

Nitrogen Dissolution in Ferritic Stainless Steels by Pressurized Sintering under Nitrogen Atmosphere

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Abstract

Sintering of ferritic stainless steel powder compacts was conducted under pressurized nitrogen atmosphere at 1300 °C. Two grades of powders, namely 430L and 434L were used. The powder compact thickness and sintering time, representing diffusion distance and time, respectively, were varied. Mechanical properties of the sintered specimens seemed to be independent of the compact thickness. This may be attributed to the porous nature of the powder compacts so the diffusion path of nitrogen is not differentiated by the powder compact thickness. Changes of mechanical properties with sintering times were obviously observed. Increasing sintering times from 45 to 90 or 135 minutes caused changes of tensile properties. The properties changes, particularly the case of increase of elongation or ductility with decreasing strengths indicates material phase change by nitrogen dissolution.

Keywords: Nitrogen alloying, sintered materials, ferritic stainless steels

1. Introduction

Austenitic stainless steels are popular choices for medical tool/device applications. However, these materials contain high contents of nickel (Ni), which possibly impact on human tissues when the materials are implanted. Materials corrosion causes release of Ni-ions, which are the cause of allergy and/or cancer [1-3]. Development of Ni-free austenitic stainless steels is an alternative for health impact mitigation.

Nitrogen addition for making Ni-free austenitic stainless steels is dependent on two factors, namely, nitrogen partial pressure and steel composition [3]. The method employing nitrogen partial pressure to dissolve nitrogen into steel is called nitrogen adsorption treatment (NAT). In this method, a piece of steel is put in a furnace with reduced pressure of 2 MPa. Then the furnace chamber is compressed with 101.3 kPa under the temperature of 1473 K for 86.4 ks. Another nitrogen addition method is nitrogen infusion [4],

in which steel powders larger than 45 micron are added to a machine for fluidized bed nitriding tests to nitride the steel powders at medium temperatures (750-800 °C) by using nitrogen or mixed nitrogen gases. The treated powders are finally cooled by mixed nitrogen and nitrogen gases respectively.

In this article, we introduce a new simple route for nitrogen dissolution in high chromium steel powders (ferritic 430L and 434L stainless steel powders) by sintering the powder compacts with different thicknesses in nitrogen atmosphere under the pressure of 8.3 MPa for different times. Cooling of the sintered test bars is done under 34.5 MPa of nitrogen.

2. Experimental procedure

Water atomized ferritic 430L and 434L stainless steel powders (Coldstream, Belgium), whose compositions are given in Table 1, were compacts into tensile test bars with a constant green density of $6.50 \pm 0.05 \text{ g/cm}^3$. Thicknesses of the test bars were varied to 3.0, 4.5, 6.0 and 7.5 cm. The powder compacts were sintered at 1300 °C in pure nitrogen at the pressure of 8.3 MPa for different holding times of 45, 90 and 135 minutes. Cooling of the sintered test bars was done under 34.5 MPa of nitrogen. Microstructures and mechanical properties of the he sintered test bars were observed and tested, respectively.

Table1 Compositions of ferritic 430L and 434L stainless steel powders (in wt. %)

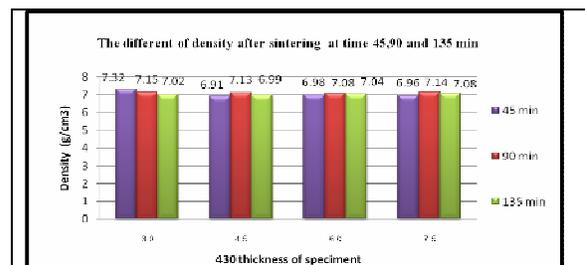
Grade	C	S	Mo	Cu	Ni	Fe	Mn	Cr	Si	O	N	Nb	D(v,0.5) (μm)
430L	0.01	0.01	-	-	-	Balance	0.12	16.03	1.08	0.22	0.03	-	85.85
434L	0.01	0.01	1.04	-	-	Balance	0.10	16.70	0.80	0.19	0.06	-	93.68

3. Results and Discussion

3.1 Sintered density

All densities of the sintered test bars were higher than those of the green test bars. Increases of density were in range of 6-12%. Density increase indicates densification of metal powder compacts. Density increase in sintered materials is related to porosity decrease and sintered neck growth [5]. Thickness difference of the test bars showed insignificant influence on sintered density. Densification of powder compacts is governed by heat-assisted materials transportation. In other hand, sintering temperature is the prime factor for powder compact densification. Because of good heat

conduction of powder compacts, the thickness difference cannot generate temperature gradient in the test bars being sintered [6]. So sintered density difference caused by thickness difference does not exist in this experimental work.



