Farzet Bikić, Dejana Kasapović

Faculty of Engineering and Natural Sciences, University of Zenica, Zenica, Bosnia and Herzegovina

Scientificpaper
ISSN 0351-9465, E-ISSN 2466-2585
https://doi.org/10.62638/ZasMat1400

Zastita Materijala 67 (1)
133 - 138 (2026)

Investigation of pitting corrosion in austenitic stainless steels AISI304L and AISI317L: With particular emphasis on the role of molybdenum

ABSTRACT

Austenitic stainless steels are among the most widely used stainless steel grades, with the American Iron and Steel Institute (AISI) 300 series being particulary common.Beginning with the base alloy 304 (Fe-19Cr-10Ni), the incorporation of molybdenum enhances pitting corrosion resistance (2-3 wt.% in AISI 316 and 3-4 wt.% in AISI 317). To prevent sensitisation caused by chromium depletion during welding and other thermal processes, and the resulting risk of intergranular corrosion, low-carbon variants such as 304L, 316L, 317L (with carbon content ≤ 0.03 wt.%) are employed. Alternatively, stabilization can be achieved by alloying with titanium (AISI 321) or niobium and tantalum (AISI 347), which bind carbon at elevated temperatures. Chromium contributes to oxidation resistance, whilst nickel improves ductility and workability at ambient conditions. This paper investigates the pitting corrosion behaviour of low-carbon austenitic stainless steels, specifically AISI317Land AISI304L. The experimental results are presented through cyclic potentiodynamic polarization curves. Findings indicate that the severity of pitting corrosion decreases with reduced temperatures in a 1.5% NaCl solution and that the presence of molybdenum in AISI317L notably enhances corrosion resistance.

Keywords:*austenitic stainless steels, molybdenum, pitting corrosion, temperature, chemical composition, cyclic polarization curves*

1. INTRODUCTION

Austenitic stainless steels are among the most commonly applied stainless steeltypes. Within this category, the American Iron and Steel Institute (AISI) 300 series alloys are especially prevalent.The base alloy, AISI 304 (Fe-19Cr-10Ni), may be modified through the addition of molybdenum to improve pitting corrosion resistance. Typical molybdenum content ranges from 2 to 3 wt.% in AISI316, and from 3 to 4 wt.% in AISI 317. Sensitisation, which arises from chromium depletion during welding or heat treatment processes and can lead to intergranular corrosion, may be avoided by using low-carbon variants such as 304L, 316L, 317L, where the carbon content is limited to a maximum of 0.03 wt.%.Alternatively, stabilisation can be achieved by alloying with titanium (AISI 321) or with niobiumand tantalum (AISI 347), which facilitate the formation of stable carbides at elevated temperatures. In addition to corrosion restance, chromium also enhaces oxidation stability, while nickel improves ductility and workability at ambient temperatures[1]. Stainless steels are valued not only for their corrosion resistance, but also for their mechanical strength, aesthetic appeal, and structuralversatility [2].

Pitting corrosion of stainless steel is manifested by the rapid growth of current flow after achieving specific values of anode potential, known as the pitting potential, after pits formation [3]. It can be prevented if the anions present in solution hinder the adsorption of chlorides, or push them from the metal surface. The introduction of competing anions containing chlorides (i.e. chromate, nitrate, environmentally-friendly organic compounds etc.) in the solution moves the value of pitting potential in anodic area. The resistance to pitting corrosion can be enhanced by increasing the content of chromium, molybdenum, and nitrogen in the alloy composition. Among these elements, molybdenum is particularly effective and is commonly added to stainless steels for this purpose[4].

