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Mutual examination of corrosion and wear resistance of sandblasting and etching surface treatments applied to AISI 316L stainless steel

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Abstract: Since AISI 316L stainless steel has excellent mechanical qualities and resistance to corrosion, it is widely used in many different industries. Surface treatments like etching and sandblasting are frequently used to improve the surface properties for certain uses. It is still difficult to comprehend how these treatments affect the material's resistance to corrosion and wear, though. In this work, we methodically examine how sandblasting and etching affect AISI 316L stainless steel's resistance to corrosion and wear. We assess the morphological, chemical, and performance changes brought about by these treatments using X-ray diffraction, scanning electron microscopy, microhardness testing, and tribological analysis. Our findings show that the surface morphology and chemistry are dramatically changed by both treatments, which has an impact on the corrosion and wear behavior of the material. The best wear resistance was obtained from the sandblasted sample (0.64 x10^{-3} mm^3/Nm) and the best corrosion resistance was obtained from the untreated sample. The optimization of surface treatment techniques for stainless steel alloys in many industrial applications is facilitated by these findings.

Keywords: 316L, Etching, Blasting, Wettability, Wear, Corrosion.

1. Introduction

Many industrial applications, such as aerospace components and biomedical implants, use AISI 316L stainless steel as a foundation material [1]. Its exceptional mechanical properties and corrosion resistance are well known. Because of its remarkable corrosion resistance and biocompatibility, AISI 316L stainless steel is a highly favored alloy among its numerous grades [2].

The surface integrity of AISI 316L stainless steel is critical to the effectiveness of material in critical applications since the material's performance can be hampered by exposure to corrosive chemicals and mechanical stresses [3]. Numerous surface treatment methods have been created to enhance surface characteristics; these methods are intended to support specific attributes like corrosion resistance, wear resistance, or visual attractiveness [4].

Sandblasting and etching surface treatments have attracted the greatest attention among these methods and have the potential to enhance surface characteristics since they can alter the chemistry and topography of the surface [5]. While sandblasting creates a rough texture by abrading the surface with high-speed abrasive particles, etching, which involves the chemical disintegration of surface layers, alters the surface morphology and composition [6].

It is difficult to fully understand how etching and shot blasting affect the corrosion and wear resistance of AISI

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316L stainless steel, despite their widespread use[7]. It is critical to close this information gap in order to enhance surface treatment protocols and material selection in a range of industrial applications [8].

When the literature was examined, it was seen that acid etching and sandblasting processes had previously been applied to the 316L material and that wear, corrosion and surface wettability had not been mutually examined. It is thought that this gap in the literature will be filled with this study.

This study methodically looked at the corrosion and wear resistance provided by surface treatments such as sandblasting and etching applied to AISI 316L stainless steel. The purpose of this work is to clarify the intricate relationships between surface morphology, chemistry, and performance properties by combining sandblasting and etching surface treatments, thereby offering crucial information on the design and optimization of surface treatment protocols for stainless steel alloys. Each sample was evaluated using scanning electron microscopy (SEM), X-ray diffraction (XRD), and microhardness testing. The electrochemical and wear properties of the samples were then examined using pin-on-disk tribotester and electrochemical impedance spectroscopy (EIS), respectively.

2. Experimental details

Austenitic stainless-steel samples (AISI 316L) with a diameter of 10 mm and a thickness of 3 mm were used for this research. Alumina powder was used to polish AISI 316L samples after they had been ground using SiC sandpapers (80-1000 mesh). It was then cleaned with ethanol and dried.

Subsequently, the AISI 316L samples underwent surface treatments, including etching and sandblasting, as depicted in **▶Figure 1**. The sample AISI 316L that was etched was created according to a different study, which involved etching it in diluted hydrofluoric acid and then controlling its oxidation in hydrogen peroxide [9]. As stated in a different work, 700 µm Al_2O_3 was used to prepare the blasted AISI 316L sample[10].

The phase of 316L samples was determined on a 2θ scale spanning 20° to 100° using an XRD-GNR-Explorer X-Ray diffraction apparatus in conjunction with a Cu-K (= 1.54059) source operating at 40 kV and 30 mA. All phases were distinguished by comparing them to the International Diffraction Data Center (ICDD) standard cards. The top was photographed using the FEI QUANTA 250 Scanning Electron Microscope. The contact angles of the samples were determined by means of a contact angle measurement system (Attension Theta Lite C204A, Biolin Scientific, Sweden). 5 mL volumes of distilled water drops were used for contact angle measurements. Five different measurements were made for each sample and average values were used. Experiments were carried out at room temperature. Distilled water was dropped onto the sample surface from a height of 3 cm. All contact angle measurements were performed under the same conditions [11]. Using a Buehler Micromet device, Vickers microhardness measurements were carried out by loading for 10 s at a force of 10 g and averaging data from 5 distinct locations as applied in the previous study [12].

