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The Effect of Shot Peening and Polishing on the Pitting Corrosion Resistance of Stainless Steel

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Abstract: An experimental work was performed to study one of the major problems encountered in industry (i.e., pitting corrosion), which cost the industrial world billions of dollars every year. Stainless Steel 304L sheets were used in the present study, the main reason for using stainless steel is their corrosion resistance and it is the most widely used in process industries, but that is not always trouble free. It suffers localized attack in specific environments, which can lead to catastrophic unexpected failures. Resistance to pitting corrosion can be greatly increased by a cold working process called shot peening and polishing. The main objective of shot peening is to induce compressive stresses on the metal surface to operate the tensile stresses that lead to cracking, while the objective of the polishing is to make the surface very smooth and soft and that may induce the compressive stresses on the metal surface and eliminate the microscopic scratches during manufacturing processes. Shot peening and polishing can prevent or retard pitting and cracking, leading to economic saving as a result of longer equipment life. The experimental work is conducted to evaluate the effect of polishing and shot peening in preventing the initiation of pitting corrosion and cracking on the 304L stainless steel under the nitric acid and NaCl environments. The results obtained showed that shot peening and polishing can be beneficial in decreasing the pitting corrosion on stainless steel 304L, also the results showed that using the high quality polishing proved to be the best inhibiter for Stainless steel corrosion.

Key words: Corrosion, stainless steel, pitting, shot penning, polishing

INTRODUCTION

Pitting corrosion is a complex phenomenon and the basic corrosion mechanisms are still not completely understood. Adding to the complexity is the fact that corrosion pitting initiation and crack growth related but different process. No single mechanism has adequately explained the corrosion in the large variety of materials in which it has been observed. It is likely that more than one process is involved[1,2,3,4].

Corrosion is defined as the destruction or deterioration of material because of reaction with its environment. Some insist that the definition should be restricted to metals, but often the corrosion engineers must consider both metals and nonmetals for solution of a given problem. Corrosion can be fast or slow; it can occur in a few hours or may take years[3,4,5].

As a result of works of many researchers on metastable pit formation and growth, the critical pitting potentials are now better defined. The kinetics of small hemispherical pits growth is established, but there is no agreement if pit growth occurs under ohmic or diffusion control. The kinetics of large pits growth with different shape was not studied extensively. The most complete investigations were done on the effect of alloy composition and on the effect of inclusions in iron-base alloys on pitting[6]. It is noted that many recent papers either repeated previously done experiments using often better experimental methods or provide information that is not substantial. There are several studies examined the inhibition of pitting[6,7,8,9,10,11,12,13]. Until now for practical purposes, the inhibitors are mainly chosen by empirical tests. However, there are studies trying successfully to explain the behavior of the inhibitors on the basis of a hard and soft acid and base principle [6,7,8]. Numerous theories on pitting have been proposed over years of investigation: penetration of Cl- on the passive film, adsorption of Cl- on passive film, mechanical disruption of the passive film and the metal vacancy production at the metal/oxide interface[12,13]. It needs to be emphasized that none of these theories explain all experimental data. Pidaparti *et al*[8] described many

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types of corrosion that may occur in aircraft structures. Corrosion generally attacks the faying surfaces in lap joints and occurs when the adhesive bond/sealant between the layers breaks down, allowing moisture to penetrate. Pitting corrosion usually follows the general attack of corrosion on faying surfaces and may sometimes evolve into exfoliation corrosion. It is well known that corrosion pitting has a strong effect on fatigue life of aluminum alloys used in aircraft structures. Fatigue cracks usually initiate from the corrosion pit sites[7,8]. Under the interaction of cyclic load and the corrosive environment, cyclic loading facilitates the pitting process and corrosion pits, acting as geometrical discontinuities, leading to crack initiation and propagation and then final failure [14]. Pitting corrosion in aluminum alloys, optical microscopy, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) techniques have been used[6,7,8]. Because of an aircraft's special service environments, for example, salt water, electrochemical reactions are possible and corrosion pits are readily formed between the constituent particles and the surrounding matrix in these alloys.

