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Impact of Surface Roughness on Marine Steels - AISI 316L & UNS S32760 under Fatigue Loadings

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Abstract

Fatigue is the temporary crackment, and permanent failure that occurs in most of the materials undergo for the continuous or Varying strains at nominal stresses that have more values. Fatigue could alter into cracks and cause fracture once a sufficient range of fluctuations come into considerations. Austenitic and Super duplex steels of different grades are widely used as marine application in the coming introduction below such as boat rails and hardware, facades of buildings, pharmaceutical and bio-processing, Dairy and Food, brewery and other beverage industries due to its high corrosion resistance, and heat resistance provide the excellent fabric ability and formability. Steel round bars are machined as per the specimen geometry to be tested on the Nano servo hydraulic fatigue testing machine to investigate the life cycles of the steels. The specimens of the given geometry is machined with various surface roughnesses and tested on the machine so as to obtain the life cycles of the specimens. Variation on the life cycles is seen depending upon the surface roughness present on the specimens. This is approached by Modified method given by Murlidhar and Mansons method given in the year 1910 and the method is known as Universal slopes method. This approach is totally based on total Strain controlled analysis.

Keywords: AISI 316L, UNSS 32760, Surface Roughness, Nano servo Hydraulic UTM, Universal slopes method

I. INTRODUCTION

When a material is subjected to repeated cycles of stress or strain, failure occurs by leading to fracture at some weak points and this type of a failure is termed as Fatigue. The process of applying repeated loads on material is called fatigue life. Localized and Progressive structural damage occurs when materials are subject to cyclic repeated loads. Fatigue can be identified by formation of cracks at particular locations in material. Cracks can form in various structures: overhead cranes, turbines, offshore platforms, cranes, transmission towers, machines parts, boats, frames, pylons, bridges, planes. Propagation of cracks is observed due to repeated cyclic loadings in Structures. There are two methods for fatigue to be tested and that are given below as High cycle fatigue and Low cycle fatigue conditions.

A. *High cycle Fatigue*

When the fatigue life cycles occurs above 10^3 cycles (usually 10^4 or more), it is known as High-cycle fatigue. The component is loaded with 2/3 of the yield stress. The deformation will be in elastic range. The fatigue life range of "high-cycle" is $10^3 \sim 10^6$. High-cycle fatigue tests take place for about 1 million cycles. Although applied stress is very low, plastic deformation occurs at the crack tip. Stress vs. number of cycles to failure is plotted from results. The stress value may be minimum, maximum, or amplitude. In this research total Strain controlled fatigue testing is done to have the life of the specimen used under marine application along with surface roughness.

For a specified value of the mean stress the S-N relationship is determined. A number of cycles a specimen can sustain before failure is fatigue life. Lower stress level increases cycles to failure. Whereas increase in static tensile strength increases the fatigue strength. The steel alloy does not fail due under lower stress levels. There is fluctuation of test results. Therefore it is recommended to test a required number of specimens to obtain optimum results.

B. *Low Cycle Fatigue*

When fatigue occurs below 10^3 cycles, it is called Low cycle fatigue. Plastic deformation occurs due to the presence of high stress. The application of load in terms of stress in not useful but applying load in terms of strain is simple and more accurate. Small number of strain cycles normally experienced by components in low cycle fatigue test. This is mainly applicable for short term devices where large overloads may occur at low cycles. Typical examples are control systems in mechanical devices. A fatigue failure initially starts at local discontinuity .As stress exceeds the elastic limit, there is a plastic strain. The crack propagation and fracture occurs due to cyclic plastic strain. Experiments are conducted with fully reversed loading and the true stress-strain hysteresis loops. The elastic limit increases for annealed steel and decreases for cold drawn steel due to cyclic strain. Low cycle fatigue analysis is done in terms of cyclic strain. For this purpose typical plot between strain amplitude versus number of stress reversals to fail is considered. Below is the hysteresis loop for plastic and elastic region under strain controlled test.

