

Surface buffing and its effect on chloride induced SCC of 304L austenitic stainless steel

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Abstract: The study focuses on the impact of buffing operation on the stress corrosion cracking (SCC) susceptibility of 304L austenitic stainless steel (SS). The SCC susceptibility of the buffed surfaces were determined by testing in boiling magnesium chloride (MgCl₂) environment as per ASTM G 36. Test was conducted for 3hr, 9hr and 72hr to study the SCC susceptibility. Buffed surfaces were resistant to SCC even after 72hr of exposure to boiling MgCl₂. The surface and cross section of the samples were examined for both before and after exposure to boiling MgCl₂ and was characterized using optical microscopy. The study revealed that buffing operation induces compressive residual stresses on the surface, which helps in protecting the surface from SCC.

1. Introduction.

Austenitic stainless steels (SS) are used in various industrial applications, owing to several advantages like excellent mechanical properties and good corrosion resistance [1]. AISI 304L stainless steels being metastable in nature are highly susceptible to martensitic transformation by the application of plastic deformation or by cooling to a temperature below 0°C [2]. The transformation of austenite to martensite phase during mechanical and thermo-mechanical treatment of AISI 304L SS has been studied [3–5]. The formation of strain-induced martensite not only results in high hardness near the surface but also results in increased dissolution of ions in presence of chloride environment resulting in early initiation of SCC [6]. Surface working has been shown to result in more damage when compared to bulk deformation of 304L SS [6–9]. However, surface working operations are indispensable in the industrial fabrication of components. The literature establishes the deleterious effects of surface working operations on the SCC susceptibility of 304L SS. However, a solution to the problem of SCC is absent in the literature. The present study aims to use one of the commonly used surface working operations, namely buffing for modifying the surface residual stress distribution of SS. Surface buffing is a conventional finishing process of a metal surface to give the desired finish. The purpose of buffing is to improve the surface appearance of a metal and produce a smooth tight surface [10]. The present study has investigated the effect of surface buffing on SCC susceptibility of 304L austenitic SS.



2. Experimental techniques

2.1. Material and methods

AISI grade 304L austenitic SS was used in this study with a chemical composition of (wt. %): 0.03 C, 18 Cr, 8 Ni, 1.6 Mn, 0.04 P, 0.4 Si, 0.013 S and balance Fe. The material was sectioned into 100 mm x 25 mm x 5 mm. These samples were solution annealed at 1025°C for 15 min. Subsequently, the material was subjected to buffing operation using 240, 400, and 600 grit paper at a fixed rotating speed of 3600 rpm which resulted in thickness reduction of 50 μm . The surface roughness was measured using surface profilometer (contact mode) and Vickers hardness measurements were taken along cross-section for surface buffed and As-received samples. X-ray diffraction studies were conducted to confirm the phases present in the material. Residual stresses distribution of the surface was determined using X ray diffraction technique.

2.2. Stress corrosion cracking tests

The stress corrosion cracking (SCC) susceptibility of 304L SS was determined by boiling MgCl_2 testing as per ASTM G 36 [11]. Strips of the surface buffed samples (dimensions 10mm x 10mm x 5mm) were exposed to boiling MgCl_2 solution maintained at $155^\circ\text{C} \pm 1^\circ\text{C}$ in a Erlenmeyer flask with a water cooled condenser and a provision of a thermometer. The condenser prevents the loss of vapor during boiling. Care has been taken to maintain the temperature inside the flask. List of apparatus required for the SCC setup are listed in Figure1 are 1) Erlenmeyer flask.2) Water-cooled condenser. 3) water Inlet/outlet pipe. 4) Thermometer (250°C). 5) Hot plate. The test has been conducted for 3hr, 9hr and 72hr. Followed by detailed characterization of the nature and morphology of the cracks.



Figure1: Stress corrosion cracking (SCC) test setup [ASTM G36-94]

3. Results:

3.1 Surface roughness and Hardness measurements

The surface roughness of the As-received and surface buffed samples were measured using surface profilometer (contact mode) and micro-vickers hardness was measured across the thickness of the samples using 100gf load and dwell time of 10 s, for each case two sample were taken and three readings were taken. Hardness profile is plotted in Figure 2 and Results are tabulated in table 1.

