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The effect of buffing on different surface working operations and to study microstructural changes by chloride induced SCC on 304L austenitic stainless steel

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ABSTRACT

Corrosion resistance and SCC susceptibility of austenitic stainless steel 304L will decrease, when it underwent different surface working operations like milling, turning, and grinding operations as, these are the last stages of industrial finishing operations. It induces tensile residual stresses on the surface of the material and due to higher surface roughness. It will undergo SCC when exposed to chloride environment which results in catastrophic failure. In the present study we report a simple machining process i.e. buffing, must follow as a last stage of industrial fabrication process after surface working operations in order to protect from SCC. The SCC susceptibility for these surface finished samples when subjected to buffing operation was determined by using boiling magnesium chloride test as per ASTM G36 for 3 h. Microstructural changes in surface after SCC test was characterized by optical microscopy (OM) and Field emission gun electron microscopy (FE-SEM). Surface roughness measurements by surface profilometer (contact mode), phase confirmation by using X-ray diffraction technique and residual stress distribution on the surface due to surface working was measured by X-ray diffraction ($\sin^2 \chi$) technique, The study reveals that buffing will improve the SCC resistance of austenitic stainless steel 304L by inducing compressive stresses on the material and having a minimum surface roughness which will helps in preventing from crack propagation. Buffing being a simple and effective method to increase the service life of the component.

Keywords: stainless steel 304L; surface working; stresses corrosion cracking

INTRODUCTION

Most of the industrial applications like, nuclear, chemical, petrochemical etc [1]. Uses austenitic stainless steels (ss), when corrosion resistance, fatigue life and fatigue strength are required. But due to surface finishing operations its effect the surface properties like surface roughness, surface defects (cracks, voids), hardness, strain-induced martensite formation and residual stresses [2]. They depend on cutting parameters (speed, feed and depth-of-cut) [3].Additionally heat generated due to machining can increase the tensile residual stresses. All this together will decrease the corrosion resistance leading to stress corrosion cracking (SCC) [4]. The corrosion resistance of stainless steels depends on a thin passive layer of complex structure, simply called Cr_2O_3 [5]. It has to be built up by the surrounding media and is under their constant attack which is influenced by chemical composition, temperature and fluid flow. However, austenitic Stainless steels are susceptible to localized forms of corrosion like pitting and stress corrosion cracking (SCC) [6-7]. In the present study deals with the effect of buffing operation on different surface finished components and microstructural changes by chloride induced SCC on 304L austenitic stainless steel. Buffing induces high magnitude of compressive stresses on the surface together with a reduction in surface roughness [8]. The presence of compressive stresses on the surface of 304L SS prevented any stress corrosion crack nucleation. Buffing being a portable, simple, and economic operation would be a cost-effective and sustainable method of ensuring structural integrity and increasing the service life of new as well as existing industrial components of austenitic SS.

EXPERIMENTAL PROCEDURE

STAINLESS STEEL 304L

In the present study material used was austenitic stainless steel (SS) 304L, with a chemical composition of (wt. %): 0.03 C, 18 Cr, 8 Ni, 1.6 Mn, 0.4 Si, 0.013 S, 0.04 P, and balance Fe. 304L SS was in the form of 5mm thick plates, was cut into 10cm x25mm x 5mm pieces

Heat Treatment

304L SS cut samples was heat treated in a tubular furnace at 1025º C and soaking for 15 min followed by solution annealed to remove stresses present in it.

Methods

Further these 304L SS samples was given for different surface working operations like turning, milling and grinding operations to remove up to a depth of 0.5 mm from the surface of the sample. And surface buffing on these different surface worked samples to remove up to a depth of 50µm. these samples was further cut into 10mm x 25 mm using precision cutting. To study the effect of microstructural changes after exposure of boiling magnesium chloride as per ASTM G 36 to find the susceptibility of SCC on these surfaces worked samples. Machining parameters of surface working operations was given in Table 1.

Table 1 shows the machining parameters of surface working operations.