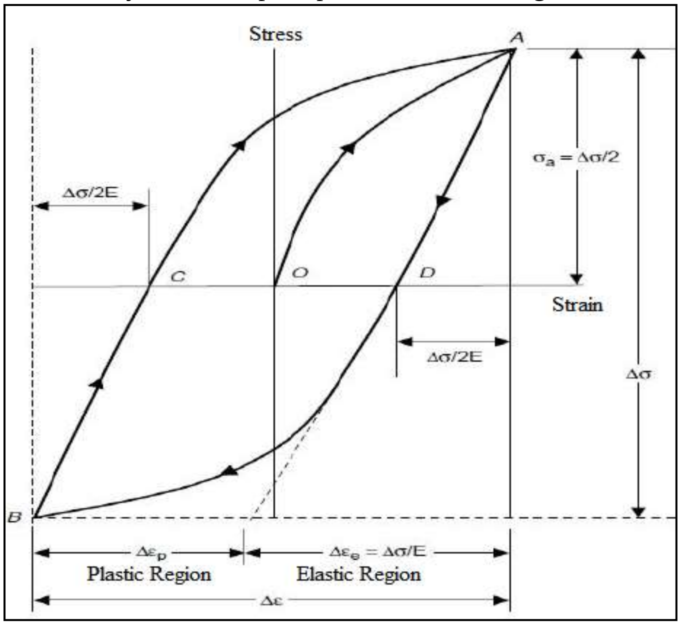

Fig. 1: Cyclic Stress vs Strain

II. Experimentation

Austenitic stainless steel and super duplex steel is a specific type of stainless steel alloy used for testing on fatigue testing machine. Stainless steels may be classified by their crystalline structures. For the work Austenitic stainless steel of grade AISI 316L and Super duplex UNS S32760 stainless steel material was selected for this research. This material is commercially pure in nature. It was available in the form of rod with diameter 16 mm. The material is bought from the available market as raw material and is allowed to undergo for machining process on CNC lathe so as to perform the fatigue test on suitable geometry. Below in the picture it displays the Austenitic Stainless Steel and Super duplex steel specimen machined from the CNC lathe and made it in its final form for fatigue testing.

Fig. 2: AISI 316L Austenitic stainless steel

Fig. 3: UNS S 32760 Super Duplex Steel

The above figured specimens are placed on the Nano servo hydraulic universal testing machine and allowed for the loading under total strain control test. By placing the material specifications in to the system control it provides various loads on the specimen and gives smooth hysteresis loop once the strain amplitude is maintained constantly. There are two strain amplitudes maintained on both of the materials so as to approach its life cycles. 0.30 % strain amplitude and 0.35 % Strain amplitude is fed in the system along with the below parameters given in the table of mechanical properties.

A. Chemical Composition:

The chemical composition of AISI 316L stainless steel is outlined in the following table.

Table – 1
Composition of 316L Stainless Steel

%	*C%*	*Si%*	*Mn%*	*P%*	*S%*	*Cr%*	*Mo%*	*Ni%*	*Al%*
COMP	*0.0180*	*0.4090*	*1.3880*	*0.0260*	*0.0290*	*16.6340*	*2.0450*	*10.0040*	*0.0130*
REQD	*-* *0.0300*	*-* *1.0000*	*-* *2.0000*	*-* *0.0450*	*-* *0.0300*	*16.0000* *18.0000*	*2.0000* *3.0000*	*10.0000* *14.0000*	*-* *-*

%	Co%	Cu%	Nb%	Ti%	V%	W%	Pb%	Fe%	N%
COMP	0.1830	0.5380	0.0240	0.0080	0.0840	0.0120	-	67.9000	-
REQD	- -	- -	- -	- -	- -	- -	- -	- -	- -

Table – 2
Composition of UNS S32760 super duplex Steel

%	C%	Si%	Mn%	P%	S%	Cr%	Mo%	Ni%	Al%
COMP	0.0240	0.2960	0.5970	0.0295	0.0050	25.0600	3.5830	6.8200	0.0120
REQD	- 0.0300	- 1.0000	- 1.0000	- 0.0300	- 0.0100	24.0000 26.0000	3.0000 4.0000	6.0000 8.0000	- -

%	Co%	Cu%	Nb%	Ti%	V%	W%	Pb%	Fe%	N%
COMP	0.0810	0.6470	0.0300	0.0090	0.1720	0.5150	-	62.0000	-
REQD	- -	0.5000 1.0000	- -	- -	- -	0.5000 1.0000	- -	- -	- -

B. *Physical Properties:*

The following table shows the physical properties of AISI 316L stainless steel.