Table 1: Hardness measurements and surface roughness readings

SAMPLE 304L stainless steel	Average Vickers Hardness (HV)	Average Surface roughness (Ra)
As-received 304L SS	170±14	0.5µm
Surface buffed (SB)	197±18	0.05µm

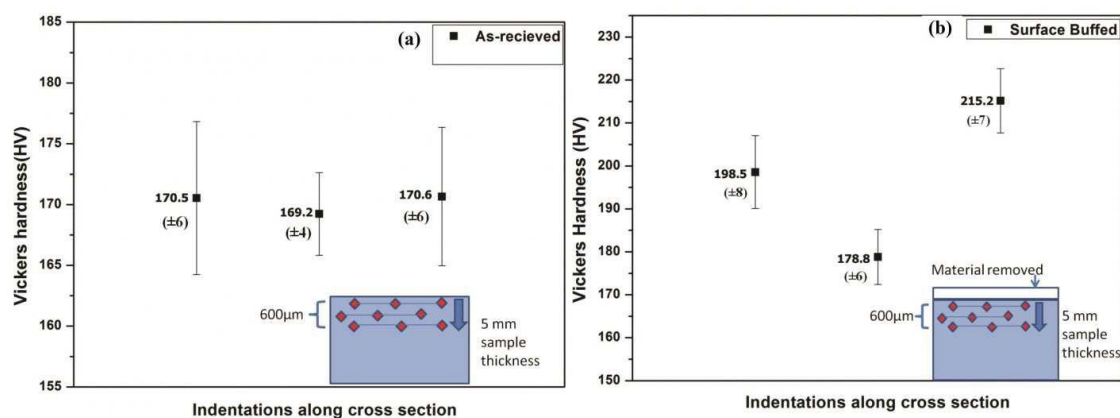


Figure 2: Hardness profile of SS 304L SS a) As-received and b) Surface buffed condition.

3.2. X-ray diffraction studies

XRD technique was used to determine the phases present by using Cu-K α radiation, wavelength of 1.54Å. Accelerating voltage 40 V, diffraction angle from 40°-100° and step size of 0.02° was used. Both Figure 3(a) and Figure 3(b) showed the typical austenite peaks and additional peaks of strain induced martensite was evident in buffed samples.

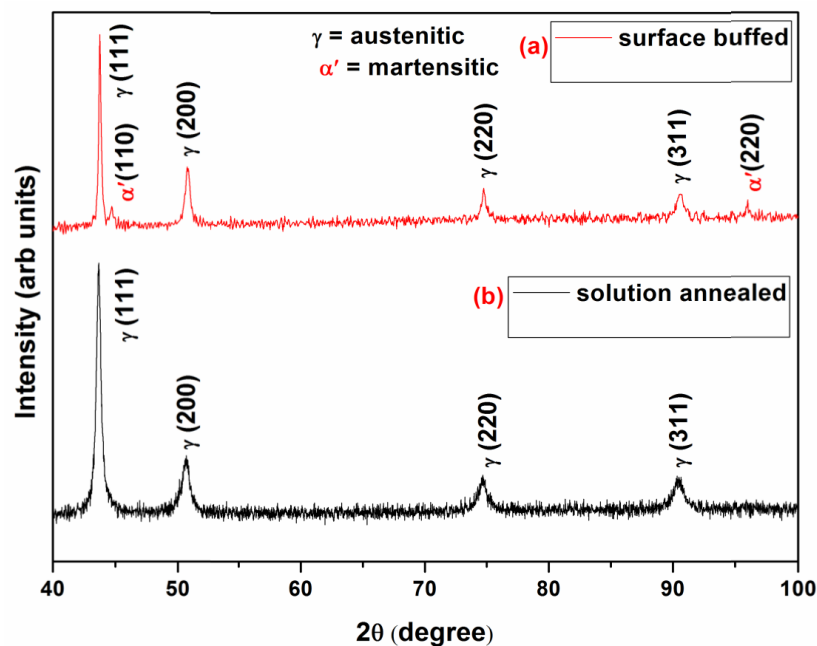


Figure 3: X-ray diffraction patterns for 304L SS in a) Surface buffed and b) Solution annealed condition

3.3. Residual stress measurements

Residual stresses present on the surface for as-received stainless steel 304L samples and surface buffed samples was determined using X-ray diffraction technique [12] with Cr-K α as X-ray radiation source with an applied voltage of 27 kV and current of 70 mA. The wavelength used was 2.28 Å. The austenitic peak (311) plane was considered for diffraction with a step size of 0.1°, Bragg angle ($2\theta = 147.6^\circ$) was kept constant. The collimeter diameter was set to 4mm to measure the surface residual stresses with an exposure time of 20 S. X-ray penetration was around 10 μ m. From Figure 4, residual stress values are calculated and tabulated in Table 2.

