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Microstructure, Mechanical Properties and Corrosion Resistance of Modified S21603 Steel with Reduced Molybdenum Content

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***Abstract*: This work presents a comparative study of the microstructure, mechanical properties, and corrosion resistance of conventional AISI 316L steel and a modified high-nitrogen S21603 steel containing 1% molybdenum and 0.35% nitrogen. The modified alloy exhibits significantly higher strength while maintaining acceptable ductility and impact toughness. Corrosion tests in chloride, sulfuric, and mixed acidic environments demonstrate a substantial improvement in pitting, intergranular, and general corrosion resistance due to the combined effect of nitrogen and increased chromium content. Electrochemical measurements further confirm the higher pitting potential of the modified steel. These results highlight the strong potential of high-nitrogen austenitic stainless steels as cost-effective materials for aggressive corrosion-prone applications.**

***Keywords*: nitrogen-alloyed austenite stainless steel, mechanical properties, corrosion resistance, cost-effectiveness.**

1. Introduction

Austenitic stainless steels are the cornerstone of numerous industries due to their excellent corrosion resistance and good formability. Among them, AISI 316L has established itself as a workhorse material, offering enhanced resistance to pitting and crevice corrosion in chloride-bearing environments thanks to its molybdenum content. However, the conventional strengthening mechanisms for steels, such as cold working, often come at the expense of ductility and toughness. This inherent trade-off has driven the search for alternative alloying strategies to achieve a superior combination of strength and corrosion performance. A promising path is the alloying with nitrogen, which serves as a potent interstitial solid solution strengthener [1].

This study presents a comparative investigation of the microstructure, mechanical properties, and corrosion resistance of a reference AISI 316L steel and a modified high-nitrogen austenitic steel, S21603 with 1% molybdenum and 0.35% nitrogen. The high-nitrogen grade leverages the synergistic effect of manganese and nitrogen to stabilize the austenitic phase, allowing for a significant increase in nitrogen content far beyond the solubility limit in standard 300-series steels. The introduction of nitrogen at a level of 0.35 wt.% does not only substantially increase the yield and tensile strength through solid solution hardening but also markedly improve the resistance to localized corrosion, particularly pitting, by enhancing the passivity of the chromium-rich oxide layer [2].

The superiority of nitrogen-alloyed steels is expected to manifest in several key areas. Compared to their conventional counterparts like AISI 316L, high-nitrogen austenitic steels typically exhibit a dramatic increase in strength and hardness in the solution-annealed condition without the need for cold working, thereby preserving ductility. Furthermore, nitrogen is known to synergize with molybdenum to improve pitting resistance, effectively increasing the Pitting Resistance Equivalent Number (PREN). This research aims to quantitatively substantiate these advantages, providing a clear rationale for the adoption of high-nitrogen austenitic stainless steels in demanding applications where mechanical integrity and exceptional corrosion resistance are paramount.

2. Materials and Methods

The article investigates two types of steel - AISI 316L and S21603 with 1% molybdenum and 0.35% nitrogen, in the form of hot-forged bars with a diameter of 45 mm. Following forging, the bars were subjected to annealing at 1150 °C for 1 hour, followed by water quenching.

Metallographic examination was conducted according to the standards GB/T 6394-2017, room temperature tensile test was conducted in accordance with the standard GB/T 228.1-2021, toughness determination was conducted in accordance with the standard ASTM A370-2023 at room temperature

Corrosion performance was characterized using: ASTM G48-11 for pitting corrosion (10% $FeCl_3 \cdot 6H_2O$, 25 ºC), ASTM A262-15 for intergranular corrosion (50% H_2SO_4-$FeSO_4$), JB/T 7901-1999 for general corrosion (boiling 5% H_2SO_4), and GB/T 17899 for electrochemical pitting potential measurements in 3.5% NaCl. All tests were conducted with 80-grit finished specimens, with corrosion rates determined by mass loss after 10-hour exposures.

3. Results and Discussion

The microstructure of the steels consists of austenite without any ferrite phase present. Table 1 presents the measured grain size data and ferrite content. As evident from the table, the

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Table 1
Grain size and ferrite content of researched steels after solid solution heat treatment – 1100 ºC, 1 hour, water

Grade	Grain size by standard ASTM E112-24	Ferrite content by standard GB/T 13305-2024, %
AISI316	1.0	0
S21603 mod	1.5	

Table 2
Mechanical properties of researched steels

Grade	**Yield strength, MPa**	**Tensile strength, MPa**	**Elong., %**	**KCV, J Room temp**
AISI316	269	564	68	360
S21603 mod	403	763	54	342

investigated steels exhibit approximately similar grain sizes, while the amount of ferrite detected by optical microscopy is 0% in all cases.

Due to nitrogen alloying, the mechanical properties of S21603 mod steel are significantly superior to those of standard AISI 316L steel (see Table 2). As can be seen from Table 2, nitrogen-alloyed steel achieves a better strength-ductility combination with approximately the same level of impact toughness.

