Journal of Material Sciences & Engineering
Sivanathan, J Material Sci Eng 2018, 7:1
DOI: 10.4172/2169-0022.1000412
Research Article
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A Study on the Effect of Surface Grinding on Chloride Induced Pitting Initiation of Austenitic Stainless Steel 304 under Thermal Insulation at Ambient Temperature

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Abstract

The investigation was carried out to study the effect of surface grinding on chloride induced stress corrosion cracking (CISCC) of austenitic stainless steels 304 at ambient temperature condition. The U-bend tests with thickness 13 mm as per ASTM G 30 were used to investigate the effect of surface grinding on chloride induced stress corrosion cracking (CISCC) of austenitic stainless steel 304 in a corrosive atmosphere containing sodium chloride at ambient temperature. At a high level of tensile residual stress had developed the pits on U-bend specimen surface at ambient temperature with the presence of low to high chloride concentration level. The experimental results recommend that develop a proper metallurgical fabrication criteria, specification, and procedures for pressure vessels to avoid a recurrence in future.

Keywords: Surface grinding; Ambient temperature; Chloride; Stress corrosion cracking

Introduction

Austenitic Stainless Steel material in the presence of tensile residual or applied stresses in a chloride environment can be degraded in the form of localized corrosion and cracking. It is suspected that Austenitic Stainless Steel type 304 susceptibility to chloride induced stress corrosion cracking (CISCC) at ambient temperature is dependent on the surface preparation method. Machining and grinding procedures of Austenitic Stainless Steel type 304 increases sensitivity to stress corrosion cracking (SCC) [1].

The metal surface layers can be altered physically and chemically due to the machining and grinding operations. The fabrication and joining process of pressure vessels in the industry is exposed to forming, machining and grinding that damages the external surface of the material used. These damages can be divided as physical due to the mechanical or geometrical damage and chemical changes leading to structural changes and compositional changes. The surface roughness on external layer has a significant effect on initiation of the cracks due to the rise of tensile residual stresses [2].

The initiation of crack usually happens on the surface layer. This operation of machining or grinding induces the initiation of micro-cracks or initiation at the metal surface and not on crack propagation. The cracks can initiate at any spot after a localized corrosion formed at severe corrosive conditions with the presence of chloride ions and where the net of tensile residual stresses is highest. Besides that, an increase in cold work also increases the stress corrosion cracking (SCC) susceptibility by approximately 40% [3].

It is known that a proper design and metal surface finish can minimize the susceptibility. In SCC tests, the bending of flat bar austenitic stainless steel also contributes to the tensile or compressive stresses as the applied load and the grinding leads to tensile residual stresses usually at the outer surface layers [4]. According to A. Turnbull, the tensile residual stress at the surface layer affects the stress corrosion cracking (SCC) behavior by surface machining or grinding [5].

In this research, in order to demonstrate the effect of tensile residual stress on the corrosion behavior in austenitic stainless steel 304 were tested by U-bend specimens at several different chloride concentrations at ambient temperature. The investigation was carried out to study the effect of surface defects such as deep grooves, smearing, adhesive, scratches and indentations on stress corrosion cracking (SCC). In this research the Austenitic Stainless Steel type 304 was exposed to aqueous sodium chloride at atmospheric environments.

Problem Statement

The surface condition of Austenitic Stainless Steel type 304 due to the local cold work can influence their susceptibility to stress corrosion cracking (SCC). In industrial application, engineering guidelines are necessary for machining and the surface grinding method used in the fabrication or in repair of pressure vessel which will not exacerbate the risk of cracking in service.

Objectives

The objective of the study was to investigate the effects of surface grinding on CISCC of austenitic stainless steels 304 in aqueous sodium chloride solution simulating the condition under thermal insulation at ambient temperature.

Methodology

The grinding operations were performed with both parallel and perpendicular to the rolling direction of the material for all the seven U-bend specimens in this experiment. The experiment was to investigate tensile residual stresses by grinding process and micro-notches on the

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Received December 18, 2017; **Accepted** January 02, 2018; **Published** January 12, 2018

Citation: Sivanathan P (2018) A Study on the Effect of Surface Grinding on Chloride Induced Pitting Initiation of Austenitic Stainless Steel 304 under Thermal Insulation at Ambient Temperature. J Material Sci Eng 7: 412. doi: 10.4172/2169-0022.1000412

outer surface as a precursor to initiation of stress corrosion cracking (SCC). The chloride concentration was derived from a failure case. The materials and specimen preparations were prepared according to constant deformation tests for U-bend guidelines from ASTM G 30 standard [6].

