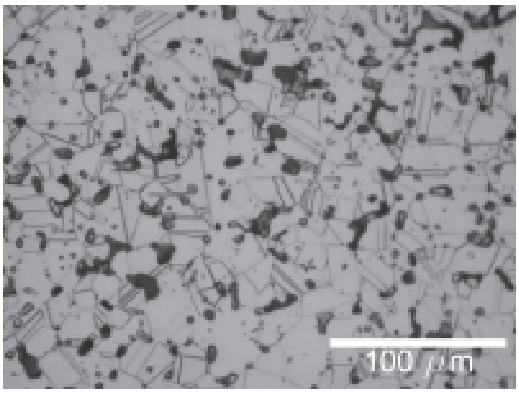


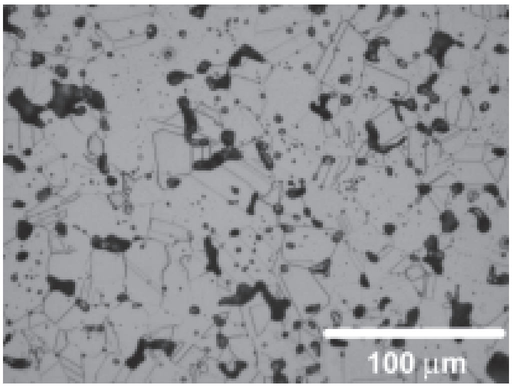
Figure 3. Shrinkage of the sintered tensile test bars made from the admixed powders at different dimensions; (a) dimension 1, (b) dimension 2 and (c) dimension 3.

3.2 Effect of Ni and Cu Powders on Microstructure

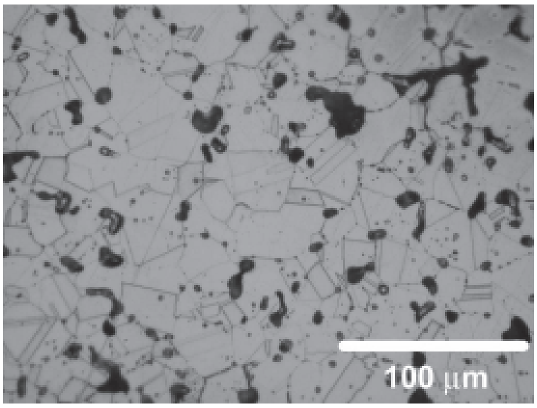
Microstructures of the tensile test bars exhibited austenitic grains with typical twinning inside and a few open interconnected pores. It was observed that addition of Ni powder to 316L stainless steel powder improved microstructure of the sintered tensile test bars. Number of open interconnected pores and pore sizes in the sintered 316L+Ni alloys were apparently decreased with increasing Ni powder content. Addition of Cu powder to the admixed 316L+Ni powders resulted in slightly increasing pore sizes. Examples of the micrographs are shown in Figure 4.



(a) 316L + 6 wt.% Ni



(b) 316L + 6 wt.% Ni + 2 wt.% Cu



(c) 316L + 6 wt.% Ni + 4 wt.% Cu

Figure 4. Microstructures of the sintered test bars made from the admixed powders with different compositions.

3.3 Effect of Alloying Powders on Mechanical Property of the Sintered Specimens

It has been found that mechanical properties such as ultimate tensile strength (UTS), 0.2% yield strength (0.2 % YS) and elongation increased with increasing Ni powder content of up to 8 wt.% (Figure 5 (a) through (c)). These properties were directly affected by sintered densities. When Ni powder content of up to 10 wt.% was added to the 316L powder, hardness of the sintered tensile test bars increased slightly with increasing Ni powder content (Figure 5(d)). Increased Ni content in wrought austenitic stainless steels, regardless chromium content, does not affect hardness of the annealed materials [8]. With hypothesis that complete diffusion of Ni atoms into the austenitic phase matrix occurs during sintering, new P/M