This study focuses on the pitting corrosion behaviour of low-carbonaustenitic stainless steels,

*Corresponding author: Farzet Bikić
E-mail: farzet.bikic@unze.ba
Paper received: 09. 03. 2025.
Paper accepted: 25. 05. 2025.

specifically AISI 304 L and AISI 317 L. The high corrosion resistance of stainless steel is attributed to the formation of a protective passive film on its surface. The properties of this film have been the subject of extensive investigation.Using direct imaging of native passive film on 304 stainless steels, Hamada demonstrated the enrichment of chromium in the film and the accumulation of nickel in the matrix side closest to the passive film/matrix interface [5].While this oxide layer is capable of rapid self-repair in clean acid environments, its protective capacity diminishes in the presence of aggressive ions, particularly chlorides, and under elevated temperatures [6].

2. EXPERIMENTAL PART

Low-carbon gradesof austenitic stainless steels, specifically AISI304L and AISI317L, were selected for pitting corrosion testing. For the sake of clarity and brevity, these materials will hereafter be referred to as304L and 317L, respectively. The nominal chemical compositions of both steels are given in Table 1.

Pitting corrosion testing of the selected austenitic stainless steels was performed at three temperatures: 20°C, 30°C, and 40°C, in a 1.5% NaCl solution. The experiments were conducted in a corrosion cell in accordancewith ASTM G5 standard, using a Princeton Applied Research potentiostat/galvanostat (model 263A-2) operated viaPowerCORR® software [7]. To evaluate the susceptibility to pitting corrosion, the electrochemical direct current (DC)cyclic polarization method wasemployed.

Table 1. Chemical composition of the tested austenitic stainless steels

Chemical element	Chemical composition, mas.%	
	AISI 304L	AISI 317L
C	≤ 0,03	≤ 0,03
Si	≤ 1,00	≤ 1,00
Mn	≤ 2,00	≤ 2,00
P_{max}	0,045	0,045
S	≤0,015	≤0,015
N	≤ 0,11	≤ 0,11
Cr	18 -20	17,5-19,5
Mo	-	3-4
Ni	10-12	13-16

This technique includes scanning the electrode potential in the anodic direction up to a predefined vertex potential, followed by a reverse scan once a critical current threshold has been reached. The potentialscan rate was maintained at 0.5 mVs^{-1}. Pitting corrosion in stainless steels is typically observed as a sudden increase in current upon reaching a specific anodic potential, known as the pitting potential (Epitt), as illustrated in Figure 1. This potential marks the onset of pit formation and corresponds to the point at which the current on the polarization curve beginsto rise.According to the present understanding of the pitting corrosion process the Epitt represents a critical threshold value, where metastable pits nuclei within the passive state of the stainless steel may be transformed into stable growingpits when the passive formation breaks down [8].

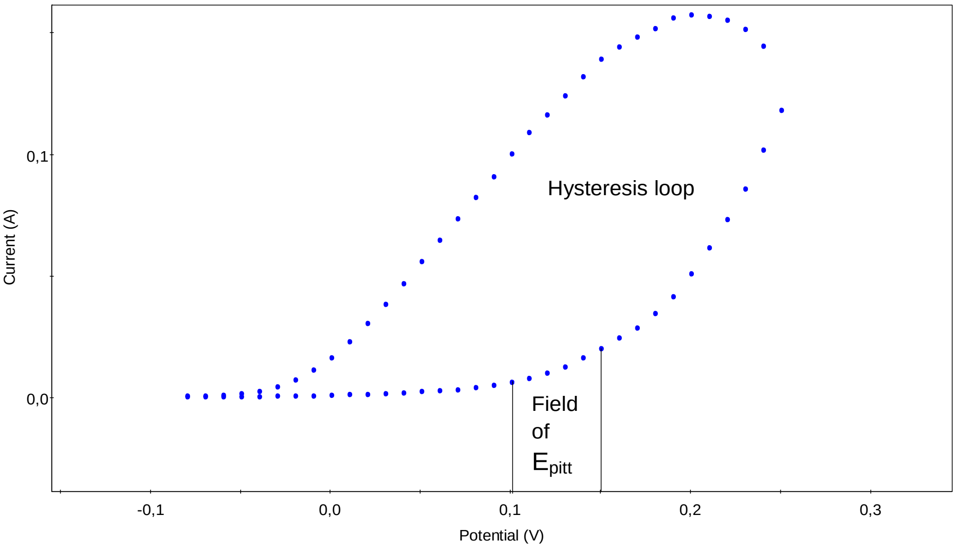

Figure 1. Cyclic polarization curve [3]