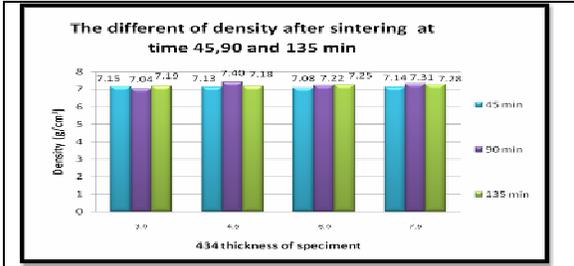


Fig. 1 Sintered densities of the sintered test bars.

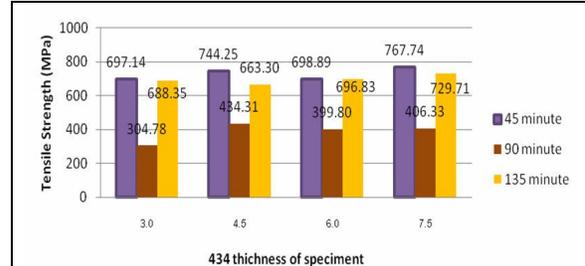


Fig. 2 Tensile strengths of the sintered test bars.

3.2 Tensile properties

According to testing results of mechanical properties given in Figs. 2-5, it was found that properties were changed according to sintering time. The powder compact thickness difference showed no influence on these properties. This may be attributed to the porous nature of the powder compacts so the diffusion path of nitrogen is not differentiated by the powder compact thickness. Changes of mechanical properties with sintering times were obviously observed. Increasing sintering times from 45 to 90 or 135 minutes caused changes of tensile properties. Drop of tensile strengths, with reversely increase of ductility, was observed when sintering was 90 minutes. However, when the hoding time was increased to 135 minutes, both strength and ductility of the sintered test bars were increased. Increases of strength and ductility for the sintering time of 135 minute were attributed to nitrogen dissolution combined with microstructural change.

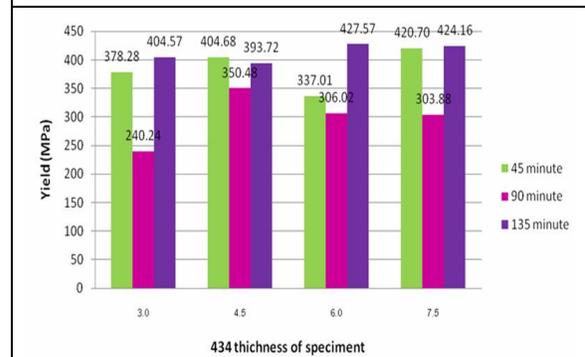
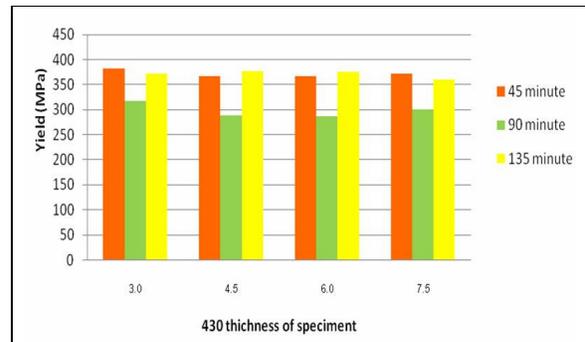
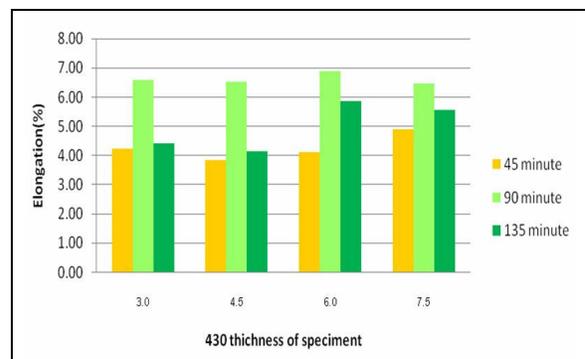
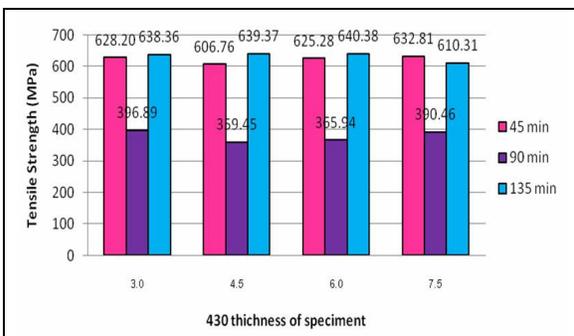


Fig. 3 Yield strengths of the sintered test bars.