The corrosion properties of the researched steels were investigated in three solutions representing: pitting corrosion (10% $FeCl_3 \cdot 6H_2O$), intergranular corrosion (50% H_2SO_4-$FeSO_4$), general corrosion (5% H_2SO_4).

The pitting corrosion test results for the investigated steels are shown in Table 3. Despite the high manganese content in nitrogen-alloyed steel - known to generally reduce corrosion resistance [3], [4]. These steels demonstrate superior performance compared to conventional steel AISI 316L due to their elevated chrome and nitrogen content. Results of this test correlate well with the pitting resistance equivalent number (PREN = %Cr + 3.3%Mo + 16%N) for stainless steels.

Table 3
Corrosion resistance – chloride contain media: 10%$FeCl_3$*$6H_2O$ – 25°C, 10 hours

Grade	**Weight loss, mm per year**			
	Sample 1	Sample 2	Sample 3	average
AISI 316L	1.284	2.979	1.259	1.84±0.99
S21603 mod	0.022	0.003	0.009	0.01±0.01

The intergranular corrosion test results for the investigated steels are presented in Table 4. Intergranular corrosion is primarily influenced by sensitization processes during aging, which promote carbide precipitation. All studied steels were examined in the quenched condition, resulting in comparable mass loss values for both AISI 316L and nitrogen-alloyed steel. However, it is clearly evident that S21603 mod steel exhibit better corrosion resistance in this solution.

Table 4
Intergranular Corrosion resistance – 50% H_2SO_4-$FeSO_4$ – 25°C, 10 hours

Grade	**Weight loss, mm per year**			
	Sample 1	Sample 2	Sample 3	average
AISI 316L	1.659	1.889	1.641	1.73±0.14
S21603 mod	0.916	1.468	0.936	1.11±0.31

The results of general corrosion testing in a boiling 5% sulfuric acid solution are presented in Figure 1. The S21603 mod exhibit better mass loss values, whereas the AISI 316L steel shows markedly lower resistance.

The electrochemical measurements depicted in Figure 1 and summarized in Table 6 reveal notable differences among the steels. S21603 mod steel exhibited a higher pitting potential than AISI 316L. The difference in the corrosion behavior is evidently due to the influence of the increased chrome and nitrogen concentration [5].

Table 6 details the calculated production costs for vacuum induction melting (VIM) of the investigated steels, assuming the use of pure raw materials (mid-2025 pricing). While these calculated values are substantially higher—by a factor of 2 to 2.5—than typical industrial costs due to the standard use of lower-grade feedstock, the data accurately reflect the *relative* cost distribution. Thus, the proportional relationships between the different cost components provide a valid basis for comparison.

Table 5
General corrosion resistance in 5% H_2SO_4 boiling solution, 10 hours

Grade	**Weight loss, mm per year**			
	Sample 1	Sample 2	Sample 3	average
AISI 316L	8.613	7.961	8.517	8.36±0.35
S21603 mod	0.031	0.163	0.147	0.11±0.07

Table 6
The results of electrochemical experiments

Grade	**Epit [mV]**
AISI 316L	0.48
S21603 mod	0.61

Table 7
Estimated production cost of the investigated steels based on pure raw material prices (Prices data as of mid-2025)

Grade	**Cost, USD**
AISI316L	5262
S21603 mod	4502

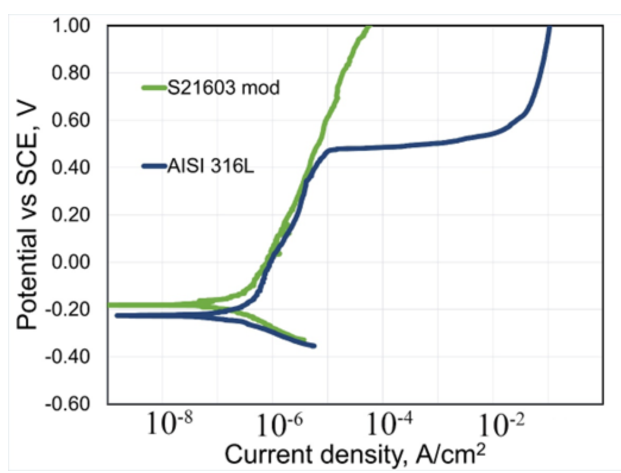

Fig. 1. Polarization curves obtained in 3.5 wt.% NaCl solution for investigated steels

4. Conclusion

The modified S21603 with 1% molybdenum and 0.35% nitrogen steel demonstrates a significant improvement in mechanical strength compared to AISI 316L while maintaining satisfactory ductility and impact toughness. Its enhanced corrosion resistance in all tested environments confirms the beneficial effect of nitrogen and increased chromium content on forming a stable passive film. Electrochemical tests also revealed a higher pitting potential for the high-nitrogen steel. An additional advantage is its lower estimated production cost compared with AISI 316L. The obtained results confirm the high potential of high-nitrogen austenitic steels for use in demanding, corrosion-active environments.

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