Prediction of pitting corrosion and corrosion fatigue is very important for the structural integrity of aircraft and aerospace materials and structures. The presence of corrosion pits can significantly shorten the fatigue crack initiation life and decrease the threshold stress intensity of an alloy by as much as 50%[6,7,12,14]. To quantify pitting-induced corrosion fatigue, a critical pit size model has to be modeled in which a corrosion fatigue crack is considered to have nucleated from a pit[1,5,12,7]. The pit grows to a critical size when the local mechanical condition is adequate for the onset of crack growth.

MATERIALS AND METHODS

The experiments were carried out in a laboratory scale aquariums at the Faculty of Engineering Technology (FET) workshops in the Mechanical Engineering Department that is fully equipped with the required equipment and facilities to carry out all experiments. All the measurements were conducted in the same period and the pitting growth were checked hourly to trace the initiation time of pitting.

The specimens were made from Stainless steel 304L sheets. Grade 304L is the standard 18/8 stainless; it is the most versatile and most widely used stainless steel, available in a wider range of products, forms and finishes than any other. It has excellent forming and welding characteristics and excellent in a wide range of atmospheric environments and many corrosive media. But it is subject to pitting and crevice corrosion in warm chloride environments. Grade 304L SS is readily brake or roll formed into a variety of components for applications in the industrial, architectural and transportation fields. Grade 304L, the low carbon version of 304, does not require post-weld annealing and so is extensively used in heavy gauge components (over about 6mm). The austenitic structure also gives these grades excellent toughness, even down to cryogenic temperatures.

Equipments shot peening machine: Shot peening is used in a wide variety of industries on an even wider variety of parts. Many materials will increase in surface hardness due to the cold working effect of shot peening, such as high strength steels, aluminium alloys, titanium alloys and other engineering alloys. Benefits obtained by shot peening are the result of the effect of the compressive stress and the cold working induced. Compressive stresses are beneficial in increasing resistance to fatigue failures, corrosion fatigue and stress corrosion cracking. A Pang born Es-1580 shot peening machine was used. This is an air blast machine in which the compressed air introduce at the rear of the nozzle (also called a gun) producing a low pressure, high velocity air flow in the gun body, the peening shots (fine glassy sand) are stored in an over head hopper and are directed to the nozzle by means of gravity assist, where they are accelerated by the air which is traveling at a high velocity. A special fixture on a rotating table which speeds is controlled by a gear and a motor system usually fixes the work piece.

Three kinds of samples were peened at different coverage depend on the pressure of peening, therefore we had chosen three different pressures 1.5, 3.5 and 5.7 bar. Peened specimens were washed with clean water then with distilled water and alcohol in order to remove the residual shots.

Corrosion Test Environment: Preliminary experiments to evaluate the corrosion of 304L specimens conducted using aggressive solution in order to test the severity of this solution as corrosion promoters. We made a glass aquarium filled with a solution consists of nitric acid, sodium chloride (NaCl) and distilled water, as shown below in the Table 1, the aquarium temperature was around 23±2°C. The test duration for the specimen exposed to these solutions was 504 hours (21 days).

Table 1: Environment of aquarium

Aquarium	Volume	Nitric acid	NaCl	Distilled water (L)
Test1	18.9	482.5	1106	18.4175

Experimental procedures specimens Preparation: All the specimens are made from stainless steel 304L and all of them have approximately the same size, the length of the specimens is around 11.2±0.3cm, width around 1.9±0.1cm and the thickness is 0.2cm. We made seven kind of preparation of the specimens and every kind has three copies to put one copy from each kind in one aquarium to test the more sever environment to be used later.

Each specimen has a tiny hole with diameter of 2mm at the top edge; this hole was used to hang up the specimens in the vertical direction with the help of plastic wire, to accommodate enough space between one specimen and the other.

Polishing: Two kinds of samples were polished at two different coverage depend on the kind of roughness of the sand paper attached to rotoflix machine, the numbers of rotoflix that we used are 80 and 320 (high quality double polish of 320). Also we cleaned the specimens by water, distilled water and alcohol to remove the residual waste. The high quality category of polishing specimen (double polishing of the 320), was suggested by Swedish Fill company engineers for conducting proof tests on their findings, so we decided to choose this category in the present experimental work to test and prove the variations of susceptibility to pitting (as optimum) with the other types of polishing surfaces.

