

Sintered Materials Prepared from Stainless Steel Series 300 and 400 Powders

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Received Mar. 4, 2008

Accepted May. 1, 2008

Abstract

Some sintered materials were prepared from mixtures of stainless steel series 300 and series 400 powders. The sintered stainless steels consisted of both austenitic and ferritic phases so they were designated as sintered duplex stainless steels (SDSSs). Microstructures and properties of the SDSSs were characterized and tested. Most SDSSs, except the 310L powder-base SDSSs, showed improved tensile strengths and hardness but exhibited inferior ductility, compared to those of the sintered stainless steels series 300. The 304L-410L SDSS showed promising mechanical properties. This SDSS were further investigated by varying weight ratio of 304L and 410L powders. It was found that sintered densities of the 304L-410L SDSSs were lower than those of the sintered 304L or 410L alloys. The 304L-410L SDSSs exhibited increased tensile strengths and hardness with scarified elongation, when the 410L powder content was increased. The SDSS prepared from 25 wt. % of 304L and 75 wt. % of 410L showed the highest strengths and hardness.

Key Words : Stainless steel powders, sintered materials

Introduction

Sintered 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⁾ Most of research activities were carried out with sintering of straight stainless steel powder grades.⁽²⁾

There were a few research works relating to development of a stainless steel from a mixture of stainless steel powders with different grades. The development of a duplex stainless steel (DSS) is one of many examples of alloy property improvement. The DSS refers to a stainless steel, whose microstructure contains both austenitic and ferritic phases.⁽³⁾ This alloy exhibits superior mechanical properties and corrosion resistance,

compared with those of typical stainless steels (austenitic, ferritic, and martensitic). The outstanding properties of the dual phase stainless steel arise from a combination of phase advantages. Because of their excellent properties, DSS are applied in a wide range of industries, especially in corrosive environments such as off-shore construction, heat-exchanger and gas/oil pipelines.⁽⁴⁾ Wrought DSS is common in the metallurgical world. However, to produce this type of alloy presents some fabrication difficulty. To obtain a dual phase microstructure, high accuracy temperature control and high metallurgist experience are needed for manufacturing of the alloy.

In this article, properties of sintered austenitic-ferritic stainless steels or sintered duplex stainless steels (SDSSs) are presented. Mixtures of austenitic and ferritic stainless steel powders, with fixed weight ratio of 50:50, were processed via the

well-known ‘press and sinter’ route, one of powder metallurgy (P/M) processes. The SDSSs exhibiting promising properties has been further investigated by varying weight ratio of austenitic and ferritic powders.

Experimental Procedures

P/M Processing of SDSSs

Stainless steel powders series 300 (303L, 304L, 310L and 316L) and series 400 (409L, 410L, 430L and 434L) were mixed with a fixed weight ratio (50 wt. % of series 300:50 wt. % of series 400). Mixing was carried out for 8 hours in order to obtain a homogeneous distribution of the powders. Zinc stearate (1.0 wt. %) was then added to the mixed metal powders. Mixed powders were pressed into tensile test bars (ASTM E8-96) with green density of $6.50 \pm 0.05 \text{ g/cm}^3$, using a uniaxial press. Green parts were delubricated at 600°C for 1 hour in argon and then sintered at 1280°C for 45 minutes in pure hydrogen atmosphere. Densities of the sintered samples were determined using the Archimedes method. A universal testing machine (Instron model 8801) was employed to determine the tensile properties of the sintered samples. Microstructures were observed using optical microscopy. Hardness (HRB, Instron UHM 930/250) of the sintered samples was also investigated. Each property of the SDSSs was compared to the maximum value of the corresponding property for the sintered series 300 and series 400 materials.⁽⁵⁾

Effect of Weight Ratio Between Austenitic and Ferritic Phases

Powder mixtures were prepared from different weight ratios of 304L and 410L powders, as shown in Table 1. P/M processing of the powder mixtures, testing and characterization of the sintered 304L-410L materials followed the procedures given above.

Table 1. List of studied materials

Wt. % of 304 L	Wt. % of 410 L	Code
100	0	100 A
75	25	75 A
50	50	50 A
25	75	25 A
0	100	0 A

Results and Discussion

P/M Processing of SDSSs

Sintered Density

There was no systematic relationship between sintered density and a pair of austenitic and ferritic powders (Figure 1). Mixtures of 434L powder with any of series 300 powders yielded highest sintered density. Density increases, from green to sintered densities, were $\geq 8.0 \%$. Density increase may indicate that sintering of powder mixtures compacts was successful.