Surface working operations	Speed (rpm)	Feed rate mm/rev	Thickness removed	Other parameters
Milling	355	0.2	0.5mm	End mill with 65mm diameter, carbide tip angle 60º, four flutes.
Turning	600	0.1	0.5mm	Silicon carbide tip radius 0.03mm, tip angle 80°, inclination angle 5°
Grinding	2800	0.1	0.5mm	Diamond wheel dia 200mm, 31.75 mm thick
Buffing	3600	Hand operated	50μm	240,400,600 grit polishing paper followed by buffing wheel to obtain mirror finish

Electro Etching

Etching solution—the solution used for etching is prepared by adding 10g of reagent grade oxalic acid crystals ($H_2C_2O_4 \cdot 2H_2O$) to 90 ml of distilled water and stirring until all crystals are dissolved. Voltage: 10 V, Cathode: Immersed steel Bar in Glass beaker. Anode: specimen to be etched. Etching conditions—the polished specimen was etched for 30 sec. these samples were cleaned and dried followed by examination using optical microscopy. Figure 1 shows the optical micrograph of solution annealed 304L SS. with polygonal grains having an average grain size on 30μm.

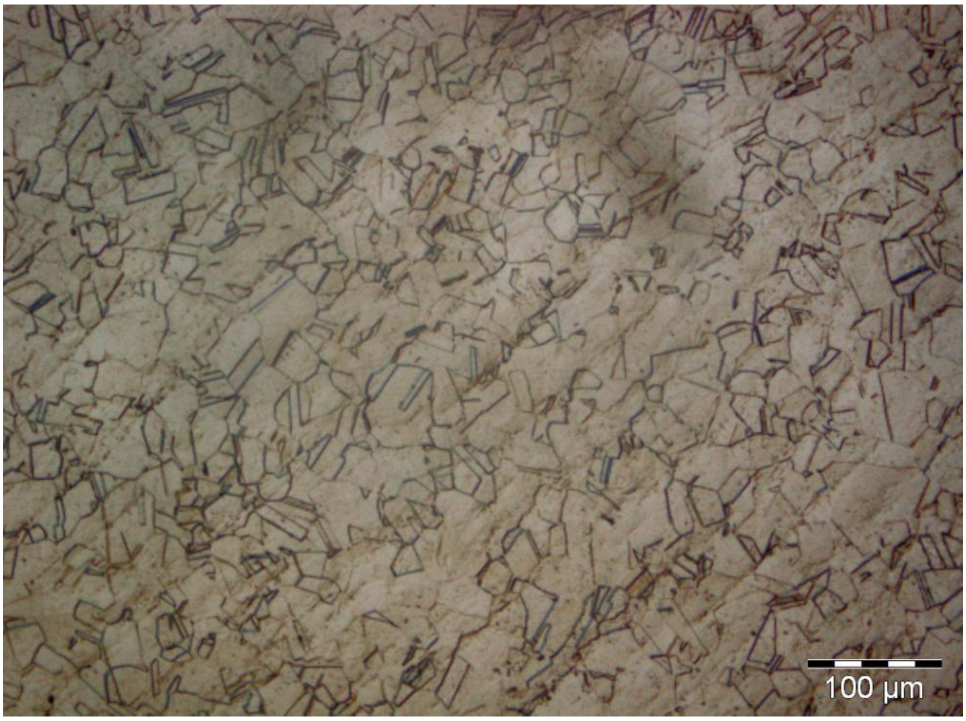

Figure1: shows the optical micrograph of solution annealed 304L SS

Surface roughness

Surface roughness (Ra) measurements were measures using AMBiOS XP200 surface profilometer (contact mode) on surface working samples with scan length of 1 μm. scan speed 0.01 mm/sec, minimum resolution step of 1 nm. For each case measured three readings and calculated the average roughness values.

X-ray diffraction and residual stresses studies

X-ray diffraction studies were done on surface worked samples to determine the phases present on the surface of surface worked samples. With Cu kα as x-ray source as X-ray radiation source with a wavelength of 1.54 Å, Bragg angle 2θ (40º-100º), step size 0.02 and time/step 0.5, accelerating voltage 40 V and current 30mA was used And residual stress measurements was conducted to find the surface residual stresses present on the surface worked samples using ($\sin^2 \chi$) technique with Cr-kα as x-ray radiation source, wavelength of 2.28 Å, hkl plane (311) at 2θ (147.6º) was kept constant for all the surface worked condition with step size of 0.1 and exposure time of 20 s was set to measure the surface residual stresses.

Stresses corrosion cracking susceptibility test:

surface working followed by buffing samples of different conditions were given to an exposure of boiling magnesium chloride test as per ASTM G 36 [9].Added distilled water (15mL) in a magnesium chloride Hexahydrate ($Mgcl_2.6H_2o$) 600grams.until the solution reaches the constant boiling temperature of 155±1 °c. Maintained constant temperature of 155 ±1º in an Erlenmeyer flask with a provision of water cooled condenser, and a thermometer was used to measure the temperature. Test has been conducted for 3 h.