Design details

Surface finishing and chloride concentration used is the main contributing factors to the susceptibility of chloride induced stress corrosion cracking (CISCC) in Austenitic Stainless Steel type 304.

Experimental design

The experimental set-up to study the effect of surface finishing on the stress corrosion cracking, chloride concentrations and at ambient temperature. Figure 1a shows the schematic diagram of flat bar sample preparation stages as per ASTM G-30.U-bend specimen preparation is prepared from a flat bar which is bent 180° levels as given dimension as shown in Figure 1b. A bolt and nuts are used to tighten up to sustain a constant strained condition throughout stress corrosion testing. Figure 1c shows the U-bend specimen after grinding and machining of the external surface. The U-bend specimens were immersed in sodium chloride solution at ambient temperature. The base metal of Austenitic Stainless Steel type 304 condition with various chloride concentrations such as 4000, 5000, 6000, 7000, & 8000 ppm chloride for set 1 was tested for the duration of 6 months at ambient temperature. After visual and dye-penetrant inspection the experiment then repeated again with 50, 000 ppm chloride for all the specimens for another 6 months [7].

Results

Non-destructive test (NDT) was conducted by using the Dye-Penetrant test (DPT) method to detect the pits on these Austenitic Stainless Steel type 304 U-bend specimens No 1, 2, 3, 4, and 5 as shown in Table 1. The effect of high tensile residual stress on the corrosion behaviour of austenitic stainless steel induces the pit with the presence of chloride concentration varies. The specimen No 2 reveals the surface defect developed due to the grinding that exhibit deep grooving after the DPT test conducted. This investigation proved that the higher tensile residual stresses with the combination of applied stress on U-bend specimens were affected by the effect of surface finish. The pits found on U-bend specimens No 1, 2, and 5 were created by the localized defect such as grooves on the external surfaces. These defects such as pit initiation will leads to cracking if there is no standard method used in the industry for the fabrication or repair of vessels over time exposure to chloride by the thermal insulation used inside the vessels [8].

Scanning electron microscopy (SEM) results

U-bend specimen No 6 and 7 was used for SEM and EDX analysis. These two specimens were immersed in sodium chloride solution for 200 ppm and 1000 ppm for 6 months. Since there was no crack indication found, the same experiment was repeated for another 6 months with 50,000 ppm for both the U-bend specimen. The scanning electron microscopy (SEM) results as shown in Figure 2. Based on the above NDT inspection, all the U-bend specimens reveals a non-uniform corrosion. The U-bend specimen corrosion was more severe as the chloride concentration increases. After removal, only U-bend specimen for No 1, 2, and 5 observed with pit initiation. Experimental evidence reveals all these U-bend specimens with numerous spots of rusted regions on the grinded surface.

Energy dispersive X-ray (EDX)

EDX results for both U-bend specimen No. 6 and 7 after 12 months in sodium chloride aqueous solution are given in Figures 3 and 4. The chemical composition of the austenitic stainless steel 304 after the U-bend specimen reveals that some element percentage was less such as Cr actual from 18% to as low as 1.9% and 1.1% at certain spot than compared to the actual element standard due to the surface finish, surface preparation, heat treatment and cold working prior to the immersion test to sodium chloride aqueous solution [9]. The investigation found that significant contribution of leachable chloride also necessary for the initiation of localized attack by pitting corrosion to micro-crack formation.

The chemical element analysis after 12 months for both the U-bend specimen No. 6 and 7 in sodium chloride aqueous solutions are given in Tables 2 and 3.