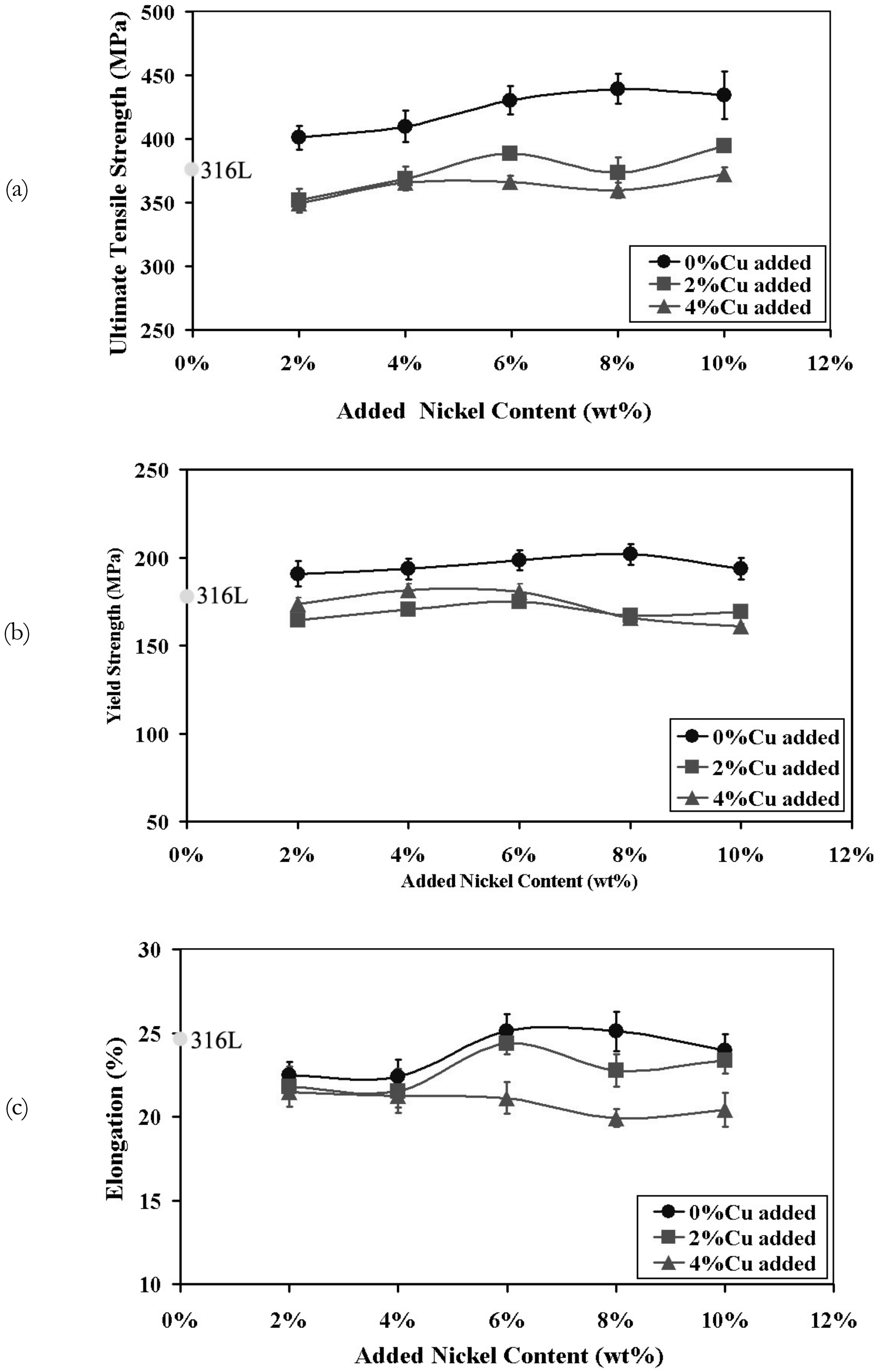


Figure 5. Influence of Ni and Cu powders on mechanical properties of the sintered tensile test bars made from the admixed powders; (a) UTS, (b) 0.2% yield strength, (c) elongation and (d) hardness.