RESULTS

Surface roughness measurements

For each case two samples were taken to measure the surface roughness (Ra) of different surface working conditions, and surface worked followed by buffed samples were also similar to buffed results. Calculated the average roughness and tabulated in table 2

Table2 shows the average roughness values of different

Surface working condition	Milled	Turned	Ground	Buffed
Roughness(μm)	2.1 ±0.15	4.3 ±0.30	0.6 ±0.4	0.05 ±0.01

X-ray diffraction studies

Figure 2 shows the X-ray diffraction patterns of surface working samples. And Figure 3 shows the X-ray diffraction patterns of surface working followed by buffing samples It shows, the standard austenitic peaks (γ) in solution annealed sample with hkl peaks (111), (200), (220) and (311).where as in surface working followed by buffed samples shows strain induced martensite (α´) peaks. More in the case of buffed and ground followed by buffed sample. And calculated the lattice strain and FWHM for the (111) peak for all conditions was tabulated in Table 3.

Table 3 shows the lattice strain and FWHM values for hkl (111) peak for different surface working conditions.

Surface working condition	Milled	Turned	Ground	Buffed	Milled + Buffed	Turned + Buffed	Ground + Buffed
Lattice strain	0.0045	0.0052	0.0039	0.0035	0.0029	0.0037	0.0034
FWHM	0.415	0.482	0.357	0.318	0.269	0.332	0.306