Table – 3
Physical Properties Stainless Steel

Properties	Metric- AISI 316L	Metric- UNS S 32760
Density	8.027g/cm^3	7.180g/cm^3
Melting point	1440^{o}C	1350 ^{o}C

C. *Mechanical Properties:*

The mechanical properties of AISI 316L stainless steel are displayed in the following table.

Table – 4
Mechanical Properties of 316L Stainless Steel

Mechanical Properties	Metric-AISI 316L	Metric- UNS S 32760
Yield Point,Mpa	300	400
Tensile strength,Mpa	719	898
Bulk modulus,GPa	166	200
Modulus of Elasticity,Gpa	193	200
Poisson's ratio	0.25-0.30	0.3
Strength at break,Mpa	425	650
Elongation at break, mm	47.40	49.2
Hardness (Brinell)	184	201

III. EQUIPMENT'S USED AND FUNCTIONING

A. *Nano Servo Hydraulic Universal Testing Machine:*

The displacement of the flat specimen is measured by control and data acquisition system during each load cycle, controls the strain in the specimen and adjusts the load applied by the loading device so specimen is tested with constant level of load on each cycle. In addition, the control and data acquisition system records load cycles, applied loads, measuring strain and computing and recording the maximum tensile stress and maximum tensile strain at load cycle intervals specified by the user.

Table – 5
Machine Specifications

Capacity	25KN
Weight	160kg
Digital servo control	6kHz
Column Clearance	400mm
Maximum Daylight	700mm
Total Frame Height	1500mm
Data acquisition	23 bit
Cycling	0-100Hz
Phase	Single phase 220V

Fig. 4: Nano Servo Hydraulic Universal Testing Machine

B. Steel Specimens:

Specimens of two different grades are selected from the market which are naval marine metals which are best to be used under corrosive environment. Two materials of grade AISI 316L Austenitic Stainless steel and Super duplex steel of UNS S32760 is taken and machined as per the below figure so as to be fixed on the fatigue testing machine and life cycles can be calibrated. On to this specimen's surface roughness is created under 60microns, 120micron and 180 microns on 6 specimens. Left 2 specimens are tested without surface roughness to be clear for the life cycle.

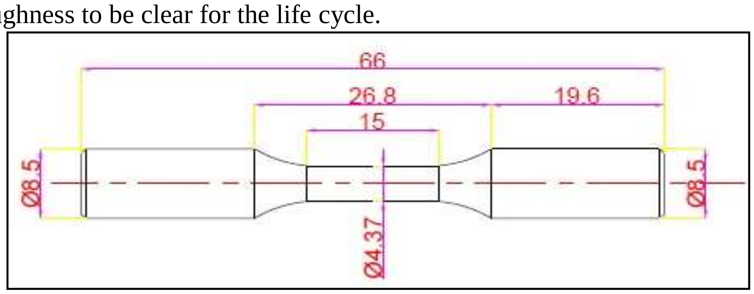

Fig. 5: Specimen geometry used for fatigue tests.