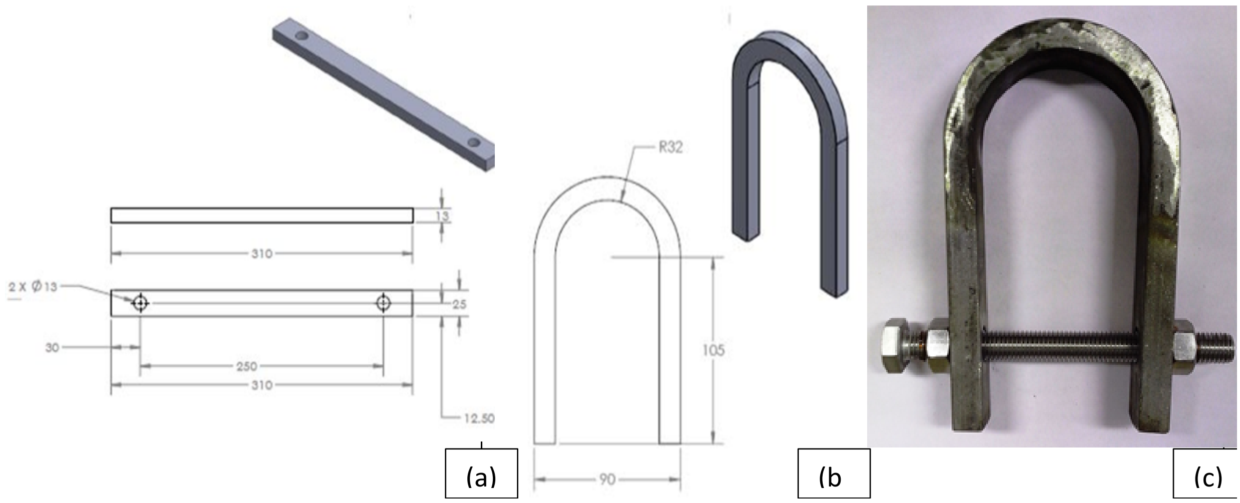

Figure-1: (a) Flat specimen with dimension (mm), (b) U-Bend test specimen with dimensions (mm) (c) U-Bend test specimen after grinding.

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Temperature (°C)	No	[Cl] ppm/[Cl] g		Visual and Stereo Microscope results after 1st round and 2nd round Pitting corrosion for all the specimens	NDT results Dye Penetrant Test after 1st round and 2nd round
		1st round (6 months)	2nd round (6 months)		
Room temperature	1	4000 ppm/4 g	50,000 ppm/50 g		
	2	5000 ppm/5 g	50,000 ppm/50 g		
	3	6000 ppm/6 g	50,000 ppm/50 g		
	4	7000 ppm/7 g	50,000 ppm/50 g		
	5	8000 ppm/8 g	50,000 ppm/50 g		

Table 1: Inspection result for U-bend specimens.

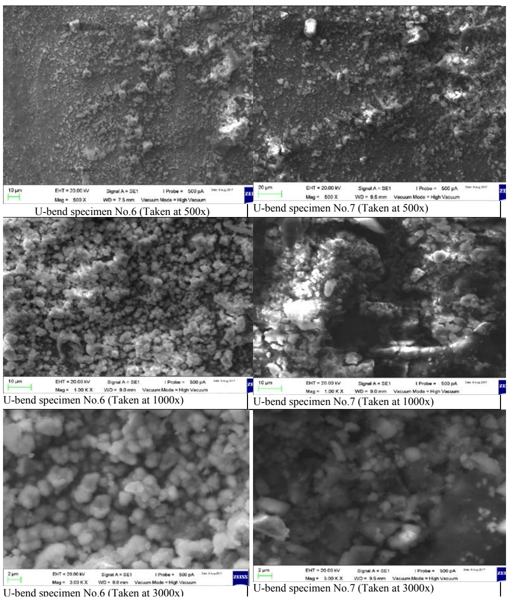

Figure 2: Scanning Electon Microscopy (SEM) Results of U-bend specimen.

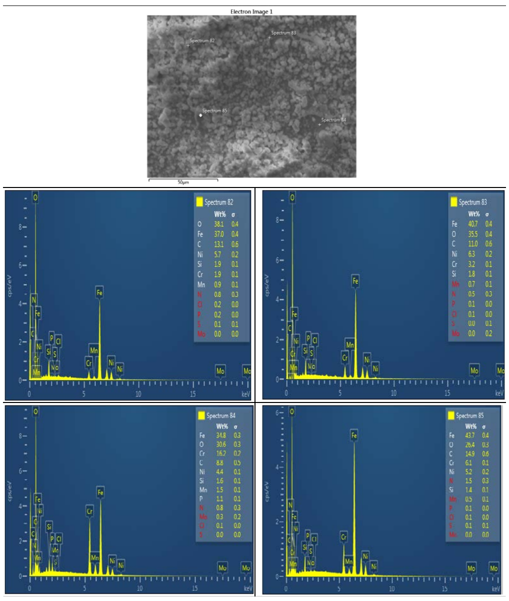

Figure 3: EDX peaks of the SS 304 at several spot.