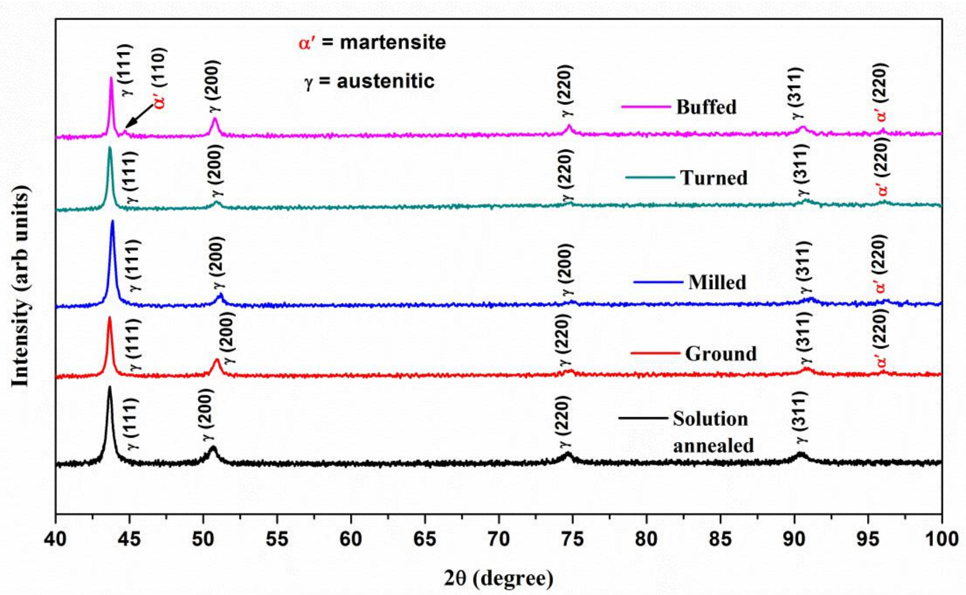

Figure 2 x-ray diffraction patterns of surface worked samples

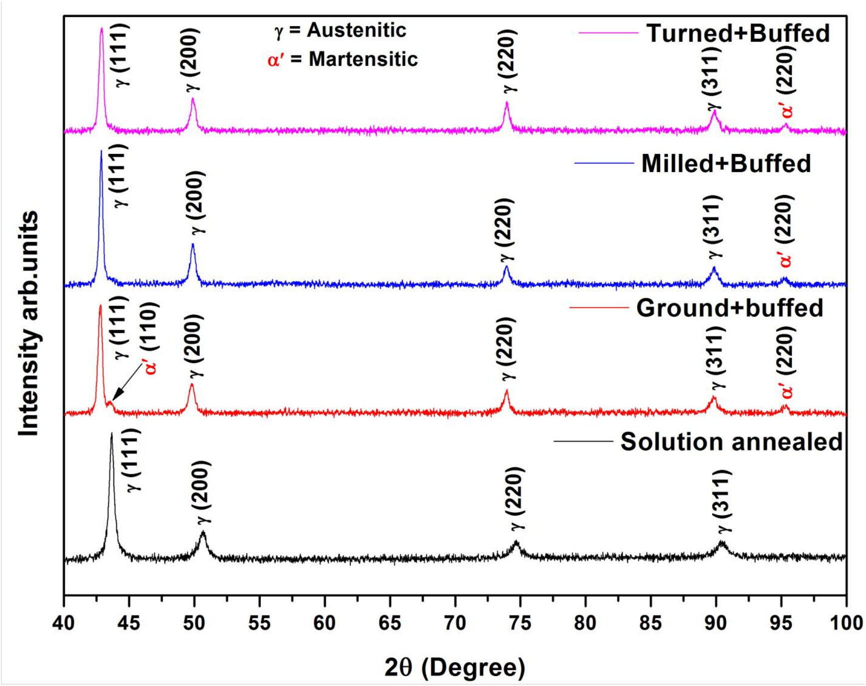

Figure 3: X-ray diffraction patterns of surface worked followed by buffed samples

Residual stresses measurements

Residual stresses measurements were calculated using ($\sin^2 \chi$) technique and tabulated in table 4. Surface worked samples shows tensile residual stresses where as in buffing and surface working followed by buffed samples shows compressive residual stresses. If tensile stresses were present, it will increase the crack propagation at a faster rate. Where as if compressive stresses are present crack propagation will be slower and also it increases the fatigue strength and fatigue life of the material.

Table 4 Residual stresses values for different surface working conditions

Different surface working condition 304L stainless steel	Longitudinal direction (0 º) MPa	Transverse direction (90 º) MPa
Surface milled	704±86	639±71
Surface turned	397 ±82	69±85
Surface ground	192±40	15±39
Surface buffed	-518±28	-481±14
Milled+ buffed	-378±16	-386±21

Turned + buffed	**-523±17**	**-504±26**
Ground+ buffed	**-409±16**	**-481±22**

Examination after SCC test

After 3 h SCC test using boiling magnesium chloride test as per ASTM G 36 [9]. These surface worked samples and surface worked followed by buffing on 304L austenitic stainless steels was examined on the surface of these samples for SCC susceptibility using FESEM. Figure 4-6 (a) shows the milled, turned and ground micrographs respectively, after 3 h of exposure. Shown high density of stress corrosion cracks (SCC). Whereas in Figure 4-6(b) shows surface working followed by buffed like milled followed by buffed, turned followed by buffed and ground followed by buffed samples respectively, micrographs showing no SCC cracks, which are more resistance to SCC even after 3h SCC test. This is due to a) minimum surface roughness, b) presence of low plastic strain and c) presence of compressive residual stresses. If a) surface roughness is more, b) higher plastic strain and c) presence of tensile residual stresses. Which will leads to catastrophic failure. And also it decreases the fatigue life, fatigue strength and environmentally assisted chloride will decrease the life of the components.

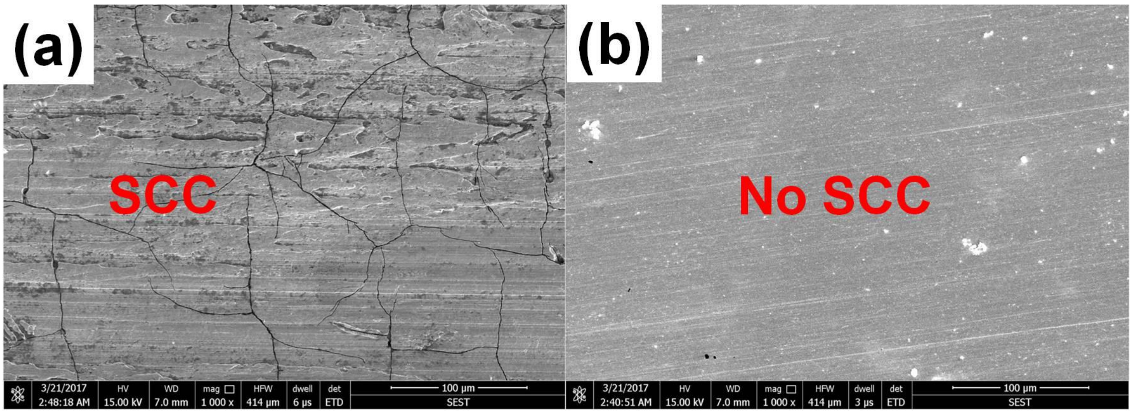

Figure 4 shows the FESEM surface micrographs of a) milled and b) milled followed by buffed after 3h exposure in Mgcl$_2$ test.