Negativepitting potential values indicate a greater susceptibility of stainless steels to pitting corrosion. The area enclosed by the hysteresis loopon a cyclic polarization curve serves as a qualitative measure of pitting corrosion severity (Figure 1). Alarger loop area generally corresponds to a higher intensity of pitting corrosion.

3. RESULTS AND DISCUSSION

The results of the pitting corrosion tests for the investigated stainless steels are given in Figures 2 to 6, and summarizedin Table 2. Figures 2 to 6 show cyclic polarization curves for 304L and 317L were obtained in the1.5% NaCl solution at three different temperatures (20 °C, 30 °C and 40 °C). Table 2 provides the corresponding pitting potential (Epitt) valuesin the specified solution and temperatures.Figures 2 and 3 specifically show the effect of temperature on the pitting corrosion behaviour of austenitic stainless steels 304L and 317L.

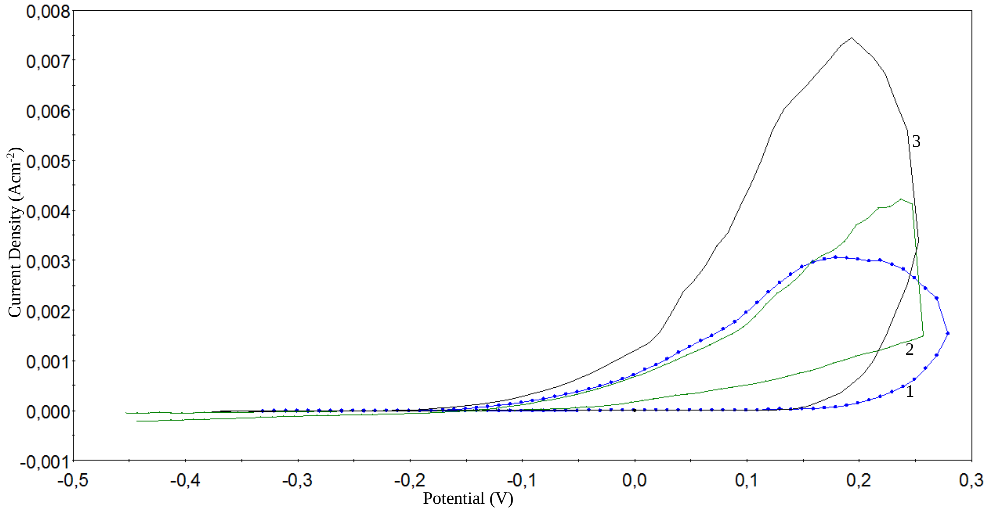

Figure 2. Cyclic polarization curves of type 304L stainless steel (1- 20 °C, 2 - 30 °C, 3 - 40 °C)

