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MICROSTRUCTURE AND MECHANICAL PROPERTIES OF NICKEL FREE AUSTENITIC STAINLESS STEELS PRODUCED BY ADDITION OF NITRIDED FERROALLOYS DURING MELTING IN INDUCTION FURNACE

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ABSTRACT
Investigation of microstructure and mechanical properties of nickel free high nitrogen austenitic stainless steel, produced by melting in induction furnace, is presented in this paper. Nitriding of steel was done by melting of nitrogen rich ferroalloy (nitrogen content up to 8%), where two levels of nitrogen content were achieved. Metallographic examination and mechanical properties investigation of forged and heat treated ingots were performed for different nitrogen content. Results obtained by this method are compared to results obtained after solution annealing, sintering and solid state nitriding. Comparison to traditional austenitic stainless steels was also presented in the paper.
Keywords: nickel free austenitic stainless steel, nitrogen, induction furnace, melting

1. INTRODUCTION
Absence of nickel, good mechanical properties and corrosion resistance of nickel free austenitic stainless steels are benefits that encourage development and improvement of its production methods. Nowadays, there are few methods that can be used to produce these steels, but the main difference between them is the way in which nitrogen, as replacement for nickel, is introduced in the steel. The most frequently used methods are production in induction furnaces, arc furnaces, AOD furnaces, plasma arc furnaces, pressure ESR process, pressure arc slag process and production by powder metallurgy technologies [1, 2, 3, 4].

Production of these steels by powder metallurgy involves gas nitrogen as sintering atmosphere. During the first stage of sintering all metal particles are in contact with gas nitrogen, absorption of nitrogen takes place, so entire cross section of the part is subjected to nitriding [4]. Production of nickel free austenitic steel can be done using solid state nitriding of cast or sintered components. This process demands long exposure to nitrogen, which can be very expensive, so it is suitable for small components. Powder metallurgy and solid state nitriding are methods for production of final component which, very often, do not require additional processing. Some of these methods introduce nitrogen during melting, where high pressure of nitrogen atmosphere creates conditions for its absorption [1].

In this study, nickel free high nitrogen austenitic stainless steels were manufactured using induction furnace by adding nitrided ferroalloy under atmospheric pressure. The microstructure and mechanical properties investigation of forged and heat treated ingots were performed for different nitrogen contents. Results obtained by this method are compared to results obtained after solution annealing, sintering and solid state nitriding.

2. EXPERIMENTAL WORK

2.1. Material and methods

Two austenitic stainless steels (A1 and A2 in table 1.), with different nitrogen contents (0,408 wt% N and 0,635 wt% N), were prepared in the form of ingots, by melting iron and ferro-alloy (Cr, Mo, Mn, high nitrogen ferro-chrome) in appropriate proportions to meet the aimed composition of alloy in an induction furnace. These ingots were hot forged at 950 °C to reduce the thickness by 50-80%. Then, specimens of 95×35×25 mm were cut from ingot, solution annealed at 1020 °C for 60 min, and water quenched. The chemical compositions of A1 and A2 steel, sintered steels and traditional austenitic stainless steel are presented in Table 1. The microstructures of the steels are observed by optical microscopy. Tensile tests were done using Zwick machine with a capacity of 30 kN.

Table 1. Composition of stainless steels (wt%)

Alloy	Cr	Mo	Mn	Si	Ni	N
A1	14,51	2,64	13,51	0,33	≤0,1	0,408
A2	14,20	3,38	13,39	0,3	≤0,1	0,635
Sintered parts [4]	16,5-17,5	3-3,5	10-12	≤1	≤0,1	0,614
316L [5]	16,8	2,21	1,62	0,23	12,1	-
904L [5]	20,4	4,63	0,85	0,22	25,2	0,04

3. RESULTS AND DISCUSSION

To achieve high percentage of nitrogen in austenitic stainless steel, Cr, Mn and Mo content should be increased [5,6]. In this regard, different values of Mo content were adjusted during experiment in order to attain two levels of nitrogen content. In case when Mo content was 2,64%, absorbed nitrogen content reached 0,408%. Increasing of Mo content to 3,38% resulted in enriching of alloy by nitrogen up to 0,635% (Table 1).