Immersion: All specimens were immersed in the acid and NaCl solutions in the same period. And everyday they were checked for filling the aquarium with distilled water in case the level of the solution decreased. It was noticed that the temperature of the surrounding was nearly constant for all days. The Table 2 shows the aquarium and the type of specimens.

After the tests the samples were taken to Al-Salt Engineering College at Al-Balqa Applied University (BAU), to be inspected for failures using the Scanning Electron Microscope (SEM). The samples were cleaned with concentrated HCl solution to reduce the thickness of the oxide layer. Some samples were tested with tension machine (HOYTOM), to check the tensile stress range.

Table 2: Specimens in the aquarium

Aquarium	Specimens No.	Specimens type
Glass	1	Polish 80
	2	Polish 320
	3	High quality polish
	4	Standard
	5	Shot peening 1.5bar
	6	Shot peening 3.5bar
	7	Shot peening 5.7bar

RESULTS AND DISCUSSION

The parameter of time in pitting corrosion phenomena is important since the major physical damage during corrosion occurs during late stages. As corrosion penetrates the material, the cross-sectional area is reduced and the final cracking failure results entirely from mechanical action. Initially, the rate of crack movement is not constant; as a result, the rate of crack movement increases with crack depth until rupture occurs.

From the Fig. 1, it can be seen that the polished specimens of grade 80 and 320 were failed after 4 days from the day of immersing. While the high quality polishing specimen resists the pitting corrosion up to the day number 24. Actually we have defined the failure when the pitting initiated and the crack appeared on the surface of the specimen.

The 80 polishing specimen has pits on the surface started with small diameters, but after 24 days, the pits became wider with larger sizes. And the corrosion rate of this specimen is too high when we compared with other specimens in the same acquarium (Fig. 1 and 2).

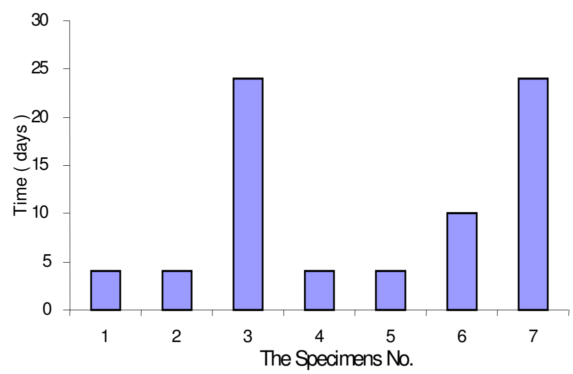


Fig. 1: Specimens time to corrosion in aquarium

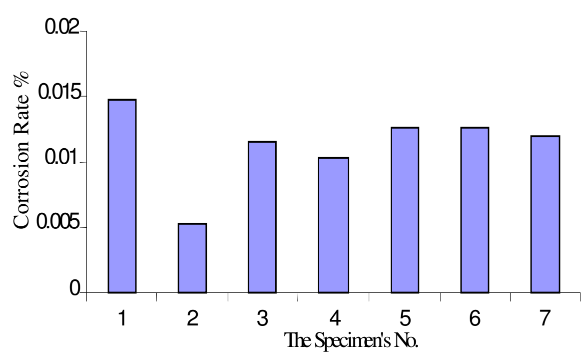


Fig. 2: Corrosion rate in the aquarium

The 320 and 80 polishing specimens had pits on the surface after 4 days from immersion and the diameter of the pits became larger especially in the middle area than other polishing specimens (Fig. 3) and the pits have been seen on the SEM scanner. In the 320 polishing specimen the microscopic scratching which represent the manufacturing defect has been detected in the surface, but the largest etching was also found in the standard specimen in form of longitudinal shape, Fig. 4a. The maximum tensile stress of this specimen is less than the maximum tensile stresses of the other polishing specimens (standard and high quality polish), this is because the pitting has weakened the internal structure of the specimen. The tensile stress were conducted for the polishing specimens only because the main purpose of the study is to concentrate on the effect of polishing (hygienic method) of stainless steel sheets on pitting corrosion rather than peening, which it is recommended for the manufacturing of the stainless steel tanks used for hygienic food and medicine mixing processes.