To find out the tribological characteristics of 316L that has been pack sandblasted, etched, and untreated, Turkyus PODT and RWT reciprocating tribotester were utilized. As per the ASTM G133-02 standard, the wear tests were conducted using a 6 mm diameter Al_2O_3 (alumina) ball and 316L under friction circumstances in dry sliding settings, at a room temperature of approximately 22 °C and a relative humidity of roughly 50% [13]. The wear test settings were set to 1 N of load, 8 mm/s of wear track length, and 141 m of sliding distance as for ASTM G133-02.

316L samples that had been sandblasted, etched, and untreated were subjected to electrochemical corrosion testing. The samples underwent two repetitions of the potentiodynamic polarization and open circuit potential (OCP) tests for each parameter assessed with the Gamry Reference 3000 potentiostat/galvanostat/ZRA [14].

3. Results and discussion

▶Figure 2 shows the X-ray diffraction (XRD) patterns of substrate 316L. It can be seen that the substrate left

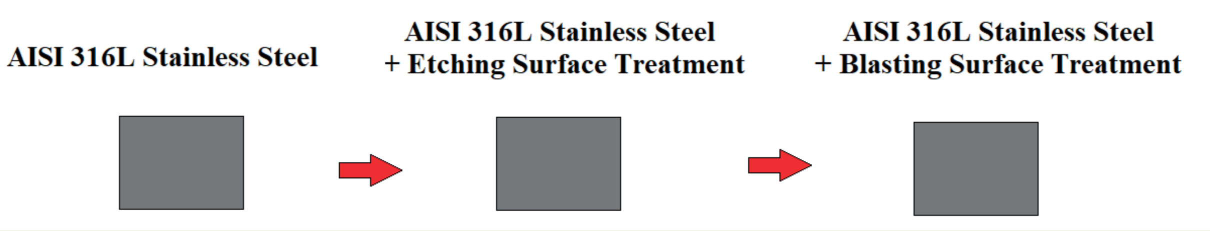

Figure 1. Schematic representation of surface treatments applied to AISI 316L samples

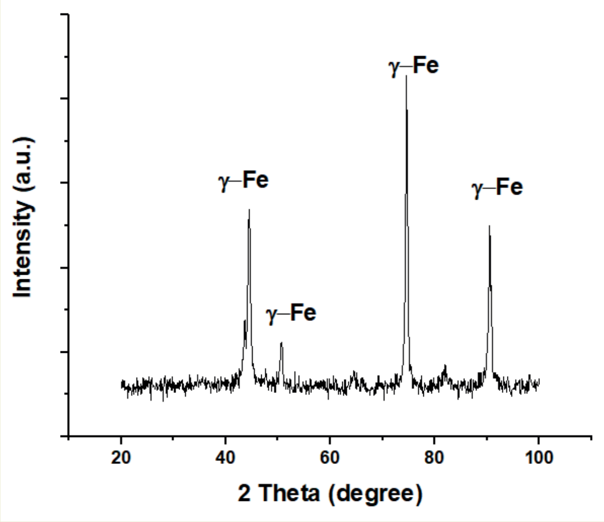

Figure 2. XRD patterns of substrate 316L

untreated consists entirely of austenite structure [15].

▶**Figure 3** shows SEM pictures of etched, sandblasted, and untreated 316L surfaces. As anticipated, the untreated surface merely shows the scratches that were created on it following the application of polishing. Surface roughness increased following the etching procedure in comparison to the untreated surface [16]. It is evident that the 316L surface is severely damaged by the sand grains sprayed on it, resulting in a rougher structure than the untreated surface [17]. Thus, following the application of both surface treatments, it is evident from the SEM pictures that the surface morphology has changed.

▶**Figure 4** presents contact angle measurements of 316L surfaces that have been etched, sandblasted, and left untreated. It is well known that a hydrophilic or hy-

Table 1. Results of tests performed on all samples for wettability, hardness, corrosion, and wear.