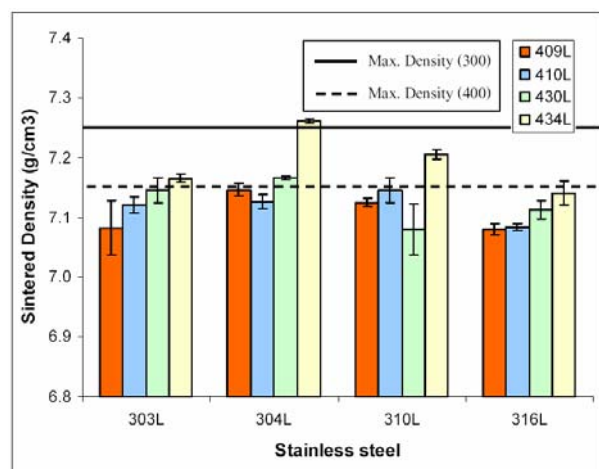
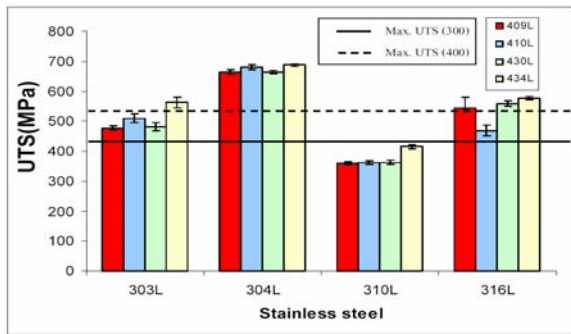


Figure 1. Sintered density of the 300-400 SDSSs.

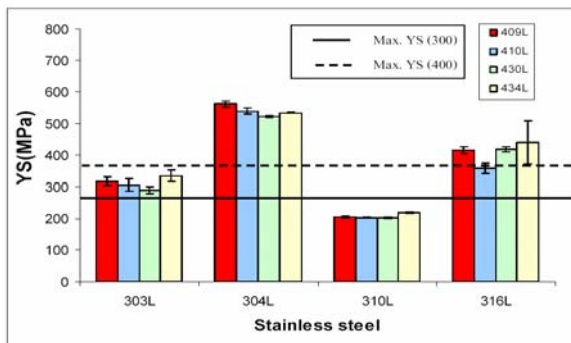
Mechanical Properties

The SDSSs based on 303L, 304L and 316L powders showed improved strengths and hardness, except elongation, compared to the maximum values of corresponding properties for the sintered stainless steels series 300 (Figure 2). The SDSSs based on 304L and 316L powders even exhibited tensile strengths and hardness higher than the maximum values of corresponding properties for the sintered stainless steels series 400. The improved tensile strengths and hardness may indicate that DSS can be prepared from mixtures of series 300 powders (303L, 304L and 316L) and series 400 powders (409L, 410L, 430L and 434L).

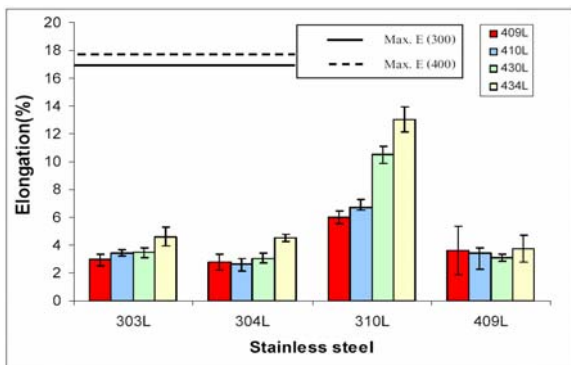
Sintered Materials Prepared from Stainless Steel Series 300 and 400 Powders