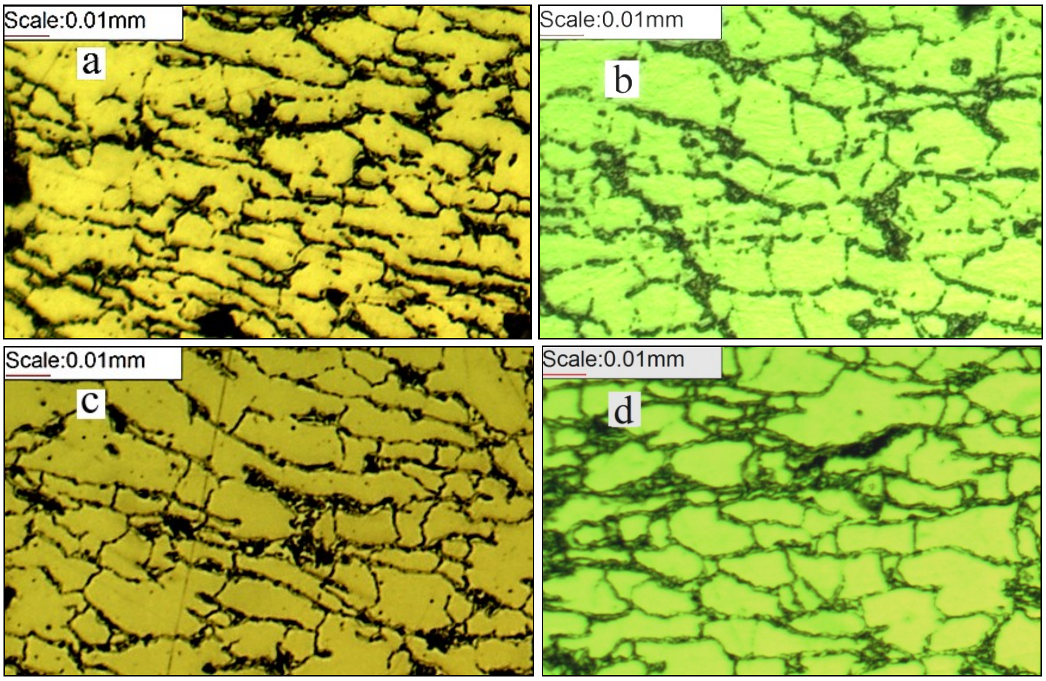
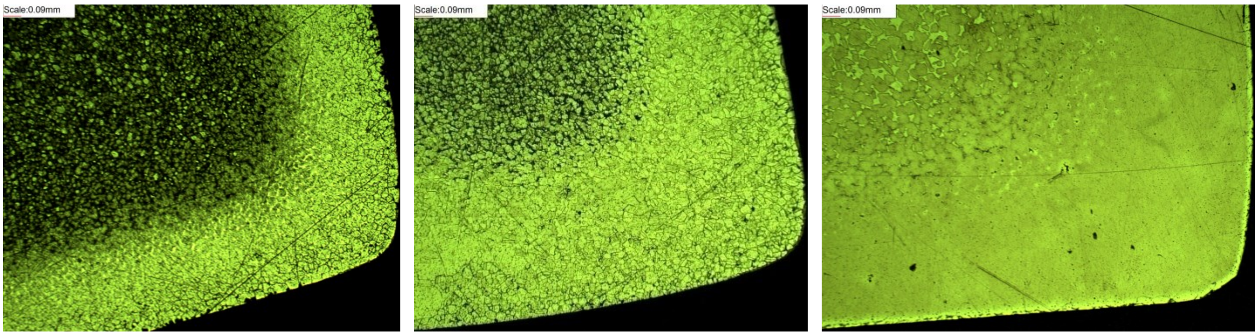


Figure 1. Microstructure of A1 and A2 alloy – hot forged 950 °C: a) A1 as etched, b) A1 as etched - solution annealed (1020 °C), c) A2 as etched, d) A2 as etched - solution annealed (1020 °C)

Figures 1a through 1d show microstructure of steel as cast-forged and after additional heat treatment. Final microstructure of parts hot forged consists of austenite, δ-ferrite and precipitates (Fig. 1a and 1c). Microstructure reveals very thick grain boundaries as a result of precipitation during slow cooling after hot forging (950 °C). Also, coarse grain boundaries are observed and after solution annealing (1020 °C) and quenching in water (Fig. 1b and 1d). Dissolution of precipitates by solution annealing at temperature of 1020 °C and quenching, was not performed successfully to dissolve precipitates existing after casting and forging. Insufficient temperature is a possible explanation for this behavior of steel after solution annealing.



a) b) c)

Figure 2. Optical micrographs: a) sample sintered in argon and reheated at 1190 °C in N_2 - 2,5h, b) sample sintered in argon and reheated at 1190 °C in N_2 -5h,c) sample sintered in argon and reheated at 1240 °C in N_2 - 5h