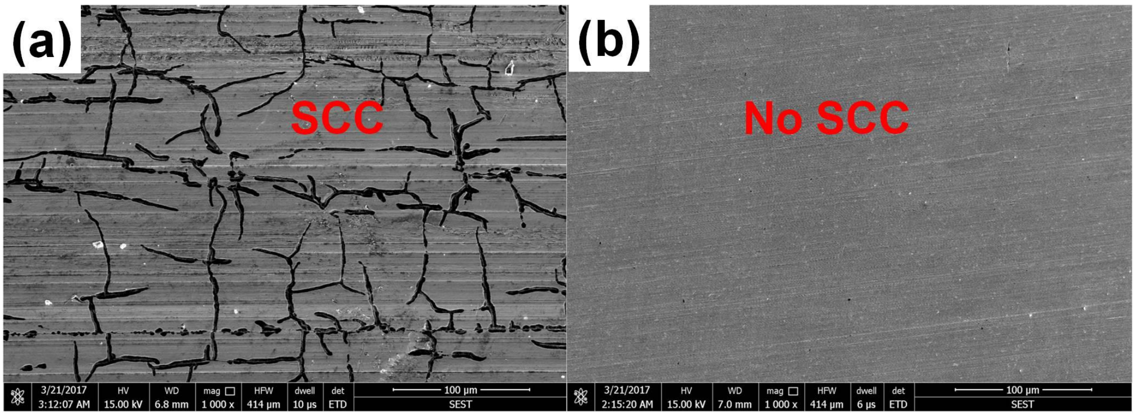

Figure 5 shows the FESEM surface micrographs of a) turned and b) turned followed by buffed after 3h exposure in $Mgcl_2$ test.

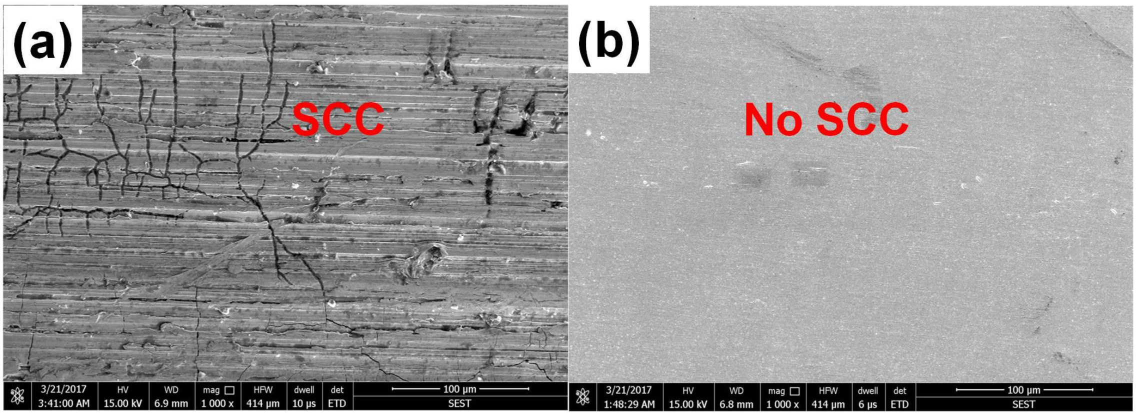

Figure 6 shows the FESEM surface micrographs of a) ground and b) ground followed by buffed after 3h exposure in $Mgcl_2$ test.

CONCLUSIONS

The results of different surface working and surface worked samples followed by buffing results have been investigated and the studies are summarized as follows:

1) Buffing samples and buffing on different surface working samples showed lower roughness.
2) Strain induced martensite formation was seen in all the surface worked samples, more in the case of buffed samples with low plastic strain and reduction of FWHM values.
3) Compressive residual stresses were present in buffed and surface worked followed by buffing samples and tensile residual stresses were present in surface worked samples.
4) Buffing samples are resistance to chloride induced SCC where as surface worked samples are susceptible to SCC.

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