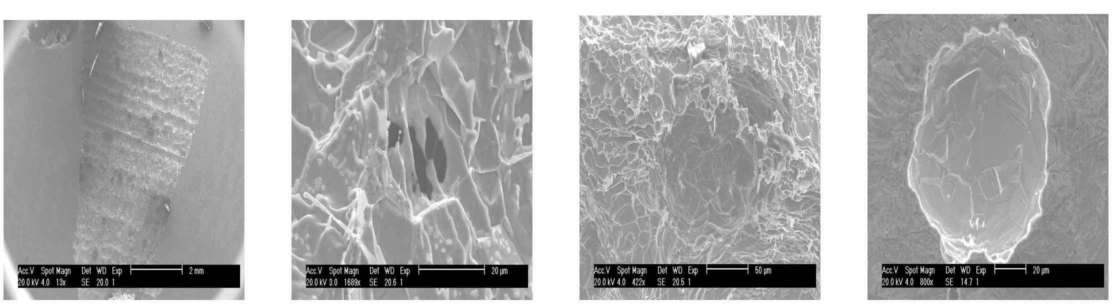
Also in Fig. 4 it can be seen that the pitting is penetrating deep in the specimen of the 320 polishing type, the pit size were growing very fast than the high quality specimen and little bit lower than standard one.

For the high quality polishing (Fig. 5), the pitting was so small in size than other polishing specimens, which means that the fine quality polishing makes a structure of the specimen more adhesive and coherent, hence prevents the pitting corrosion to penetrate the surface, this is the optimum case which can be used as a reference in the present study and consistent with the industrial findings

For the high quality polishing (Fig. 5) and as we can see from Fig. 1, this specimen resisted the pitting corrosion for up to 24 days, afterward some tiny pits were initiated on the surface. It has a high value of the tensile stress than other specimens; which shows that this specimen is too homogenous and coherent in structure.

The standard specimen doesn't fail until the day number 4. At this period some pits in the middle area formed having a small diameter and then the diameters of the pits became larger in size longitudinally, this may be attributed to the manufacturing defect in the sheet structure (Fig. 6). The peened specimens resisted the pitting corrosion and they are dependant on the coverage and the pressure intensity of peening. It can be

Fig. 3: Pitting in the polishing 80 specimen



a b c d

Fig. 4: Pitting and crack for 320 polishing specimen

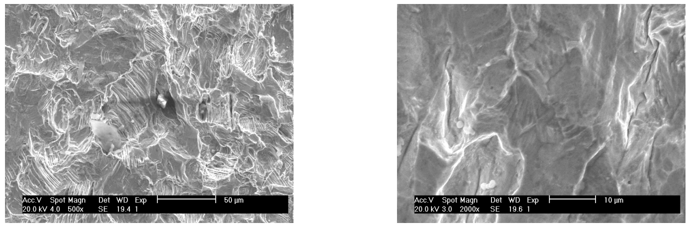


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Fig. 5: Pitting and cracks for the high quality-polishing specimen

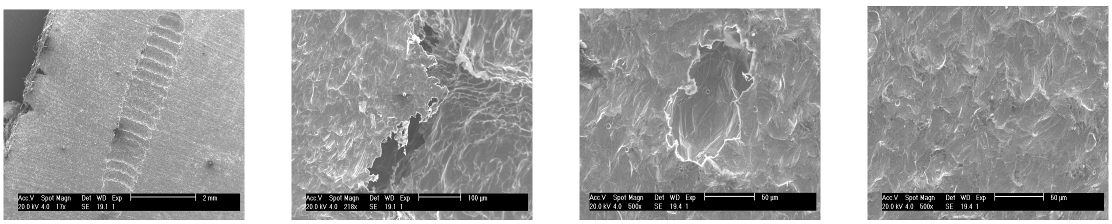

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Fig. 6: Pitting and cracks for the standard polishing specimen