Table 2: Residual stress values of as-received 304L SS and surface buffed operations

SAMPLE ID	Longitudinal	Transverse
304L stainless steel	direction	direction
	(0 degree)	(90 degree)
	MPa	MPa
As-received 304L SS	-298 \pm 26	-152 \pm 10
Surface buffed (SB)	-518 \pm 28	-481 \pm 14

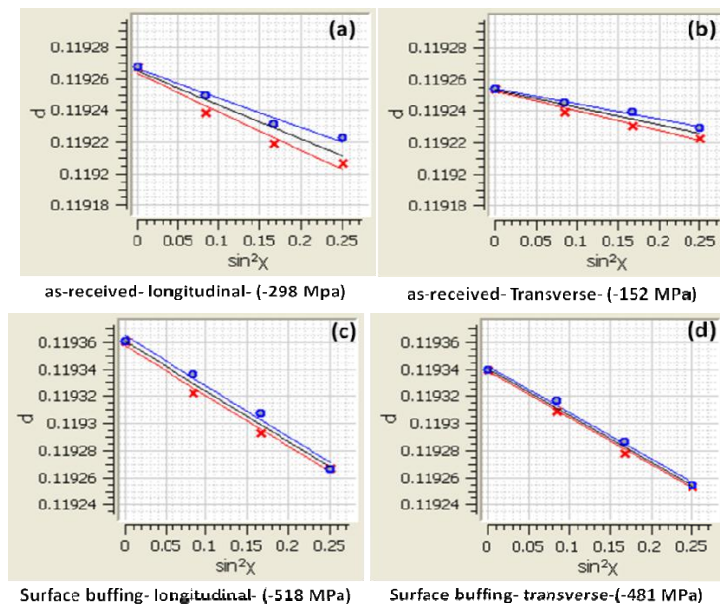


Figure 4: Residual stresses plot of d vs. $\sin^2\chi$ of (a-b) as-received 304L (c-d) surface buffed.

3.4 Stress corrosion cracking (SCC)

Figure: 5 (a-c) shows the optical micrographs of surface buffed samples after exposure in boiling MgCl_2 solution for 3hr, 9hr and 72hr respectively. Figure: 6(a-c) shows the cross-sectional micrographs along the thickness of buffed samples for 3hr, 9hr and 72hr respectively. Buffed samples did not show any signs of cracking. However on prolonged exposure to chloride environment these samples showed intergranular corrosion which is expected. However, no SCC occurred in the case of buffed samples even after 72hr exposure to boiling MgCl_2 in cross-sectional images. The SCC behavior of the machined surfaces could be correlated to the residual stress distribution on the surfaces as discussed in Section 3.3. Buffed samples had compressive stresses on the surface which protected these from SCC. The increased SCC resistance of the 304L SS samples subjected to buffing operation would have extensive application for major industrial components facing severe corrosive environments. If the surface after machining is subjected to buffing operation prior to its industrial application, the nature of residual stress distribution on the surface can be modified and the surface would be made more resistant to SCC. Hence buffing operation which would directly lead to an increase in the service life of the component.

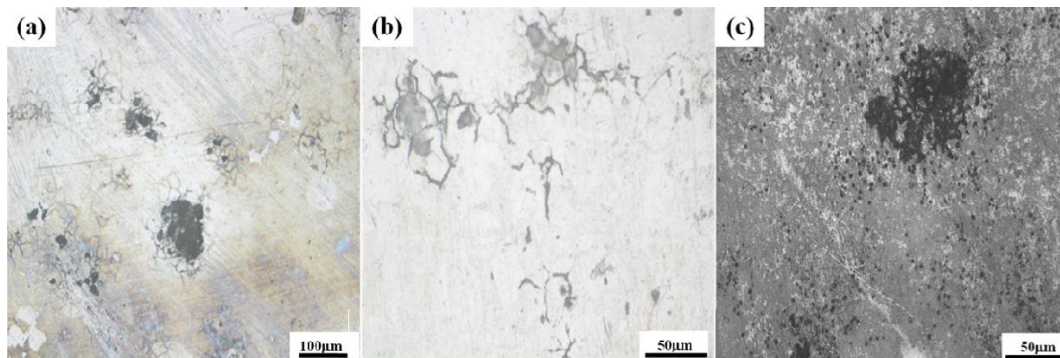


Figure 5: optical micrographs of the surface of 304L SS in buffed condition after exposure to boiling MgCl_2 a) 3 hr, b) 9hr, and c) 72hr.

