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Investigation of Stress Corrosion Cracking Behaviour of 316 Austenitic Stainless Steel in Magnesium Chloride Environment

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***Abstract*: Stress corrosion cracking (SCC) is a result of the combined effect of tensile stress and a corrosive environment, often at elevated temperatures. This SCC often occurs in stainless steel in chloride environment. The major cause of Stress corrosion cracking in 316 austenitic stainless steel is due to the tensile load acting on it and the presence of corrosive environment. Here the comparison of the stress corrosion cracking (SCC) behavior of 316 austenitic stainless steel of three samples S1 (surface finished), S2 (shot peened) and S3 (surface roughened) are analyzed. These samples are immersed in the 42% of MgCl2 solution and maintained at 155oC in Muffle furnace for 72 hours as per ASTM G36 standard to analyze the Stress corrosion cracking behavior. The results concluded that the shot peened sample has shown more resistance towards stress corrosion cracking than other two samples.**

***Keywords*: Austenitic Stainless Steel, Stress Corrosion Cracking, Magnesium Chloride Solution**

1. Introduction

The 316 austenitic stainless steel is one of the grades of steel with the alloying metals as shown in the table 1. Austenitic stainless steel has excellent mechanical properties like high corrosion resistance, high strength and hardness, high toughness, ductility and higher hot strength etc..,[1]. Due to its good mechanical properties, it is widely used in power plants where the high temperature involves like boilers, turbine, pipelines, heat exchanger etc..,[2]. Even though it has good mechanical properties, when it is subjected to tensile load in the presence of chloride corrosion environment the corrosion will occurs [3]. This corrosion is known as stress corrosion cracking. Stress corrosion cracking (SCC) is a result of the combined effect of tensile stress and a corrosive environment, often at elevated temperatures. The favorable condition for the formation of SCC cracking is follows

- Corrosive medium
- Susceptible material
- Elevated temperature

A. Stress corrosion cracking

Stress corrosion cracking (SCC) is the formation of crack in the metal due to combination of tensile stress and a corrosive environment. This leads to the unexpected sudden failure of a ductile metals subjected to a tensile stress, especially at elevated temperature. SCC occurs in the metal only when it is exposed to a corrosive environment at highly specific chemical environment. The crack initiates at surface and thereafter propagates at a rate governed by the slowest process. One of the major problems with SCC is its unexpected failure in nature.

B. Causes of stress corrosion cracking

One of the major cause for stress corrosion cracking (SCC) is the tensile residual stress induced on the material while machining [4]. This SCC micro crack is initiated when the residual stress reaches the critical value of 190MPa for 316 austenitic stainless steel [4]. And also the surface roughness has a greater impact on the formation of stress corrosion cracking. Greater the surface roughness, the greater is the cracking in the material where the susceptible corrosion ions will concentrate on the grooves.

- *Controlling methods:* The following are the major classification of methods to prevent the stress corrosion cracking.
- Reducing the residual tensile stress
- Reducing the corrosive environment
- Eliminating the susceptible materials
- Providing inhibitors.

The stainless steel subjected to surface treatments like surface finishing has more resistance towards corrosion [9], [10]. The compressive residual stress induced by shot peening process will also leads to increased resistance towards stress corrosion cracking [10]. The pitting corrosion behaviour of 316L austenitic stainless steel in a NaCl solution is reduced by surface modifications made through laser peening and shot peening [11]. The machined surface conditions of 316 austenitic stainless steel results in change of thickness and the elemental distribution of oxide film composed of a double layer structure [2]. The pitting corrosion resistance and intergranular resistance of 304 austenitic stainless steel is increased by grain refining[12]. The laser engraving has the greater influence to resist the SCC [13].

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2. Experimental work

A. *Material selection*

The austenitic stainless steel has its wide application due to its excellent mechanical properties and chemical properties including high tensile strength, high corrosion resistance, high ultimate tensile strength and high hardness. The composition of 316 austenitic stainless steel are shown in the in the table 1.