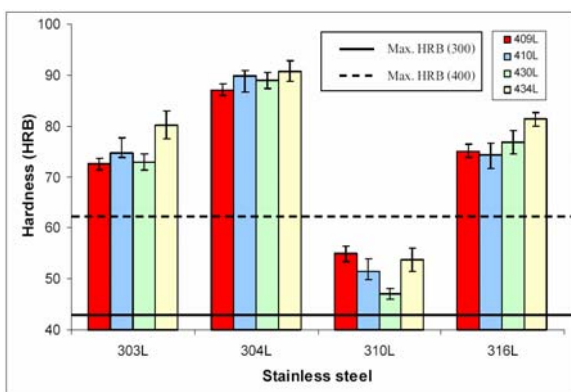
(a) Ultimate tensile strength



(b) Yield strength



(c) Elongation

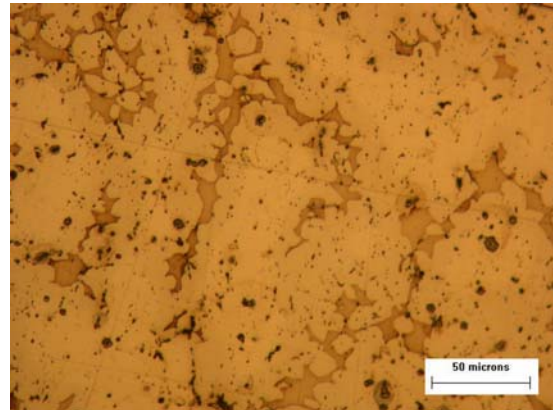


(d) Hardness

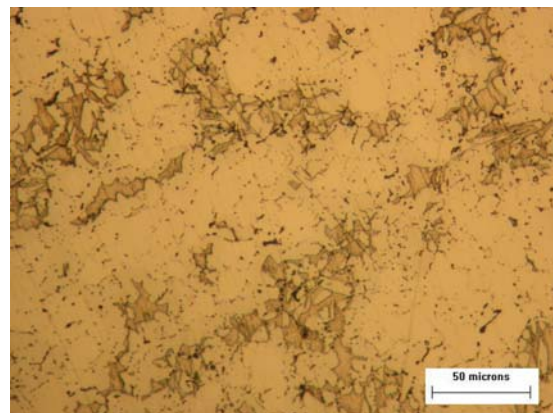
Figure 2. Mechanical properties of the sintered 300-400 stainless steels

Microstructure

Microstructures of the SDSS exhibiting promising properties and of that exhibiting worst properties are shown in Figure 3. Both micrographs showed clear separation of austenitic (brighter grains) and ferritic (darker grains) phases. The microstructure indicates successful preparation of DSS using powder metallurgical method.



Sintered 304L-434L stainless steel



Sintered 310L-430L stainless steel

Figure 3. Microstructures of the 300-400 SDSSs.

Effect of Weight Ratio Between Austenitic and Ferritic Phases

Sintered Density

Sintered densities of the studied samples showed no significant difference (Figure 4). The 25A sample exhibited the lowest sintered density. The sintered density values conform to the shrinkage data as mentioned above.

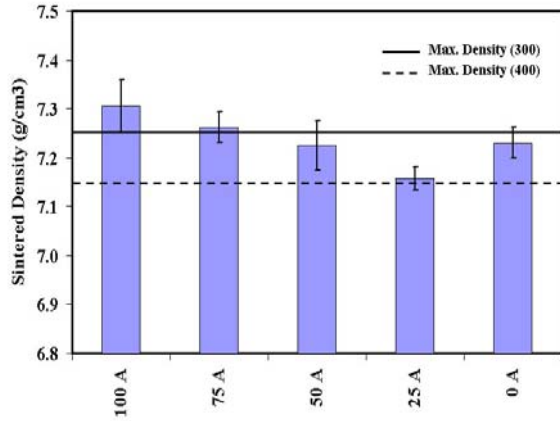


Figure 4. Density of the sintered materials.

Mechanical Properties

Mechanical properties of the sintered samples are illustrated in Figure 5. Yield strength, ultimate tensile strength and hardness of the sintered materials followed the same trend, in which strengths and hardness increased with increasing 410L content. It was noticed that the 25A sample showed significantly improved yield strength, almost 2 times of yield strength of the sintered 304L material and also obviously higher than that of the sintered 410L material.

In contrast, it was found that elongation of the sintered dual phase samples was dramatically decreased when the percentage of 410L was increased. Loss of the material ductility is needed to be improved in further investigation. Otherwise, the sintered DSS will be considered as poor candidates for engineering parts applications.