(d)

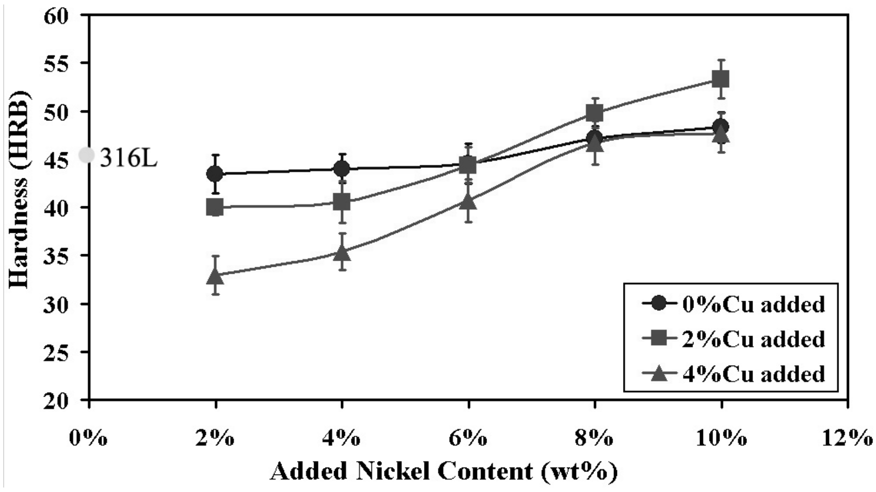


Figure 5. (Continue)

stainless steel alloys obtained by addition of up to 10 wt.% Ni will exhibit slightly increased hardness.

When Cu powder (up to 4 wt.%) was added to the admixed 316L+Ni powders, decrease of tensile properties (UTS, 0.2% YS and elongation) of the sintered 316L+Ni+Cu test pieces were obviously noticed. Inferior tensile properties of the sintered 316L+Ni+Cu tensile test bars may be attributed to sintered density, which is directly affected from swelling effect.

For the sintered 316L+Ni+Cu tensile test bars, significant increasing hardness with increasing Cu powder content was observed in Figure 5 (d). The reason for hardness increase is not yet known. However, it is speculated that some forms of precipitation may be present in microstructures of the sintered test pieces. Microstructural observation with higher magnification and chemical analysis is recommended here for further investigation.

4. Conclusions

Sintered density and mechanical properties of P/M AISI 316L stainless steel parts can be improved by admixing with elemental Ni powders. The composition of the admixed powders, which exhibits optimum mechanical properties and hardness is 316L+6wt.%Ni. Addition of Cu powder to the admixed of 316L+Ni powders results in decrease of sintered density and mechanical properties. Addition of Cu powder to the admixed 316L+Ni powders reduces shrinkage after sintering of the test pieces made from them.

Acknowledgements

The authors express their gratitude to National Metal and Materials Technology Center (MTEC), Pathum Thani, Thailand, for financial support.

References

[1] Reinshagen J.H., and Neupaver A.J., Fundamentals of P/M Stainless Steels, *Advances in Powder Metallurgy*, 1989, 283-295.

[2] Yikun W., HeYi L., Yi D., and Chuanxi L., Effect of Carbon, Silicon, and Aluminium on Surface Reaction of Austenitic Stainless Steel Powder During Sintering, *Advances in Powder Metallurgy and Particulate Materials*, 1992, 353-362.

[3] Sharon A., and Itzhak D., Mechanical Properties of Sintered Austenitic Stainless Steel-Effect of Silicon Addition, *Advances in Powder Metallurgy and Particulate Materials*, 1992, 373-384.

[4] Sharon A., Melman N., and Itzhak D.,

Corrosion Resistance of Sintered Stainless Steel Containing Ni-Base Additives, *Advances in Powder Metallurgy and Particulate Materials*, 1992, 399-408.

[5] Rosso M., Porto G., and Wood J.V., Properties of High Density Sintered 316L Stainless Steels, *Advances in Powder Metallurgy and Particulate Materials*, vol. 5, compiled by T. M. Cadle and K. S. Narasimhan, Metal Powder Industries Federation, Princeton, NJ, pp. 1996, (17-87)-(17-9).

[6] Samal P.K., and Terrell J.B., Corrosion Resistance of Boron Containing P/M 316L, *Advances in Powder Metallurgy and Particulate Materials*, 2000, (7-17)-(7-31).

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

[8] Kovach C.W., and Redmond J.D., Austenitic Stainless Steels, *Practical Handbook of Stainless Steels and Nickel Alloys*, ASM International, Ohio, 1999, 159-179.