Table 1
Material composition of 316 austenitic stainless steel

C	Mn	Si	S	Cr	Mo	Ni	N	Fe
0.08	2.0	0.75	0.03	18	3.0	14	0.10	balance

Every metal has its own disadvantages, and this 316 austenitic stainless steel has also some of the drawbacks like less corrosion resistance towards chloride environment, high cost and frequent maintenance. The main problem associated with stainless steel was the stress corrosion cracking which is occurred without any previous evidence of occurrence. This stress corrosion cracking occurs when the stainless steel was exposed to tensile load combined with chloride solution at elevated temperature. This SCC results in the cracking and the explosion may also occurs in case of boiler, heat exchanger and pipelines. This confines the usage of stainless steel in application where the higher temperature involves.

B. *Specimen design*

The specimen we used for testing the behavior of stainless steel towards stress corrosion cracking is the U bend samples with the specification as given in the table 2, as per the ASTM standard G30. The geometrical specifications and the detail drawings are shown in the fig. 1 and fig. 2 respectively.

Table 2
U bend sample Specification

Parameters	Dimensions
Length, L	80mm
Thickness, T	2.5mm
Middle distance, M	50mm
Width, W	20mm
Radius, R	5mm
Diameter, D	10mm
X	32mm
Y	14mm

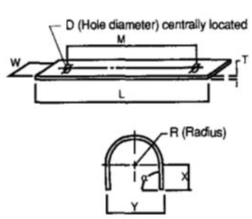

Fig. 1. U bend sample


Fig. 2. Photograph of the specimens

C. *Corrosive medium preparation*

Among the all chloride salts, the major corrosive environment, where the 316 austenitic stainless steel will undergoes severe cracking is in magnesium chloride solution. Magnesium chloride is a naturally occurring inorganic compound composed of one magnesium and two chloride ions. It is usually extracted from places with high salt content like Great Salt Lake and the Dead Sea. This compound comes in anhydrous and multiple hydrated crystal forms which is also called as magnesium chloride hexahydrate. So the corrosive environment used in SCC testing is solution of MgCl2 and water where MgCl2 is in the proportion of 42% as per the ASTM G36 standards of testing.

The solution of 200ml is used for the SCC testing where the U bend sample is made to immerse inside the solution. The solution contains 116 ml of distilled water and 84 g of magnesium chloride powder. Where the magnesium chloride is added at 42% and the remaining portion of 58% is the distilled water.

D. *SCC testing and experimental procedure*

The SCC testing for three samples S1 (surface finished), S2 (shot peened) and S3 (surface roughened) were conducted in order to study the corrosion behaviour of differently processed 316 austenitic stainless steel. The surface roughness value of sample S1 and S3 are shown in the table 4 and table 5 respectively by measuring using the Mitutoyo surface roughness measuring instrument by ISO1997 standard. The shot peening was done by the glass ceramic beads of size 0.02 mm diameter with 100% coverage for 20 minutes at 7 bar pressure to the U bend sample S2. The sample S3 was made to surface roughness as to the shown value by uniformly making the mechanical contact between the surface of the sample and with the silicon carbide paper of grit size 80(fine).

Table 3
Surface roughness of Sample S1

Ra (average roughness value) µm	**Rq (root mean square value) µm**	**Rz (average maximum height of profile) µm**
0.480	0.607	3.859

Table 4
Surface roughness of Sample S3

Ra (average roughness value) µm	**Rq (root mean square value) µm**	**Rz (average maximum height of profile) µm**
0.772	1.107	7.134

3. Experimental procedure

The prepared samples S1, S2, S3 are immersed in the 42% MgCl2 solution for 72 hours at 155 0C as per the ASTM G36 standards. The test samples were kept inside the muffle furnace of dimensions length, height and width as 100 mm, 100 mm and 220 mm respectively. During the testing, the concentration of MgCl2 was changed when it is kept at the furnace due to the maintaining of higher temperature. So the addition of MgCl2 solution was introduced.