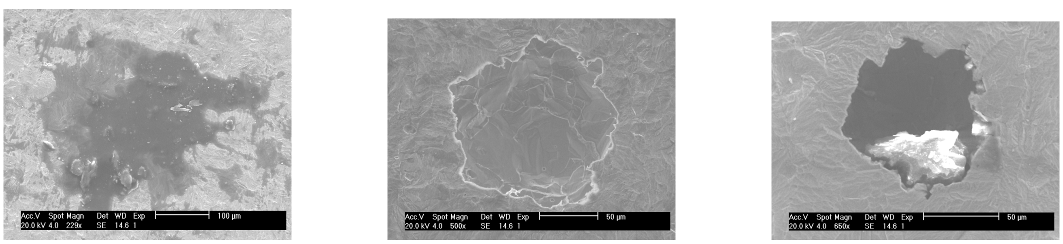

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Fig. 7: Pitting in the 1.5 shot peening specimen

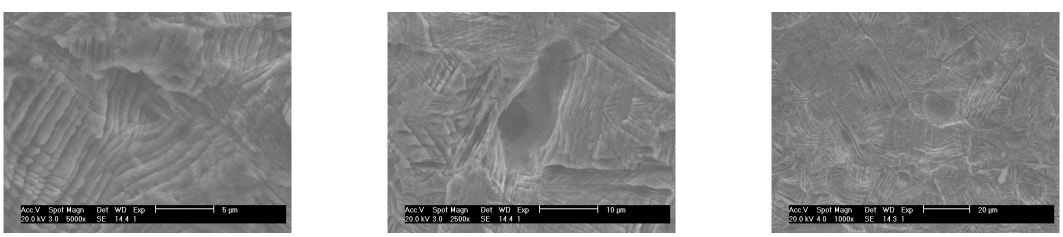

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Fig. 8: Pitting in the 3.5 shot peening specimen

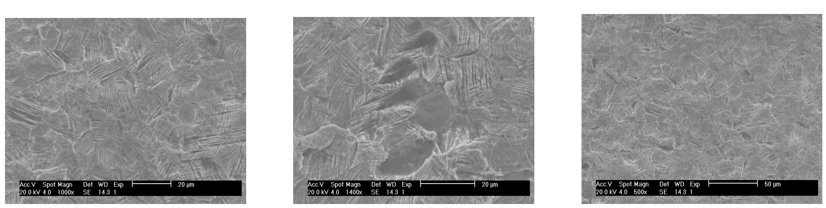

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Fig. 9: Pitting in the 5.7 shot peening specimen

seen from Fig. 7-9, that the specimens peened with high pressure (5.7bar) resisted the pitting corrosion more than the other peened specimens (i.e. 1.5 and 3.5 bar). It was found that, once the pitting corrosion occurred in low pressure peening specimen, it spreads faster than other intensities.

In Fig. 7, we can see that the pitting has increased in size and depth than the polishing specimens, which means that the peening has coarse microscopic structure adjustments and makes the pitting to grow faster in the specimen structure than polishing.

Figure 8 and 9 shows peening lines on the surface; and also the pits formation and in the high pressure peening the compressibility of structure effect was evident. Also a tiny pit occurred in the middle area after 10 days and then after 24 days, another pit grown in the top side of the specimen.

CONCULSIONS

From the results obtained it can be concluded that shot peening and polishing can be beneficial in delaying and decreasing the pitting corrosion on stainless steel 304 and it can improved the alloy life to nearly 3 times. The polishing process will eliminate the microscopic etching defect formed during the manufacturing process of steel sheets.

The shot peening improves corrosion resistance of the 304 SS due to the homogenous cold worked surface layer and the compressive residual stresses produced during shot peening. Also increasing the pressure of peening, can increase the corrosion resistance of the SS. The high quality polishing can increase the pitting and corrosion resistance of the 304L SS, since even in its worst conditions it has improved the alloy life to nearly 4 times. Also it is very beneficial in preventing any manufacturing defect and can delay pitting corrosion of the Stainless Steel.

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