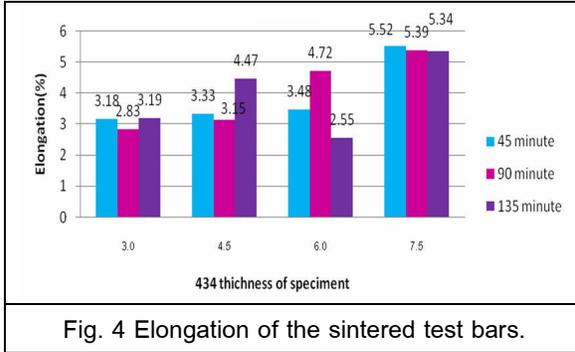


Fig. 4 Elongation of the sintered test bars.

It should be noted here that original nitrogen contents in these two alloy powder types (Table 1) already contribute their effect on the material strength by solution strengthening. All the strengths presented in this work are the combinations of the effects from the existing nitrogen in the powders and the additional nitrogen contents gained from the sintering and cooling processes.

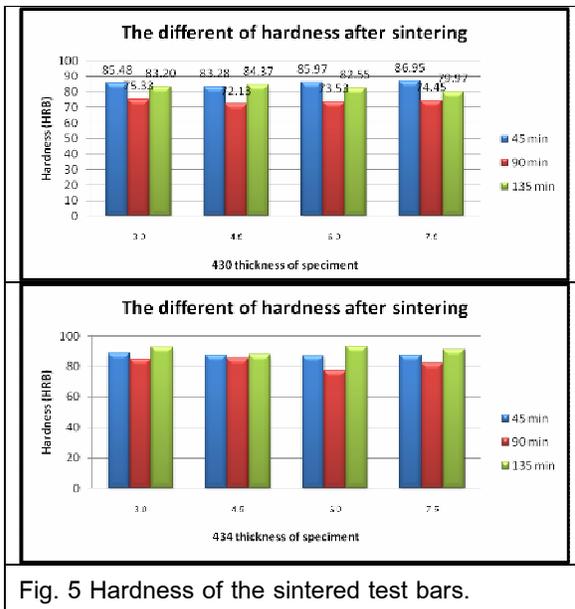


Fig. 5 Hardness of the sintered test bars.

3.3 Microstructure

Under sintering and cooling conditions, microstructures of the sintered test bars consisted of retained austenite grains (Fig. 6). Volume

fraction of austenite grains was increased when sintering time was increased to 90 minutes. The austenite phase is responsible for the ductility increase. Other phase appeared in the sintered test bars was suspected to be lath martensite, represented by as parallel arrays or packets of lath-shape units or dirty grains in Fig. 6. Formation of lath martensite is attributed to two factors. The first is that the investigated materials are low carbon steels. Low carbon content in steels increases martensite forming temperature (M_s) [7], as given by Equation 1.

$$M_s (\text{°C}) = 561 - 474(\%C) - 33(\%Mn) - 17(\%Ni) - 17(\%Cr) - 21(\%Mo) \quad (1)$$

The second is high cooling rate due to increased pressure (from 8.3 to 34.5 MPa) of nitrogen during the cooling cycle.

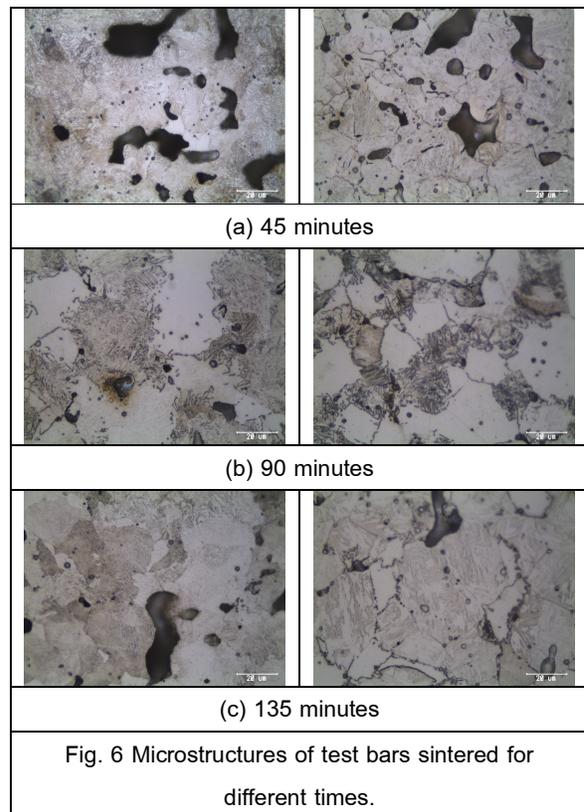


Fig. 6 Microstructures of test bars sintered for different times.

4. Conclusions

Mechanical properties of the sintered specimens are independent of the powder compact thickness. This may be attributed to the porous nature of the powder compacts so the diffusion path of nitrogen is not differentiated by the powder compact thickness. Changes of mechanical properties with sintering times were obviously observed. Increasing sintering times from 45 to 90 or 135 minutes caused changes of tensile properties. The properties changes, particularly the case of increase of elongation or ductility with decreasing strengths indicates material phase change by nitrogen dissolution.

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6. References

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