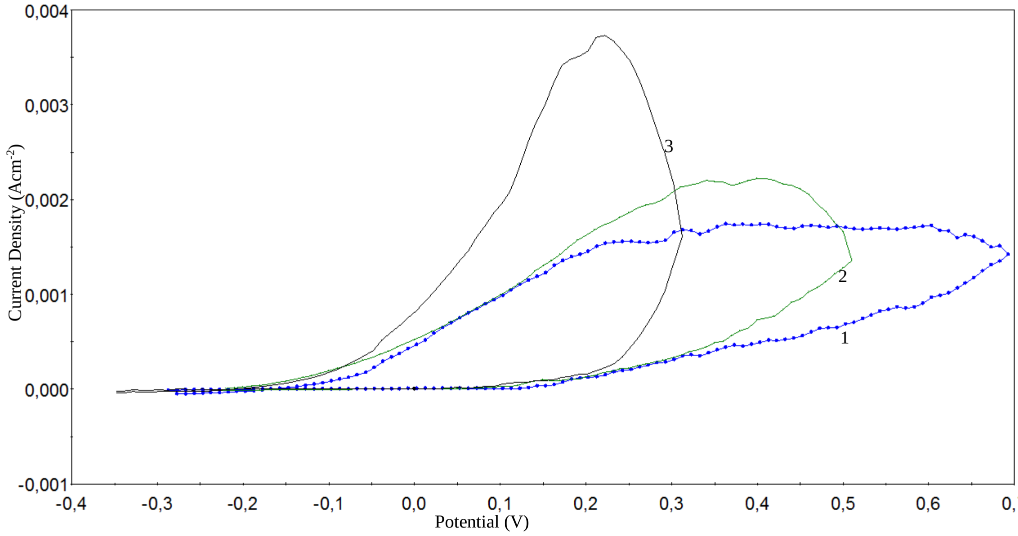

Figure 3. Cyclic polarization curves of type 317L stainless steel (1- 20 °C, 2 - 30 °C, 3 - 40 °C)

Temperature plays a significant role in the corrosionbehaviour of stainless steels. In general, a rise in temperature leads to a decrease in corrosion resistance [9]. Escrivàreported that passive films formed at elevated temperatures are likely to be more defective [10]. This was beneficial for the mitigation of aggressive ions inside the passive film and consequently could accelerate the dissolution process and the exchange kinetics between the electrode surface and the electrolyte [11].

The results shown in Figures 2 and 3 indicate that the severity of pitting corrosion in both tested austenitic stainless steels, 304L and 317L, increases with rising temperature in the 1.5% NaCl solution.

Figures 4, 5 and 6 illustrate the influence of chemical compositionon pitting corrosionbehaviour in 304L and 317L,withparticular emphasis on the role of molybdenum.

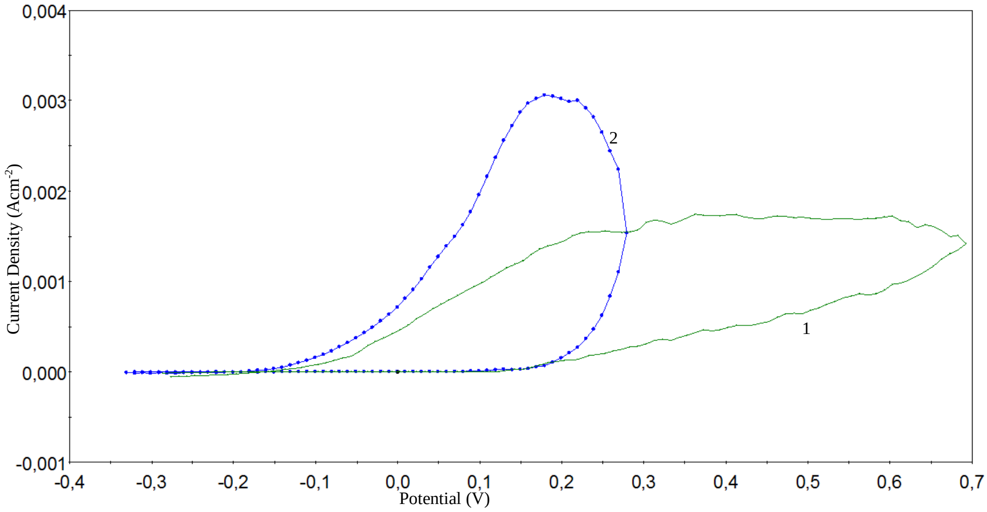

Figure 4. Cyclic polarization curves of stainless steels treated at 20 °C (1 - 317L, 2 - 304L)