Table 5
Weight percentage calculation

Name	Wt%	Calculation	Total weight
$MgCl_2$	42%	200*0.42	84g
Water	58%	200*0.58	116g
Solution(Water+$MgCl_2$)	100%	200*1	200g

4. Result and discussions

As the testing was conducted as per the standards said in the experimental procedure, the stress corrosion cracking results of each samples was analyzed by using the metallurgical microscope where the microstructure of each specimen was tested. The inspecting local sample was cut and the removed sample from the specimens S1, S2 and S3 are involved in the microstructure analysis. The samples from the specimens removed are made as shown in the fig. 4, fig. 5 and fig. 6. The photographs of the samples S1, S2 and S3 was given below which shows their conditions after the occurrence of corrosion.

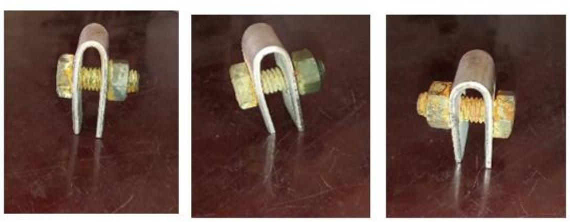

Fig. 3. Photograph of the samples S1, S2, S3 respectively after SCC testing

5. Microstructure analysis

Micro structure analysis of the Samples S1, S2 and S3 are analyzed by using the metallurgical microscope with the following specifications.

Table 6
Specification of Metallurgical Microscope

Name	Description
Testing Facility	METAVIS IMAGE ANALYSIS
Machine No	CL/ME/IMAG/15
Model	MVMS1310
Ambient Temperature	25.6^0C

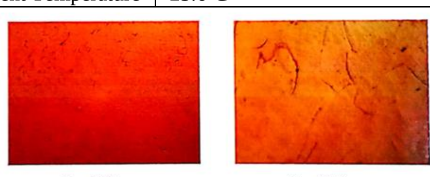

Fig. 4. Microstructure of sample S1 (raw material)

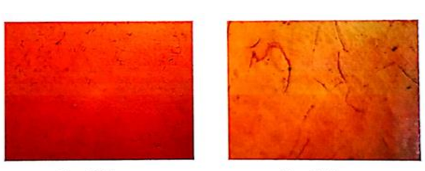

Fig. 5. Microstructure of sample S2 (shot peened)

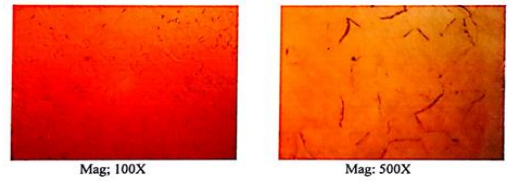

Fig. 6. Microstructure of sample S3 (surface roughened)

The microstructure analysis was carried out by using the test reference ASTM E 03-01 & ASM handbook volume 9. From the above microstructures of sample S1, S2 and S3, it is observed that the cracks formation in the sample S3 was more than the other two samples, the sample S2 has the least crack formation among all other samples, so it is clear that the shot peened sample has shown more resistance towards the stress corrosion cracking.

6. Conclusion

From the above microstructure analysis, the following conclusions are made.

1. The material with surface finish has more resistance towards initiation of stress corrosion cracking. When the surface finish is more, then it takes long period for the initiation of cracking.
2. When the surface roughness is more, then it favors for the initiation of micro cracks. The crests and troughs of surface roughed samples has more impact towards the initiation of cracking.
3. The machining induced residual tensile stress also has the greater impact on the formation of stress corrosion cracking.
4. Here the shot peened sample has shown the very less susceptibility towards the stress corrosion cracking due to the formation of compressive residual stress during the shot peening process. The process parameters that are involved in the shot peening process are said under the chapter “Stress Corrosion Cracking Testing”.
5. On making the comparisons between the samples with respect to the microstructure analysis, it is concluded that the shot peening has more resistance towards stress corrosion cracking than other two samples.
6. In addition to shot peening process, the next effective method for controlling the initiation of cracking is the surface finishing. Meanwhile the surface roughness will increases the chance of stress corrosion cracking formation.

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