In order to compare microstructure of nickel free austenitic stainless steel produced by casting-forging (A1 and A2) and solid solution nitriding, additional microstructural investigation were performed for solid state nitrided parts. Figures 2a, 2b, 2c show the microstructure of parts after solid state nitriding at temperatures of 1190 °C and 1240 °C, for 2,5 h and 5 h . These parts, before solid state nitriding, were subjected to sintering in argon atmosphere, so as their chemical composition do not contain nitrogen. The initial microstructure consisting of austenite and ferrite is result of absence of nitrogen and nickel. Two main parameters that govern solid state nitriding are temperature and time. By nitriding at 1190 °C (nitrogen atmosphere -dynamic conditions), fully austenitic microstructure up to depth of 0,4 mm was achieved. Prolongation of time from 2,5 h to 5 h caused increasing of depth of the nitrided layer for about 42 %. Longer time enables nitrogen to diffuse more in depth of the part, which creates conditions for formation of austenitic microstructure. The deepest austenitic layer was achieved by nitriding at temperature of 1240 °C for 5h. Some positions on testing parts showed thickness of austenitic layer of about 0,85 mm, Figure 2c.

Table 2. Mechanical properties of all alloys investigated

Alloy	Rm (MPa)	Strain (%)	wt% N
A1 – hot forged	795	38,22	0,408
A2 – hot forged	817	32,91	0,635
A1 – SA	654	22,98	0,408
A2 – SA	723	23,98	0,635
316L [5]	517	60	-
904L [5]	535	62	0,04
Sintered part [4]	802	20	0,614

It was found that the tensile strength and elongation of the alloys A1 and A2, where austenitic microstructure was formed, are susceptible to nitrogen content. It is noticeable that strength of the part A2 in hot-forged state is slightly higher then strength of A1 (up to 3 %).
Precipitation of chromium nitrides during slow cooling of steel, after hot forging caused reduction of its ductility. In this case, elongation was reduced from 38,22 % to 32,91 % as nitrogen content increases from 0,408% to 0,635%.
The tensile strength of both alloys with nitrogen is significantly larger than that of 316L and 904L steels (Table 2.). However, this increase of tensile strength is at the expense of ductility (Table 2.).
Strengthening of the material by nitrogen is also noticed after solution annealing. The maximum tensile strength of 723 MPa was achieved for the alloy A2 due to higher content of nitrogen. It can be noted that solution annealing at temperature of 1020 °C resulted in reducing of elongation of A1 and A2 alloys, which needs more investigation for explanation. Metallographic examination of cast-forged ingots showed existing of inclusions and inhomogeneities.

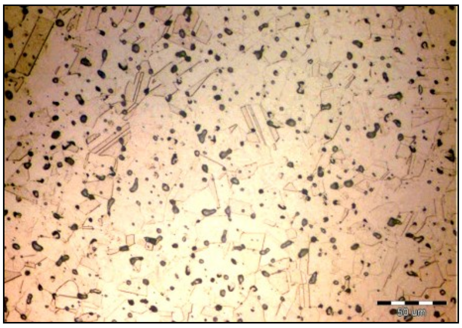


Figure 3. Microstructure of sintered part: nitrogen, 1200 °C-800 mbar [4]

As mentioned before, technologies of powder metallurgy are very suitable for production of nickel free austenitic stainless steels, where the main factor of the process is sintering in nitrogen atmosphere. Mechanical properties of parts produced by sintering and melting of iron and ferro-alloy are very similar (Table 2.). It can be seen that the tensile strength of the sintered parts does not deviate much from the cast parts. However, the key difference between the cast and sintered parts are the percentage of elongation (Table 2). In addition to microstructure, residual porosity is very important characteristic that affect the ductility of the sintered components (Figure 3) [4].

4. CONCLUSION

Production of nickel free austenitic stainless steels by melting of nitrogen rich ferroalloy in induction furnace is very suitable process for production of larger pieces. Production of ingots with dimensions of approximately 200x70x70 required less than 2 h, at temperature over 1550°C. Produced ingots needs to be forged and solution annealed to attain wanted properties. Mechanical properties of steel are acceptable with tensile strength even superior compared to tradition stainless steels. One of the main drawback of this process is material inhomogeneity and inclusions, specially near to surface of the ingot. Production of this kind of steel by powder metallurgy needs metal powder and includes few very complex phases. However, this method is suitable for small parts with geometry, surface finish, and dimensional accuracy that, very often, do not require addition processing. Third process presented in the paper involves solid state nitriding of finished parts. But this process takes too long time and demands high temperature. As shown, maximum rate at which austenitic layer moves in the depth of the part was 0,17 mm/h, at temperature of 1240 °C.

5. REFERENCES

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