Hardness values of the SDSSs were higher than those of the sintered 304L and 410L materials. The 25A sample showed the highest hardness. Hardness of the sintered dual phase samples was directly resulted from microstructural characters, shown in Figure 6. It was observed that a new phase was formed in the SDSSs.

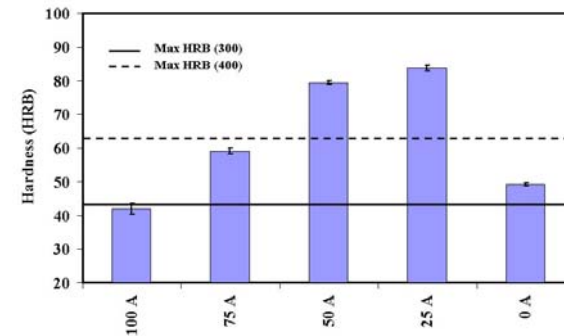
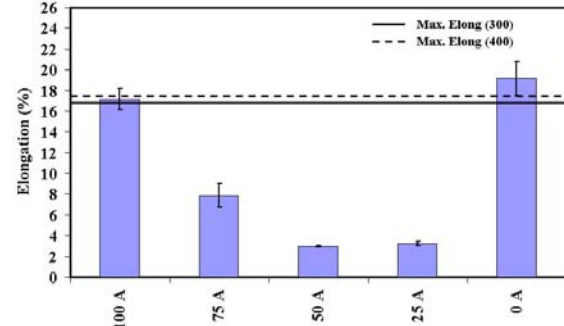
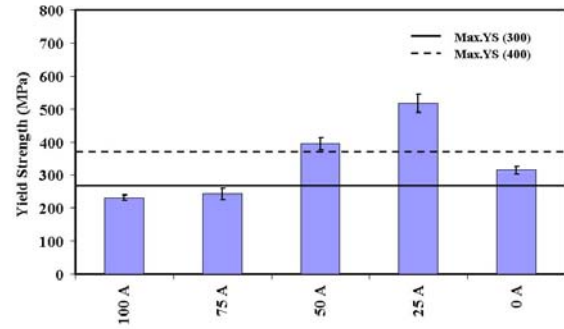
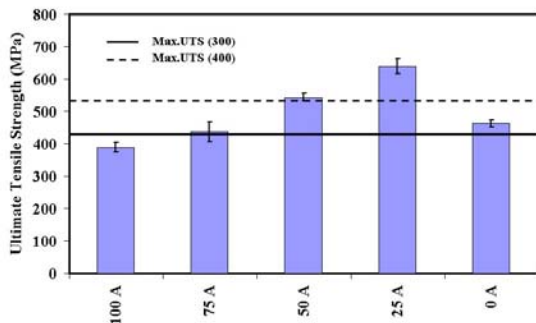


Figure 5. Mechanical properties of the sintered materials.

Microstructure

In order to observe microstructures, the sintered samples were polished and chemically etched using Beraha reagent. Optical micrograph (Figure 6) showed three different phases. According to previous study by Puscas et al.⁽⁵⁾ the phases in microstructure (Figure 6) could be identified. The dark grey zone with irregular shape and rough texture was identified as a ferritic phase, designated as 'F'. The lightest grey zone in a microstructure was an austenitic phase, designated as 'A'. The pale grey zone between ferrite and austenite phases was a new phase, designated as 'N'.

The new phase is formed by diffusion of Ni from austenite into ferrite during sintering.⁽⁵⁾ Microhardness tests, performed on each phases, showed that the new phase exhibited the highest microhardness (Table 2). Hardness of the new

phase was 50% higher than that of the austenitic phase and 38% higher than that of the ferritic phase.