IV. FATIGUE TEST ON NANO SERVO HYDRAULIC UNIVERSAL TESTING MACHINE

Table - 6
Strain Amplitude and Surface Roughness

	AISI 316L	
S.No	*Strain Amplitude*	*Surface Roughness*
1	*0.30*	*0 µ*
2	*0.30*	*60 µ*
3	*0.30*	*120 µ*
4	*0.30*	*180 µ*
	UNS S32760	
5	*0.35*	*0 µ*
6	*0.35*	*60 µ*
7	*0.35*	*120 µ*
8	*0.35*	*180 µ*

V. SAMPLE CALCULATION

1) This method uses strain range instead of stress range to have a fatigue life of material. Generally it is used to model the low cycle fatigue when plastic strain range $\Delta\epsilon\rho$ and Elastic range $\Delta\epsilon e$ at critical are under seismic loads. This method is useful for estimation of crack initiation and propagation life of material. Through ϵN method, the strain range $\Delta\epsilon$ at critical location and its initiation life (N) is related by "Coffin- Mansons" expression introduced in 1910, given below.

Strain Amplitude = Elastic range + Plastic range

$$\frac{\Delta\varepsilon}{2} = \frac{\Delta\varepsilon_e}{2} + \frac{\Delta\varepsilon_p}{2}$$

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma_f'}{E}(2N)^b + \varepsilon_f'(2N)^c$$

2) From Murlidhar – Mansons method (Modified Universal Slopes Method), we can have a form for Fatigue Strength Coefficient as

$$\sigma_f' = 0.623 * \left(\frac{S_u}{E}\right)^{0.832} * (2N)^{-0.09}$$

3) From Roessle Fatemi method for steels of Brinell hardness between 100 to 700 the Fatigue ductility Coefficient can be calculated using below relation.

$$\varepsilon_f' = 0.0196 * (\epsilon_f)^{0.155} * \left(\frac{S_u}{E}\right)^{-0.53} * (2N)^{-0.56}$$

Therefore, $\epsilon_f = \left(\frac{0.32*H_b^2 - 487*H_b + 191000}{E}\right) * (2N)^{-0.56}$

Where,

$\frac{\Delta\varepsilon}{2}$ = total strain amplitude

$\frac{\Delta\varepsilon_e}{2}$ = elastic strain amplitude

$\frac{\Delta\varepsilon_p}{2}$ = plastic strain amplitude

ε_f' = fatigue ductility coefficient

S_u = ultimate fatigue strength

c = fatigue ductility exponent

σ_f' = fatigue strength coefficient

b = fatigue strength exponent

H_b = Brinell hardness

N = fatigue life cycles

E = modulus of elasticity

VI. RESULT

This experiment has provided better results of Austenitic stainless steel and super duplex steel grades of AISI 316L and UNS S 32760. The work done with AISI 316L and UNS S32760, Experiment performed was good to approach for better fatigue life. The various scenarios of surface roughness where the life of specimen was slightly decreasing and found good at increased surface roughness of 180 µ. When comparing with each of the steels UNS S32760 was more precise to be used in to the marine applications due to its properties under constant strain amplitude of 0.35 than the AISI 316L which approached a fatigue life under constant Strain amplitude of 0.30.

Table – 7
Fatigue life cycle of AISI 316L and UNS S32760 steels

S.No	*Strain Amplitude*	*Surface roughness*	*Fatigue Life AISI 316L*
1	*0.30*	*0 µ*	*6911*
2	*0.30*	*60 µ*	*3190*
3	*0.30*	*120 µ*	*2285*
4	*0.30*	*180 µ*	*5992*
			Fatigue Life UNS S32760
5	*0.35*	*0 µ*	*7055*
6	*0.35*	*60 µ*	*6452*
7	*0.35*	*120 µ*	*3246*
8	*0.35*	*180 µ*	*6115*

VII. CONCLUSION

The aim of the present paper was to investigate "Impact of surface roughness on marine steels AISI 316L & UNS S32760 under Fatigue loadings". Experimental study of two different steels with surface roughness effects on fatigue strength has been conducted by Nano Servo Hydraulic Universal Testing Machine on constant strain amplitude for both the steel materials respectively. The AISI 316L Austenitic stainless steel is more sensitive to surface roughness than the UNS S 32760 Super duplex steel. Furthermore, the specimen is more prone to surface crack initiation than the specimen without surface roughness in both condition. A unified model is proposed to predict the S-N property that accounts for the effects of surface roughness and defect sensitivity of material. Fairly good agreement between prediction and experiment is achieved.

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