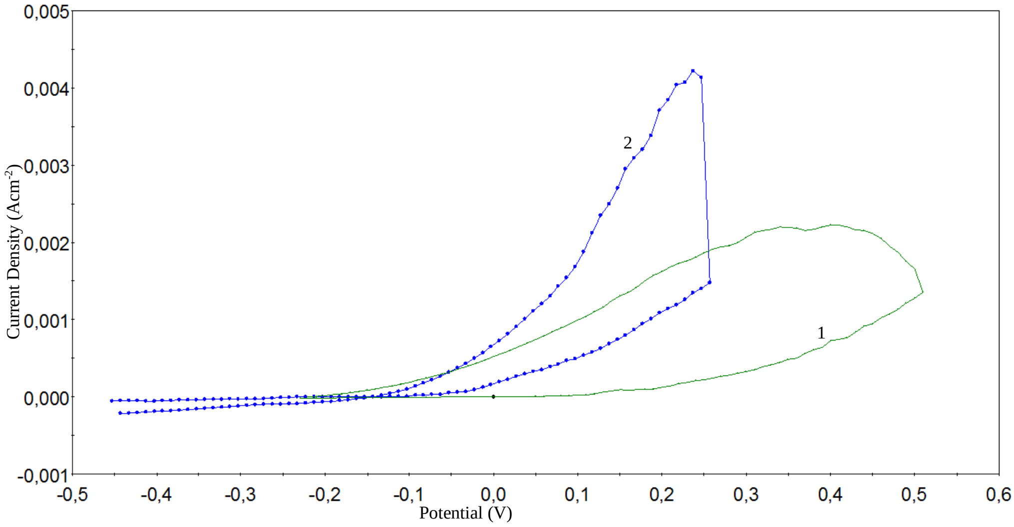

Figure 5. Cyclic polarization curves of stainless steels treated at 30 °C (1 - 317L, 2 - 304L)

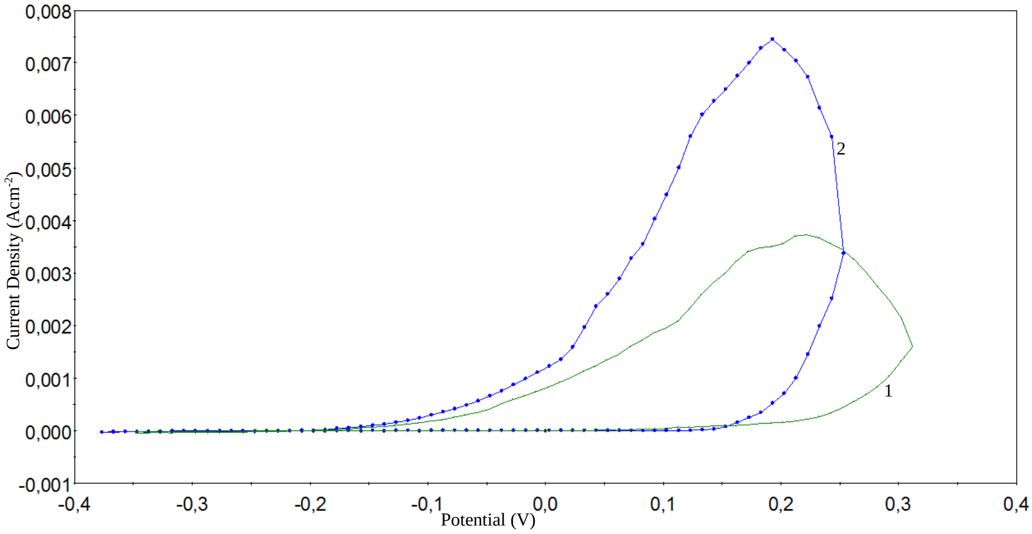

Figure 6. Cyclic polarization curves of stainless steels treated at 40 °C (1 - 317L, 2 - 304L)