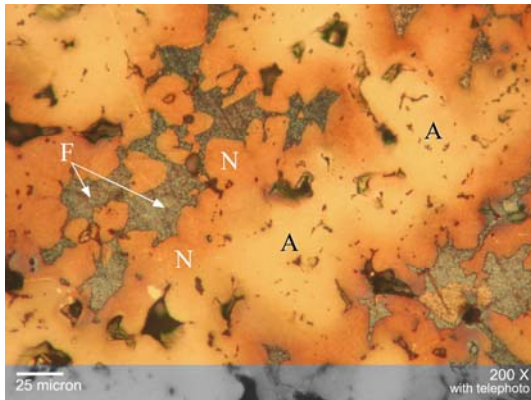
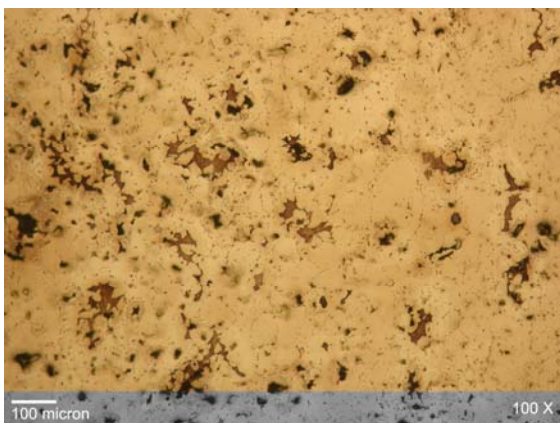


Figure 6. Phase identification in the sintered 304L-410L material.

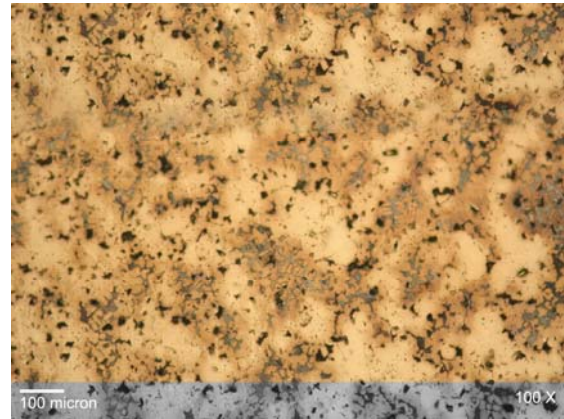
Table 2. Microhardness of each phase presented in the sintered 25A sample.

Phase	Microhardness (HV0.05)
A	175.95
F	198.16
N	272.52

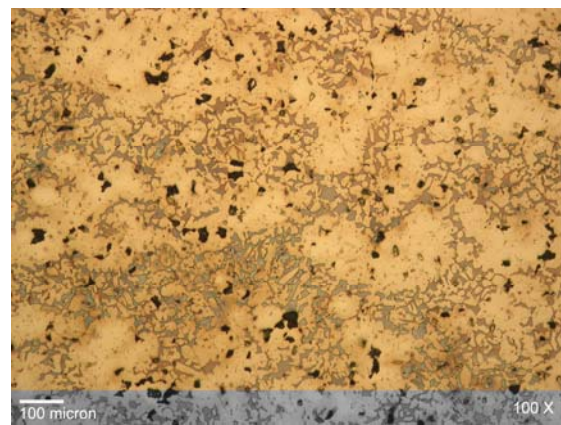
The number of the new phase increased with increasing 410L powder content (Figure 7). Diffusion of Ni to 410 powder particles causes formation of the new phase. When the Ni receivers are increased, probability for new phase formation is also increased. Volume fraction of the new phase seems to affect mechanical properties of the sintered DSS. Increase of the new phase volume fraction (Figure 7) results in improved strengths and hardness.



(a) 75A



(b) 50A



25A

Figure 7. Microstructures of the sintered 304L-410L materials.

Conclusions

Some sintered materials were prepared from mixtures of stainless steel series 300 and series 400 powders. The sintered stainless steels consisted of both austenitic and ferritic phases so they were designated as sintered duplex stainless steels (SDSSs). Microstructures and properties of the SDSSs were characterized and tested. Most SDSSs, except the 310L powder-base SDSSs, showed improved tensile strengths and hardness but exhibited inferior ductility, compared to those of the sintered stainless steels series 300.

The SDSSs, prepared from mixtures of 304L and 410L powders, exhibited microstructure consisting of ferritic, austenitic and N phases. The N phase is formed by diffusion of Ni from 304L to 410L. The N phase is perhaps the combination between austenitic, ferritic and martensitic structures.

Volume fraction of the N phase is increased with 410L content. This enhances mechanical properties of the SDSSs. Yield strength, ultimate tensile strength and hardness of the 304L-410L SDSSs are higher than those of the sintered 304L and 410L materials. Loss of ductility makes the SDSSs be a poor candidate for engineering applications. Ductility improvement is therefore recommended for further investigation.

Acknowledgment

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

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