An influence on the analytical analysis of the UNS S32760 stress of notched super duplex stainless steel

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ABSTRACT

The current project aims to investigate how the notch shape affects the tensile strength of the superb duplex stainless steel UNS S32760. The strain-lifestyles curve for the chosen fabric is initially calculated using Finite Element Method and empirical methodologies. Afterwards, an experimental inquiry is conducted to assess the consequences. The investigations' scope includes measuring the strain on the experimentally chosen material. Research on the effects of the notch parameters (depth, breadth, and notch crucial angle) on the tensile strength and fatigue life of the aforementioned material is also included in the scope. The structure of the tests uses project notches of various parameters using response floor methods to quantify the impact of notch parameters on fatigue lifetimes. Prediction of the effect of any notch variation at the fatigue lifestyles is likewise completed the use of regression analysis.

Keywords: Keywords: Fatigue Life, fatigue analysis, Fatigue failure, Low Fatigue analysis, S-N curve, ϵ-N curve, Super Duplex Stainless Steel, UNS S32760.

INTRODUCTION

Fatigue failure is the degradation of a material brought on by cyclic stress, which results in recent and localized structural damage that may be seen with the use of a cracking boom. A crack that has already started will get smaller with each load cycle until it reaches a significant length, at which point the pressure depth aspect of the crack causes fast propagation and often complete fracture of the component or form. Steel fatigue originated from the traditional association of fatigue with metal system failure.

Ship systems are exposed to many different cyclic mass variations from wind, waves, and load operations, which might cause fatigue damages in them. Fatigue cracks usually arise in advance than expected in numerous places of ships/different marine systems which significantly have an effect on their wellness and operations. During the last decades, there has been a speedy boom within side the international delivery markets and this created the want for accelerated length of ships. The improvements in production technology enabled this with the aid of using novel versions of stainless steels with better electricity to weight ratio in ships. The OOCL Hong Kong is the primary deliver ever to surpass the 21,000 TEU mark. With accelerated dimensions, the deliver's shape is liable to greater risk from the tidal masses that may bring about fatigue damages and this will venture the deliver's layout and safety. Hence, deliver systems must be designed with good enough fatigue electricity banking upon general policies and procedures. Though the deliver systems are constructed primarily based totally on general policies and pressure-primarily based totally strategies, screw ups are nonetheless determined because of fatigue. Due to the massive uncertainties like numerous wave environments, unsure hydro-dynamic repetitive masses, pressure concentrations etc. concerned with inside the fatigue layout procedure of ships, fatigue cracks arise a great deal in advance than expected. One of the motives for the poor fatigue layout of ships is the absence/ inadequate utilization of stress-primarily based totally strategies in the course of fatigue studies. The presence of unexpected geometry changes, notches and cracks at the surface additionally want to receive weightage in the course of the fatigue layout. Hence layout of deliver systems for fatigue loading is inadequate with out stress-primarily based totally fatigue analysis. The modern studies targets at investigating the fatigue lifestyles/ electricity of grades of marine steels; UNS S32760 the use of stress primarily based totally approach. The scope of the studies encompasses, investigating the low cycle fatigue lifestyles of the figure material of the above versions of steels and their similar. The scope similarly consists of research at the impact of notch parameters (depth, width and notch principal angle) upon the fatigue lifestyles of the above stated steels. Effect of notch parameters at the fatigue lifestyles is quantified the use of layout of experiments with the aid of using project notches of various parameters by Taguchi L9 orthogonal array.

LITERATURE REVIEW

Fatigue is slow, restricted, and everlasting failure that takes place in a thing uncovered to fluctuating stresses which might be frequently a whole lot decrease in value than the fabric‟s tensile power. Fatigue loading may also first of all create cracks and reason fracture after an good enough number of fluctuations. Fatigue failure consists of 3 stages [1]: • Preliminary fatigue failure and initiation of crack. • Propagation of the crack to a vital size. • Ultimate abrupt fracture with inside the residual cross-section. Damage because of fatigue loading is instigated with the aid of using the simultaneous acts of cyclic pressure, plastic stress and tensile pressure. If any of those is absent, fatigue crack does now no longer crop up and propagate. The plastic stress that is a effect of cyclic pressure reasons the crack and the tensile pressure makes the crack to propagate. Vigilant quantification of lines depict that plastic lines aleven though microscopic in nature should exist even at decrease magnitudes of pressure wherein the stress if discovered at macroscopic stage seem like definitely elastic. Even aleven though compressive stresses do now no longer reason fatigue failure, compressive masses may also crop up nearby tensile stresses [2]. Fatigue power of steels is usually taken into consideration to be proportional to hardness and tensile power, however this generalization might not be authentic always. Processing operations, fabrication methods, warmness/floor treatments, completing done, and provider situations profoundly effect the behaviour of a cloth uncovered to cyclic loading. Forecasting the fatigue existence of a thing is complicated as substances are generally touchy toward minor versions in loading pattern, pressure concentrations etc.