	E_{corr} (mV)	i_{corr} (x10^{-6}A/cm^2)	Contact Angle (°)	Hardness ($HV_{0.1}$)	Wear rate (x10^{-3} mm^3/Nm)
Blasted	-150	15.45	65	470-500	0.64
Etched	-140	15.40	30	290-310	0.86
Untreated	-160	15.50	53	280-300	0.84

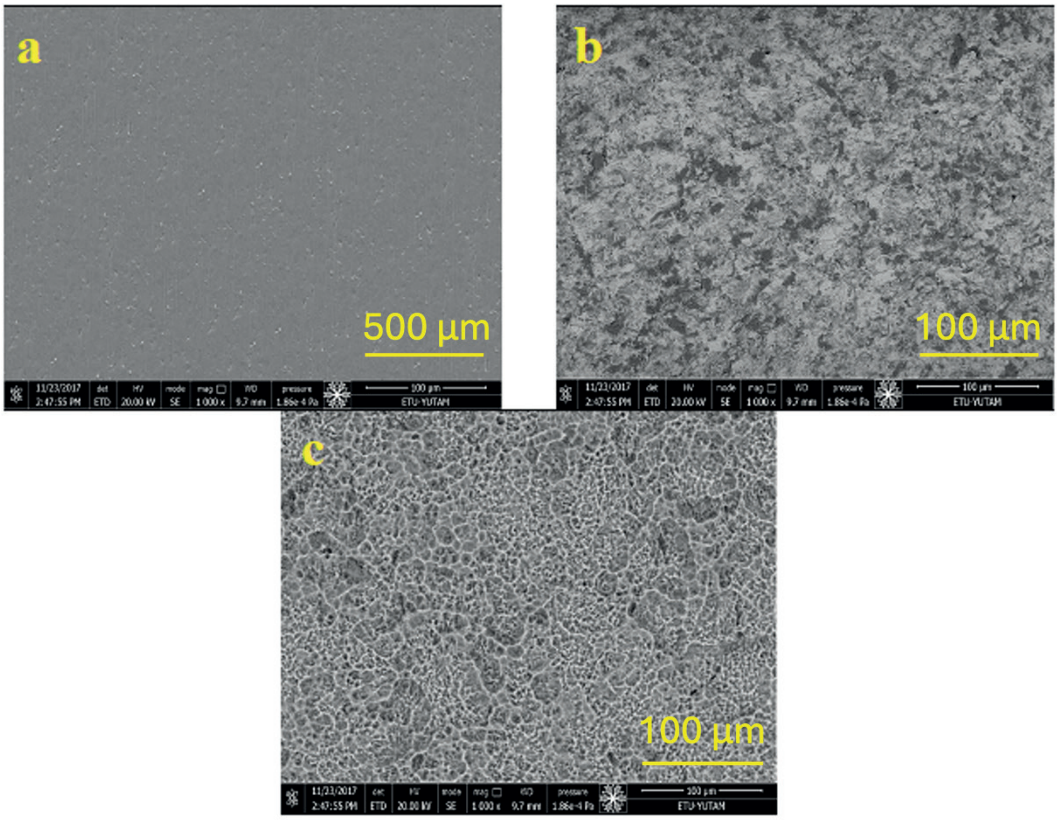

Figure 3. SEM images of (a) substrate, (b) etched, and (c) blasted 316L samples.

drophobic characteristics of surface can be determined by the contact angle values that are derived from the surface [18]. It is known that contact angles less than 90° are hydrophilic, while those greater than 90° are hydrophobic [19]. Hydrophilicity was observed on the untreated surface, with a contact angle of roughly 53°. At a contact angle of 30°, the etched surface exhibited more hydrophilicity than the untreated surface. According to published research, the increase in hydroxyl groups on the surface of etched samples is primarily responsible for their enhanced wettability when compared to untreated samples [20]. At a contact angle of 65°, a hydrophobic surface was achieved on the blasted surface. Prior research in the literature has indicated that the contact angle increases in tandem with surface roughness [21].

