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Research Article

Enhancement of Fatigue Strength of 316L Austenitic Stainless Steel using Sand Blasting

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Abstract

To investigate the effects of sand blasting on high-cycle fatigue properties of Type 316L austenitic stainless steel, rotating bending fatigue tests were conducted on sand blasted specimens by varying sand blasting parameters. The benefit expected from using sand blasting process is to introduce residual compressive stresses that lead to an improvement in material's properties such as fatigue strength and hardness by a cheap and rather quick treatment. This paper aimed to estimate the effect of varying the sand grain size employed in sand blasting process and treatment duration and blasting distance on fatigue strength of austenitic stainless steel grade 316L, and comparing the results of different cases. Since fatigue strength strongly depends on surface properties, surface roughness and hardness tests were conducted as well. Results revealed a considerable enhancement in fatigue strength for all cases and a good reduction in surface roughness (34-74) %, but a slight increase in hardness (6.5-10) %.

Keywords: *Fatigue Strength, Stainless Steel etc.*

1. Introduction

Researches reveal that 90% of the failures in the mechanical rotating parts resulting from exposure to periodic loads lower than the critical loads at which the failure accurse as a result to fatigue Phenomenon (Callister *et al*, 2008), So there are many thermal , chemical and mechanical methods have been developed to strengthen the surfaces of the rotating parts because fatigue failure usually starts from the surface layer, hardening the surface layer changes the fracture site from surface crack origin type into subsurface crack origin type (K. Masaki *et al*, 2013).

Type 316L is an austenitic chromium-nickel-molybdenum stainless steel, this type cannot be hardened by heat treatment, solution treatment or annealing can be done by rapid cooling after heating to 1008-1120°C, Its mechanical properties can be improved only by cold work (stainless steel product manual, 1999; H. Bhadeshia *et al*, 2006), sand blasting was used as cold working process to attack the surface layer by small sand grains which introduces compressive stresses on the surface and improves fatigue strength and surface hardness through increasing the amount of plastic deformation induced by this treatment. Figure (1) shows the compressive residual stresses resulted from sand blasting process. There are many parameters effect hardening by sand blasting process such as sand grain size, exposure period, blasting distance and blasting velocity (depending on blasting pressure).

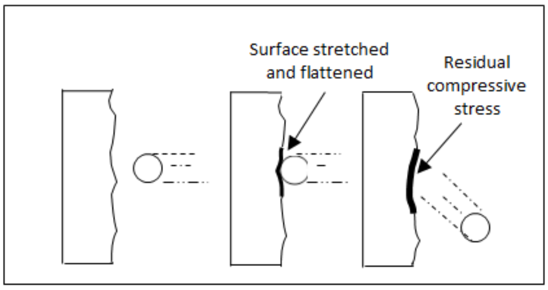

Figure 1 The compressive stresses resulted from sand blasting process (Averbach B. *et al*, 1985)

2. Experimental work

2.1 The material

The material used in this study was Type 316L chromium-nickel-molybdenum austenitic stainless steel, having the chemical compositions (weight %) listed in table (1), it was selected because it's a non-heat treatable material and its properties can be improved only by cold working (stainless steel product manual, 1999). it's important in engineering applications exposed to periodic loading in service like rotating parts in pumps and automobiles, it's also an important material in chemical and food industries, surgery, cutlery, plumbing, parts which come into

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contact with sulfur dioxide, fans, nozzles, heat exchangers, in nuclear power stations as heat generators and pumps(D. Surpi *et al*, 2011).

Table 1 The chemical composition for AISI 316L, w%

C%	0.016
Cr	16.66
Ni	12.2
Mo	2.34
Mn	1.4
Si	0.51
Cu	0.26
Co	0.14
Zr	0.013
Ti	0.01
S	<0.002
P	<0.003
Nb	<0.009

2.2 Specimens manufacturing

Fatigue specimens were machined and shaped according to the standard specification ASTM E3-01[7].the standard neck diameter is (4mm) but in this study it was reduced to (3mm) to increase the stress induced by fatigue test machine according to the user guide of the machine (SM1090 rotating fatigue machine user guide, 2009) as seen figure (2). Sixty eight specimens were used in this study.

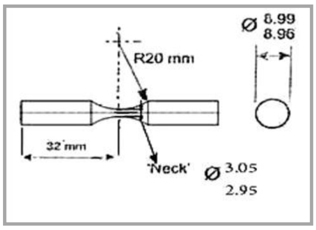

Figure 2 Schematic diagram for fatigue specimen (SM1090 rotating fatigue machine user guide, 2009)

2.3 Sand sieving

Large amount of sand like that used in building works was sieved and classified into three grades: grade1 (0.3-0.5) mm, grade2 (0.5-1) mm, grade3 (1-2) mm and a fourth grade formed from mixing these three grades.