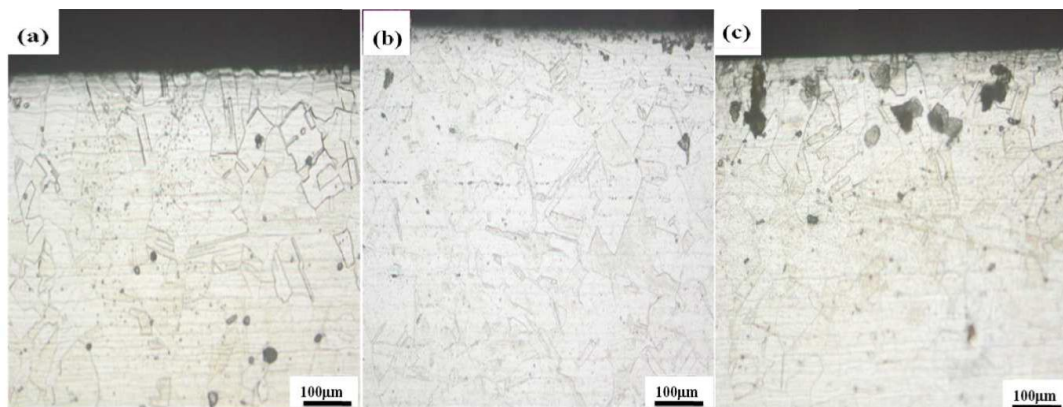


Figure 6: cross sectional micrographs of buffed 304L SS after exposure to boiling MgCl_2 a) 3 hr, b) 9hr, and c) 72hr.

Conclusions:

The effect of surface buffing on chloride-induced SCC of austenitic SS 304L has been investigated.

The results obtained from the study are summarized as follows:

- (a) Buffing induced high compressive residual stresses on the surface of the 304 L SS
- (b) Buffed samples did not undergo SCC even after 72hr of exposure to boiling MgCl_2 .
- (c) Buffing operation made 304L SS more resistant to SCC in an aggressive chloride environment.

References:

- [1] Lo KH, Shek CH, Lai JKL. Recent developments in stainless steels. Mater. Sci. Eng. R 2009; 65:39–104.

- [2] Bayerlein M, Mughrabi H, Kesten, Meier B. Improvement of the strength of a metastable austenitic stainless steel by cyclic deformation-induced martensitic transformation at 103 K. *Mater. Sci.Eng. A* 1992; 159:35–41.
- [3] Maxwell PC, Goldberg A, Shyne JC. Stress-assisted and strain-induced martensites in Fe–Ni–C alloys. *Metall Trans* 1974; 5:1305–24.
- [4] Manganon Jr PL, Thomas G. Structure and properties of thermal-mechanically treated 304 stainless steel. *Metall Trans* 1970; 1:1587–94.
- [5] Hecker SS, Stout MG, Staudhammer KP, Smith JL. Effect of strain state and strain rate on deformation induced transformation in 304 stainless steel: magnetic measurements and mechanical behavior. *Metall Trans* 1982; 13A:619–26.
- [6] S. Ghosh, V.Kain, Microstructural changes in AISI 304L stainless steel due to surface machining: Effect on its susceptibility to chloride stress corrosion cracking, *J.Nucl.Mater.*403 (2010) 62–67.
- [7] T. Shoji, Progress in mechanistic understanding of BWR SCC and its implication to prediction of SCC growth behavior in plants, in 11th International Symposium on Environmental Degradation of Materials in Nuclear Power Systems-Water Reactors, Stevenson, WA, 2003.
- [8] G.G. Scatigno, M.P.Ryan, F.Giuliani, M.R.Wenman, The effect of prior cold work on the chloride stress corrosion cracking of 304L austenitic stainless steel under atmospheric conditions, *J.Mater.Sci.Eng. A* 668(2016)20–29.
- [9] D.T. Spencer, M.R. Edwards, M.R. Wenman, C. Tsitsios, G.G. Scatigno, P.R. Chard-Tuckey, The initiation and propagation of chloride-induced transgranular stress-corrosion cracking (TGSCC) of 304L austenitic stainless steel under atmospheric conditions, *Corros. Sci.* 88 (2014) 76–88.
- [10] Al Dickman, Mechanical surface preparation- polishing and buffing (1999).
- [11] ASTM, G36-94, Standard Practice for Evaluating Stress-Corrosion-Cracking Resistance of Metals And Alloys in a Boiling Magnesium Chloride Solution, Reapproved 2006.
- [12] P. Withers, H. Bhadeshia, Residual stress. Part 1 – measurement techniques, *Mater. Sci. Tech.*17 (2001) pp.355-365.