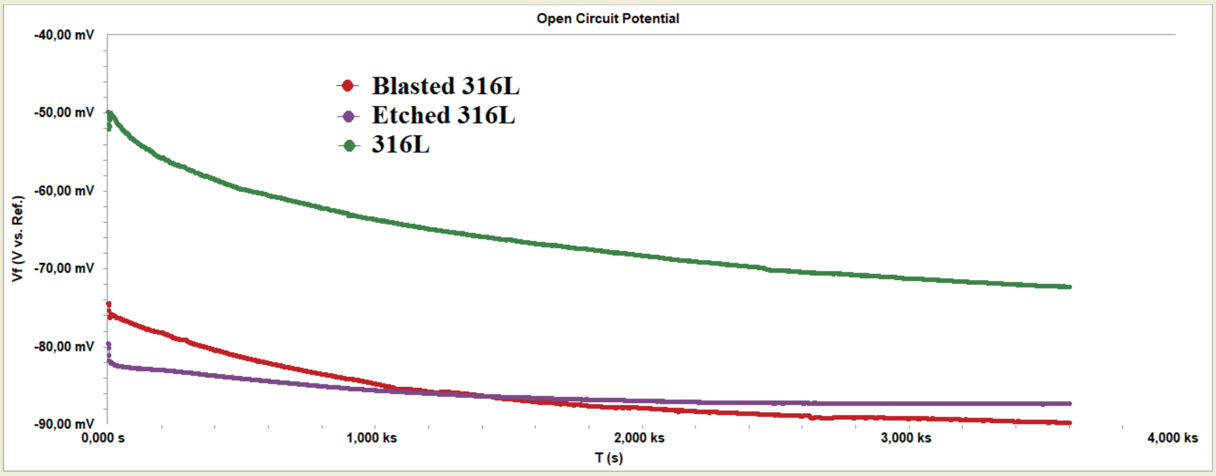

Figure 5. OCP of untreated, etched, and blasted 316L samples.