2.4 Sand blasting

Sand blasting system consists of the following basic parts: compressor, blasting vessel, blasting hose and a nozzle, In addition to a rotating system to fix and rotate the specimen. After machining, the center of the specimen was sand blasted with different sand grades, exposure durations and blasting distances, with blasting pressure of 100 Kpa. Every four specimens were treated at the same condition.

2.5 Mechanical Tests

Roughness test

The device used for measuring the surface roughness was a surface roughness tester, portable-type (qualitest TR-110, US) in terms of surface roughness factor Ra (roughness average) in (μm) according to ISO 4287:1997 standard specifications. The average value of four readings for each specimen was calculated before and after treatment, and then the average of every four specimens blasted at the same conditions was calculated.

Hardness Test

Rockwell hardness test type B was used to measure the hardness value by determining the depth of penetration of 1/16'' hardness steel ball into specimen under certain fixed conditions. These tests were done according to ASTM E 18 [9], standard by using (Brooks Inspection Equipment LTD, England made). All specimens were tested before and after sand blasting.

Table 2 surface roughness and hardness tests results

Specimens groups according to blasting conditions			surface roughness Ra (μm)		HRB hardness No. results after sand blasting*
Sand grade	Blasting duration (min.)	Blasting distance (cm)	Before	After	
As- received			0.984	0.984	102.2
Grade1	5	5	1.108	0.285	110.41
Grade2	5	5	0.753	0.37	110.8
Grade3	5	5	1.4	0.838	110.8
Grade4	5	5	1.095	0.321	109.25
Grade1	10	5	1.06	0.293	112.587
Grade2	10	5	0.934	0.325	111.125
Grade3	10	5	1.17	0.34	111.34
Grade4	10	5	1.024	0.35	108.94
Grade1	5	10	0.939	0.25	112.62
Grade2	5	10	0.763	0.5	109.635
Grade3	5	10	0.957	0.395	112.117
Grade4	5	10	1.182	0.3	109.5
Grade1	10	10	1.067	0.327	112.3
Grade2	10	10	0.8	0.32	111.05
Grade3	10	10	0.89	0.282	111.275
Grade4	10	10	0.929	0.3	108.9

* Conventional hardness

Fatigue Test

A rotating–bending fatigue test was carried out at constant load ratio ($R = -1$) and stable frequency of 60Hz throughout the test, and varying mean stresses (380, 486, 592 and 697) MPa. the stress–number of cycles (S–N) relations for AISI 316L have been plotted for specimens sand blasted at different conditions. Fifty two specimens were used to estimate the effect of sand blasting parameters (sand grades: 1, 2 and 3, blasting duration: 5 and 10 minutes and nozzle distances: 5 and 10 cm).

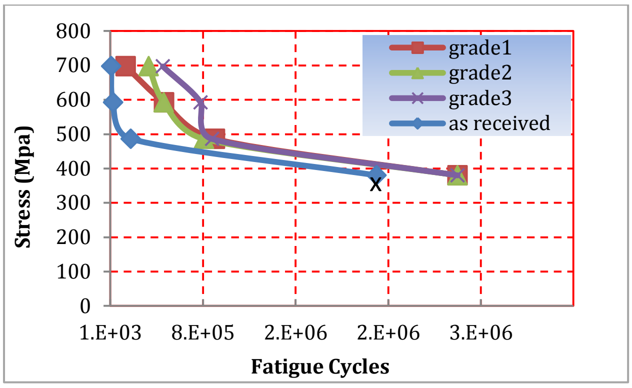

Figure 3 S-N curves of sand blasted specimens at different sand grades when the blasting duration is 5 minutes, blasting distance 5 cm

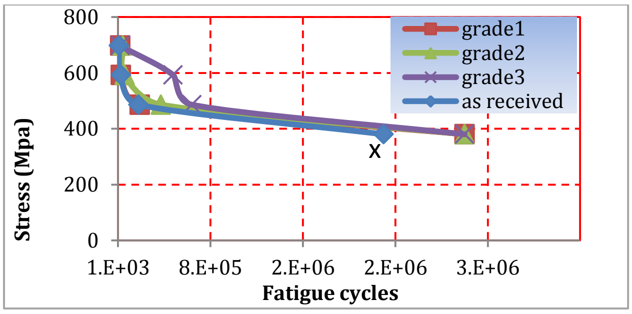

Figure 5 S-N curves of sand blasted specimens at different sand grades when the blasting duration is 5 minutes, blasting distance 10 cm