Table 2. Pitting potential of tested stainless steels

t, °C	AISI	Pitting potential,± 10 mv
20	304L	199
	317L	233
30	304L	27
	317L	220
40 6	304L	163
	317L	212

A comparative analysis of the hysteresis loop areas (Figures 4, 5 and 6) and the measured pitting potentials(Table 2),reveals that all the tested samples of 317L exhibit lowerpitting corrosion activity than those of 304L.Samples of 317L austenitic stainless steel have a smaller hysteresis loop area (Figures 4, 5 and 6) and more positive pitting potential values (Table 2) compared to samples of 304L stainless steel. This difference in corrosion performance can be attributed to the presence of molybdenum in the chemical compositionof 317L, which is absent in 304 L. Given that the primary compositional distinction between these two steel grades lies in the molybdenum content, it reasonable to associate the enhanced corrosion resistance of 317L with alloying effect of molybdenum. In general, the addition of molybdenum to wrought austenitic stainless steels is known to improve their corrosion resistance [12].

4. CONCLUSIONS

Based on the conducted tests examining the influence of temperature and chemical composition, particularly molybdenum content, on the pitting corrosionbehaviour of austenitic stainless steels, the following conclusions can be drawn:

- An increase in the temperature of the 1.5% NaCl solution leads to a higher rate of pitting corrosion in both tested steel grades,304L and 317L
- 317Ldemonstrates superior resistance to pitting corrosion compared to 304L. This improved performance is attributed to the presenceof molybdenum in the 317 alloy, which is absent in the composition
- Overall, the results confirm that the addition of molybdenum enhances the pitting corrosion resistance of austenitic stainless steels.

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IZVOD

ISPITIVANJE PITTING KOROZIJE AUSTENITNIH NEHRĐAJUĆIH ČELIKA TIPOVA AISI304L I AISI317L: S POSEBNIM NAGLASKOM NA ULOGU MOLIBDENA

Austenitni nehrđajući čelici su među najčešće korišćenim vrstama nehrđajućeg čelika, a posebno je uobičajena serija 300 Američkog instituta za gvožđe i čelik (AISI). Počevši od osnovne legure 304 (Fe-19Cr-10Ni), ugradnja molibdena poboljšava otpornost na koroziju u obliku tačkaste korozije (2-3 tež.% kod AISI 316 i 3-4 tež.% kod AISI 317). Da bi se sprečila senzibilizacija izazvana smanjenjem hroma tokom zavarivanja i drugih termičkih procesa, i rezultirajući rizik od interkristalne korozije, koriste se varijante sa niskim sadržajem ugljenika kao što su 304L, 316L, 317L (sa sadržajem ugljenika ≤ 0,03 tež.%). Alternativno, stabilizacija se može postići legiranjem sa titanijumom (AISI 321) ili niobijumom i tantalom (AISI 347), koji vezuju ugljenik na povišenim temperaturama. Hrom doprinosi otpornosti na oksidaciju, dok nikl poboljšava duktilnost i obradivost u ambijentalnim uslovima. Ovaj rad istražuje ponašanje niskougljeničnih austenitnih nehrđajućih čelika, posebno AISI317L i AISI304L, usled tačkaste korozije. Eksperimentalni rezultati su predstavljeni kroz ciklične potenciodinamske polarizacione krive. Rezultati ukazuju na to da se intenzitet tačkaste korozije smanjuje sa smanjenjem temperature u 1,5% rastvoru NaCl i da prisustvo molibdena u AISI317L značajno poboljšava otpornost na koroziju.

Ključne reči: *Austenitni nehrđajući čelici, molibden, tačkasta korozija, temperatura, hemijski sastav, ciklične polarizacione krive*

Naučni rad
Rad primljen:09.03.2025.
Rad prihvaćen: 25.05.2025.

Farzet Bikić: https://orcid.org/0009-0002-9797-8883
Dejana Kasapović: https://orcid.org/0009-0003-2066-6053