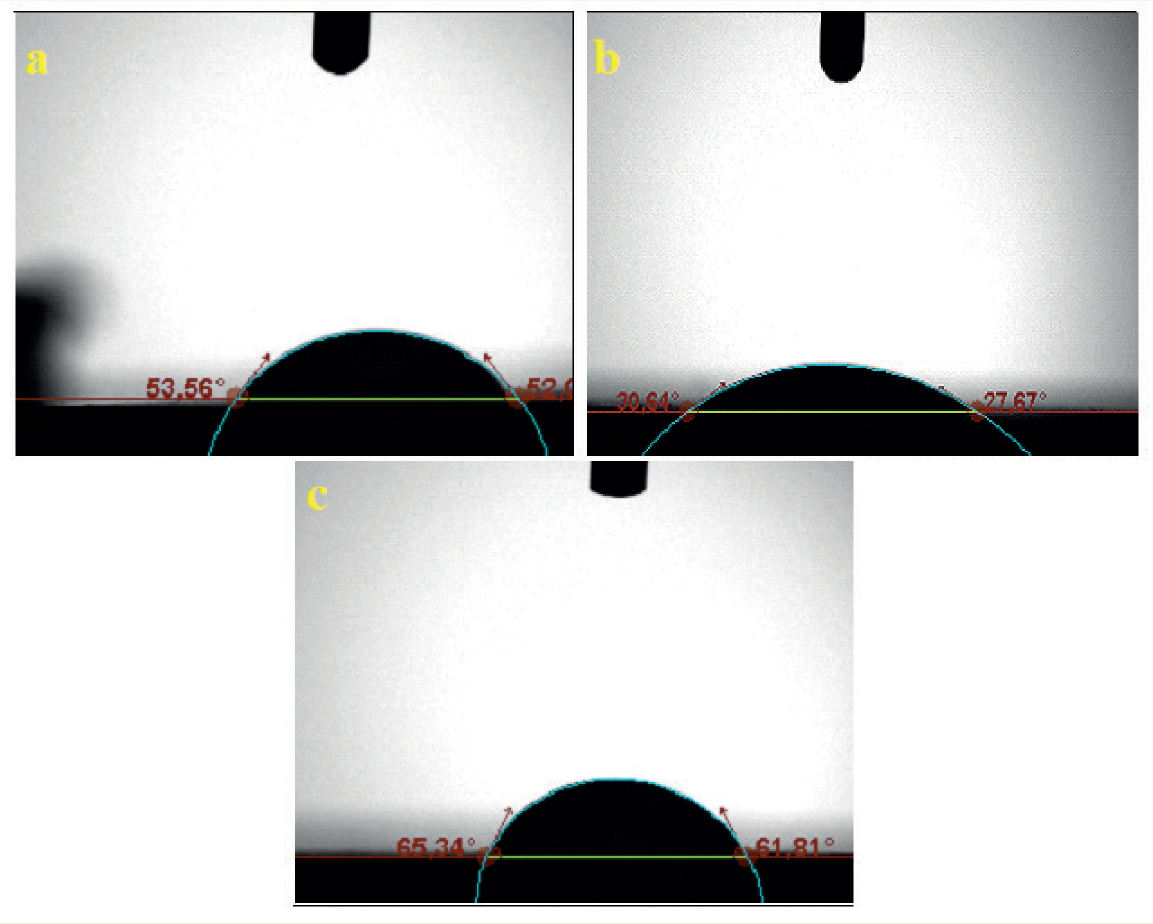

Figure 4. Contact angles of (a) substrate, (b) etched, and (c) blasted 316L samples.

The open circuit potential (OCP) data of 316L samples that were etched, blasted, and untreated are displayed in **▶Figure 5**. Untreated, etched, and blasted samples show comparable OCP curves this trend is common for passive metals [22]. The trend of 316L sample suggests that corrosion cannot happen until voltage is provided [23]. In contrast to the untreated sample, it is evident that the OCP values of the blasted and etched samples moved negatively. This suggests that following the application of surface treatments, the corrosion resistance of surface has decreased.

▶Figure 6 displays the potentiodynamic polarization data that were acquired from electrochemical tests conducted on untreated, etched, and blasted samples in SBF solution. **▶Table 1** presents the data on corrosion potential (Ecorr) and corrosion current density (Icorr) derived from the polarization curves. The corrosion current density (Icorr = 15.5 × 10^{-6}A/cm^2) and corrosion potential (Ecorr = − 160 mV) are highest and lowest, respectively, in the untreated sample. In contrast, the etched sample exhibits the lowest corrosion Icorr (15.4×10^{-6}A/cm^2) and the highest positive Ecorr (− 140 mV) when compared to the etched and blasted sample. Higher Ecorr and lower Icorr values indicate better corrosion resistance [24]. Every potentiodynamic curve

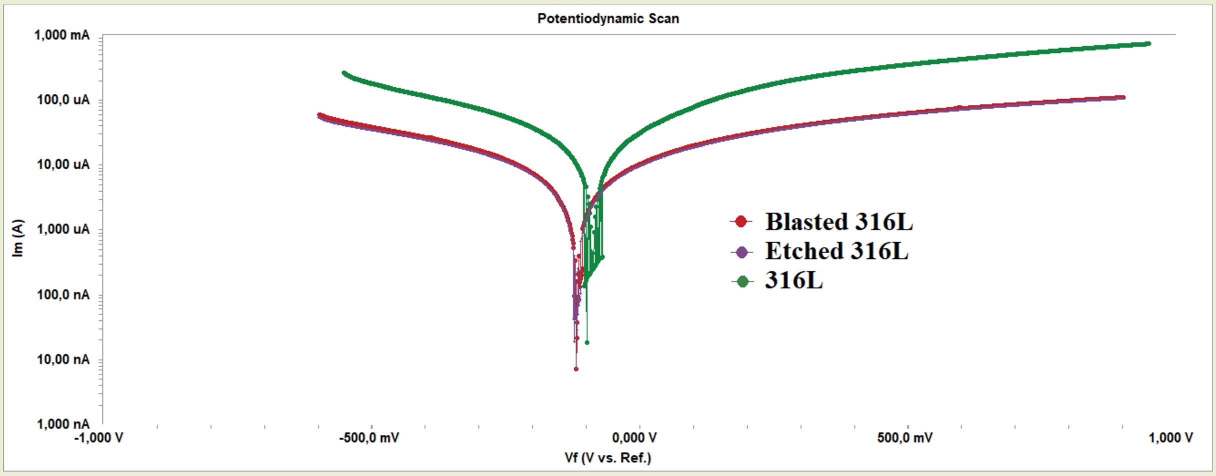

Figure 6. Potentiodynamic polarization curves of untreated, etched, and blasted 316L samples.