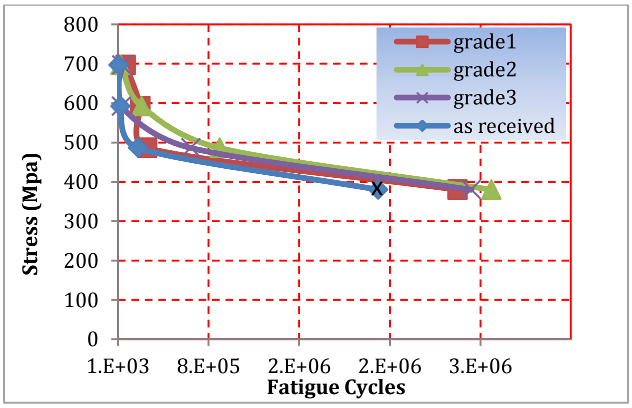

Figure 4 S-N curves of sand blasted specimens at different sand grades when the blasting duration is 10 minutes, blasting distance 5 cm

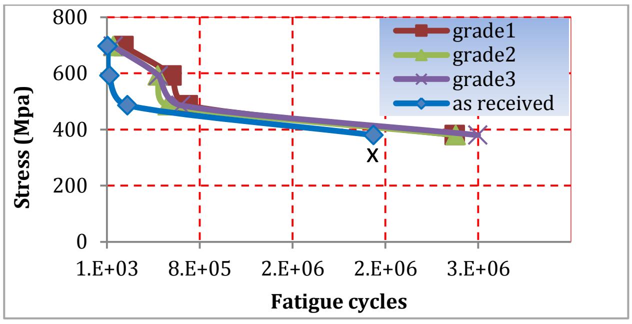

Figure 6 S-N curves of sand blasted specimens at different sand grades when the blasting duration is 10 minutes, blasting distance 10 cm

3. Results and Discussion

Figures (3), (4) and figures (5), (6) show fatigue behavior of 316L stainless steel specimens after sand blasting process. According to the results in these figures, the maximum fatigue strength of 316L corresponds to sand grain size, treatment duration and blasting distance.

It can be seen from the obtained results that fatigue life was significantly improved in all specimens after sand blasting, but the amount of the improvement varies according to sand blasting parameters. The repeated random impacts of sand grains with high pressure resulted in high level of compressive stresses and plastic deformation, or work hardening.

In general, sand blasting for 5 minutes and at distance 5 cm imparts best fatigue strength to 316L stainless steel for all sand grades at all stresses in particular grade3 figure (3). Fatigue life improvement starts from 0.3 up to 55 times, from the low stress to the higher stress, respectively. Any mechanical surface hardening treatment includes attacking the surface layer has a positive effect within a certain time limits of exposure to that treatment, beyond these limits the mechanical treatment can leads to an adverse effects, where continuing treatment for a long time can erode the surface layer and deteriorate materials properties such as corrosion resistance and fatigue strength. In this study, (5) minutes blasting and at distance (5) cm was sufficient parameters at all sand grades to obtain a superior fatigue resistance and very high cycle fatigue compared to the untreated specimens. Results in table (2) shows that surface roughness was reduced after sand blasting for all specimens; with a reduction percentage varies from 34% to 74% depending on the initial surface roughness values. Sand blasting reduced and integrated roughness all over the treated surfaces, in addition, it repaired the manufacturing defects that are present on the surface of the specimen; of course, this would introduce higher fatigue life.

It can be seen from hardness results for specimens which blasted for (10) minutes at all sand grades -except grade 4- imparts relatively higher increase in hardness values than specimens blasted for (5) minutes, hardness enhancement varied between (6.5-10)%. The best results recorded was at grade 1 when the blasting duration is (10) minutes and blasting distance is (5) cm with 112.587HRB and when the blasting duration is (5) minutes and blasting distance is (10) cm with 112.62HRB. This can be explained depending on the effect of blasting distance and sand grain size effect, where when blasting nozzle is relatively close to the specimen and the sand grain size is comparatively fine as in grade1 (0.3-0.5) mm, then the surface of the specimen will be exposed to an abundant, concentrated stream of fine sand grains with high pressure for a relatively long time, that would soften the grains in the surface layer besides introducing an abundant dislocations and compressive stresses and increases the amount of plastic deformation..

Conclusions

- Sand blasting process can improves resistance to fatigue failure to a large extent by increasing the compressive stresses, where sand grains directed to the material surface with high pressure refines metal's grains in the surface layer, compresses and pushes them into inside to obtain a hard and highly compacted surface layer.
- Fatigue life was enhanced at most blasting cases, but the best results recorded at sand grade3 (1-2) mm although the results for the other grades were relatively close to each other.
- Sand blasting treatment results shows that surface roughness was considerably reduced and the surface hardness was slightly increased, the best improvement to surface roughness and hardness was obtained at the fine sand grade1 (0.3-0.5) mm.

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