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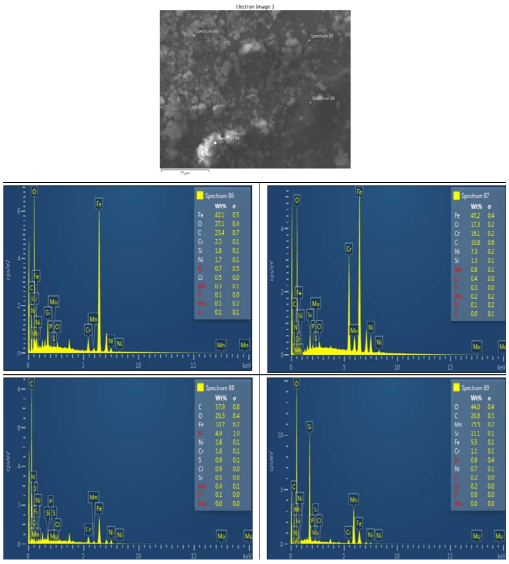

Figure 4: EDX peaks of the SS 304 at several spot

Element (%)	Spectrum 82	Spectrum 83	Spectrum 84	Spectrum 85
Fe	37.0	40.7	34.8	43.7
C	13.1	11.0	8.8	14.9
O	38.1	35.5	30.6	26.4
Ni	5.7	6.3	4.4	5.2
Si	1.9	1.8	1.6	1.4
Cr	1.9	3.2	16.2	6.1
Mn	0.9	0.7	1.5	0.5
N	0.8	0.5	0.8	1.5
Cl	0.2	0.1	0.1	0.1
P	0.2	0.1	1.1	0.1
S	0.1	0.0	0.0	0.1
Mo	0.0	0.0	0.3	0.0

Table 2: Chemical composition of U-bend specimen.

Element (%)	Spectrum 86	Spectrum 87	Spectrum 88	Spectrum 89
Fe	42.1	45.2	10.7	5.5
C	23.4	10.8	57.9	20.8
O	27.1	17.3	20.3	44.0
Ni	1.7	7.3	1.8	0.7
Si	1.8	1.3	0.5	11.1
Cr	2.3	16.1	1.6	1.1
Mn	0.3	0.8	0.4	15.5
N	0.7	0.1	4.9	0.9
Cl	0.5	0.4	0.9	0.2
P	0.1	0.3	0.1	0.0
S	0.1	0.0	0.9	0.2
Mo	0.1	0.2	0.0	0.0

Table 3: Chemical composition of U-bend specimen.

Discussion

The effect of tensile residual stress on chloride induced stress corrosion cracking (CISCC) at the surface film was investigated. Beyond the nominal stress estimated from minimum cross-sectional area and load was observed to increase as a result from geometrical discontinuities in order for specimens No 3, 4, 1, 5, and 2. The stress concentration factor is the factor by which the stress is locally increased. In this investigation, only pits were noticed and the only if the threshold stress intensity factor is above the metal yield stress there is a possibility for the initiation of chloride induced stress corrosion cracking to happen in the presence of chloride ions at ambient temperature with a longer exposure time. The crack initiation time is the time elapsed from the day start of the experiment to the first detection of the crack. The effect of surface grinding on chloride induced stress corrosion cracking (CISCC) of austenitic stainless steels 304 in sodium chloride aqueous solution at ambient temperature has been investigated [10].

The austenitic stainless steels 304 have about 18% of chromium and 8% of Nickel content to protect the metal surface from corrosion. Based on the EDX analysis, both the specimens contain a high level of chromium concentration at a certain spot about 16.2 and 16.1 percentages respectively. In this case of austenitic stainless steels type 304 chromium acts as a protective film which prevent the metal from degradation due to the corrosion effect? The metallic structure such as austenite, martensite or ferrite also influences the corrosion behavior of steels. The surface machining or grinding operation increases the current density by ferrite and carbide formation due to the heating effect. The non-magnetic in annealed condition and the manganese steels might not hardenable. Chloride induced stress corrosion cracking (CISCC) at ambient temperature is possible for all the exposed U-bend specimens in sodium chloride aqueous solution as the effect of the surface layer by tensile residual stresses. In industry, the failed pressure vessel might have faced the same environment if the material surface roughness was removed by the welding process. The surface textures and sensitivity of the grinding operations on metal surfaces induces stress corrosion cracking (SCC).

Conclusion

The mechanism of chloride induced stress corrosion cracking (CISCC) of austenitic stainless steels at ambient temperature still remains unclear. There are a variety of mechanisms which can possible to initiate the chloride induced stress corrosion cracking by surface films. At ambient temperature failure only happens with chloride induced stress corrosion cracking in pits and crevices where a low pH solution may develop. Based on the Dye penetrant test (DPT) observation revealed pits only on specimen No 1, 2, and 5 for U-bend specimens. All these five U-bend specimens were grinded on surface to induce the chloride induced stress corrosion cracking at ambient temperature. The grinding process developed tensile residual stress on these U-bend specimens. Surface layer with a high level of tensile residual stress for specimen No 1, 2, and 5 were observed at ambient temperature [11]. Based on SEM analysis, it reveals that pits formed before the macro-cracks and acted as a precursor to micro-cracks development. These specimens will eventually crack after a longer duration of exposure time [12].

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