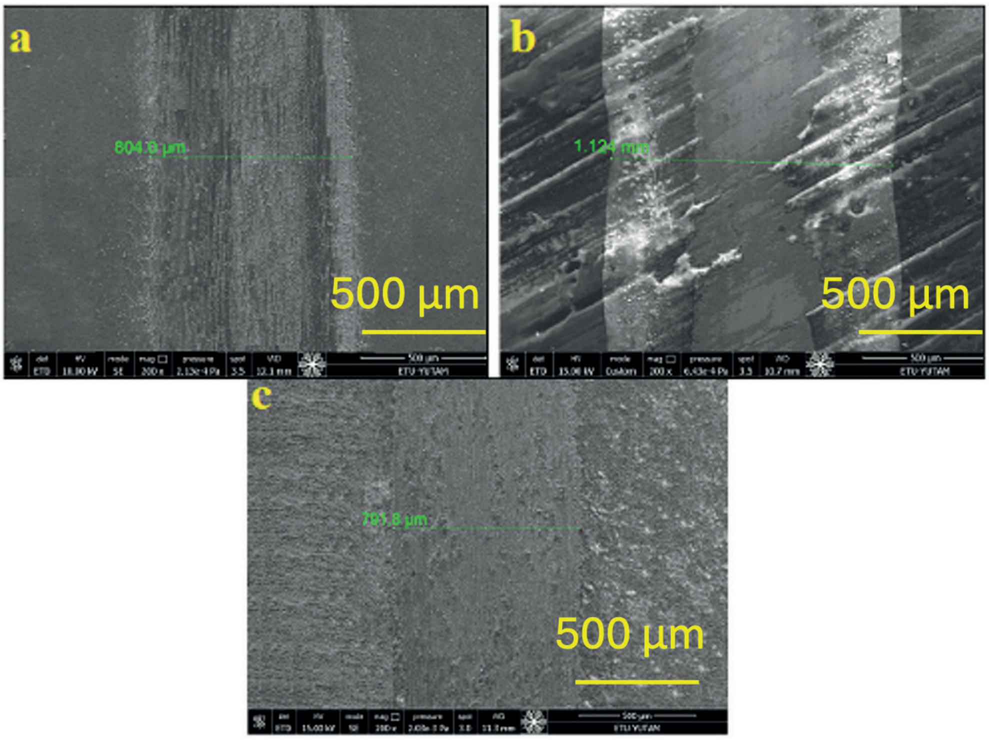

Figure 7. SEM wear trace images of (a) substrate, (b) etched, and (c) blasted 316L samples.

of samples has a 316L-typical form. The etched sample and the blasted sample both stabilize at the lowest potential. As can be observed from the OCP values, the stabilization of the etched and blasted sample at a lower potential than the untreated sample suggests that the 316L surface is damaged as a result of the applied surface treatments [25].

It was clear from looking at **▶Figure 7** and the wear rate statistics in **▶Table 1** that the etched sample with the lowest wear resistance was the one with a wear rate of 0.86×10^{-3} mm^3/Nm. After the etched sample, untreated and blasted samples were placed in that order. The blast sample with the highest wear resistance value was the one with the shortest wear trace and lowest wear rate (0.64×10^{-3} mm^3/Nm). It is commonly recognized that an ability of materials to withstand wear is significantly influenced by its surface hardness [26]. Archard's law states that a higher surface hardness actively increases wear resistance by reducing the contact between the coating system and the wear ball [27].

4. Conclusion

Our comprehensive research investigated the effects of sandblasting and etching surface treatments on the corrosion and wear resistance of AISI 316L stainless steel, revealing significant changes in surface properties following these treatments, which notably affected the material's performance in industrial environments. Both sandblasting and etching altered the surface morphology and chemistry, leading to changes in corrosion behavior. Despite the observed increase in surface roughness and hydrophilicity after etching, the corrosion resistance of the material decreased, as evidenced by negative shifts in the open circuit potential. Similarly, while sandblasting provided a rougher surface and higher hydrophobicity, it also compromised the corrosion resistance of the material. Moreover, our tribological investigation revealed significant differences in wear resistance between untreated samples. The etched surface exhibited the lowest wear resistance despite its increased roughness, while the sandblasted surface showed the highest wear resistance, supported by a lower wear rate and smaller wear scar, consistent with Archard's law, which emphasizes the critical role of surface hardness in determining wear resistance. These findings are of practical importance, providing valuable information for optimizing surface treatment protocols in the selection and application of 316L in various industrial contexts.

Research Ethics

Ethical approval not required.

Author Contributions

The author(s) accept full responsibility for the content of this article and have approved its submission.

Competing Interests

The author(s) declare that there are no competing interests.

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Not reported.

Data Availability

Not applicable.

Peer-review

Externally peer-reviewed.

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