Terminology in Fatigue

Stress Range: The stress range, σr is given by the maximum stress minus the minimum stress in a cycle;

$$\sigma r = \sigma max - \sigma min \qquad \text{(Equ. 2.1)}$$

Alternating Stress: The alternating stress is given by 0.5.

$$\sigma a = \sigma r/2 = \sigma max\ \sigma min$$

(Equ. 2.2)

Mean Stress: The mean stress is the mean of the maximum and minimum stress in a cycle:

$$\sigma m = \sigma max + \sigma min/2$$

Stress Ratio: The stress ratio R is given by the ratio of σmax and σmin;

$$R = \sigma max/\sigma min \qquad \text{(Equ. 2.3)}$$

Amplitude Ratio: The amplitude ratio A is the ratio of σa and σm;

$\boldsymbol{A}= \boldsymbol{\sigma a}/\boldsymbol{\sigma m}= \mathbf{1}-\boldsymbol{R}/\mathbf{1}+\mathrm{R}$(Equ. 2.4)

Effect of Notch on the Fatigue Life of Steels

In case of pointed notches, the „notch sensitivity" Kf / Kt raises along with the notch size. For as-received steels, the notch sensitivity is much superior at a stress ratio R = -1 when compared to R = 0. This means that, at R = -1, the as-received steels are less sensitive to notches compared to the heat-treated counterparts. For a given notch size, tempering temperature does not have considerably influence on notch sensitivity in the case of heat-treated steels. Further, notch sensitivity and ductility from true fracture strain cannot be related through any direct relation M.Makkonen et. al. studied the fatigue overall performance of tempered metal specimens with grooves and got here to a end that a unmarried approach can not be used by myself to estimate the staying power limits of sharp notches and blunt notches. In the case of very sharp notches, the plastic pressure even on the staying power restrict became widespread, and that have to be accounted for. In case of blunt notches in which the plastic pressure became insignificant, staying power restrict became exactly predicted with the combination of statistical and geometric length results. The statistical length impact itself supplied sufficiently unique solutions for engineering purposes. Fatigue restrict of sharp notches have to be approximated through a way that considers the truth that, because the notch"s radius of root reduces, the fatigue/staying power restrict actions closer to a price this is attained as follows

METHODOLOGY Types of stainless steels

Stainless steels are typically divided into 4 groups: Austenitic. Most common types of stainless steels are comprised in the austenitic group. Austenitic stainless steels incorporate Higher degrees of chromium, molybdenum and nickel. they are in particularversatile and are known for super strength andmalle¬ability.

Ferritic. ferritic stainless steels typically are low carbon content material of much less than 0.1%. Containing between 10.5% and 30% chromium, Ferritic stainless steels are magnetic and are generally selected for the temperature oxidation and stress corrosion cracking resistance.

Duplex. Duplex stainless steel combines the austenitic with the ferritic, leading to a metal that is stronger than both: this higher strength can cause considerable weight reductions. Its high resistance to corrosion, even in demanding envi¬ron¬ments, make it ideal for use in marine appli-cations.

Martensitic. Structurally like ferritic stainless steel butwith an increased carbon content (< 1.2%), martensitic stainless-steel are mostly hardened to a large degree. **Super Austenitic Stainless Steel**

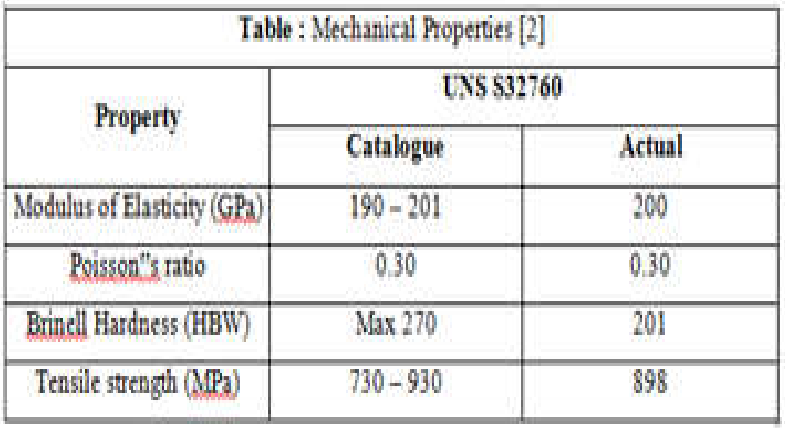

Table : Mechanical Properties [2]

Property	UNS S32760	
	Catalogue	Actual
Modulus of Elasticity (GPa)	190 – 201	200
Poisson"s ratio	0.30	0.30
Brinell Hardness (HBW)	Max 270	201
Tensile strength (MPa)	730 – 930	898

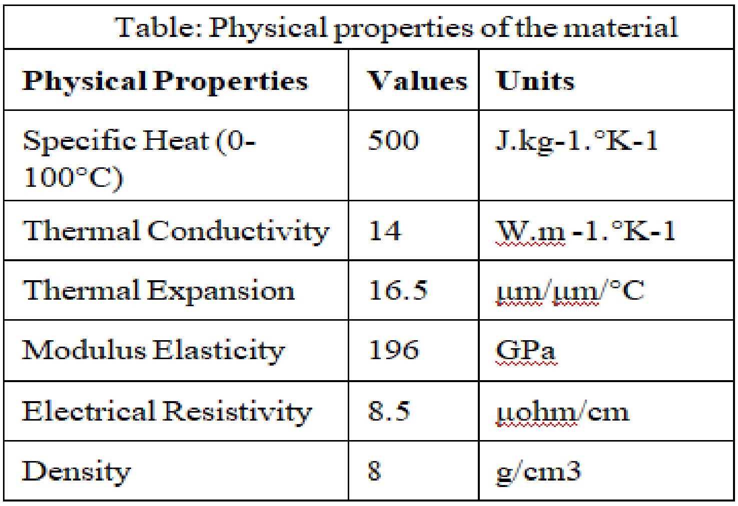

Table: Physical properties of the material		
Physical Properties	**Values**	**Units**
Specific Heat (0-100°C)	500	J.kg-1.°K-1
Thermal Conductivity	14	W.m -1.°K-1
Thermal Expansion	16.5	µm/µm/°C
Modulus Elasticity	196	GPa
Electrical Resistivity	8.5	µohm/cm
Density	8	g/cm3

Design criteria

The fatigue specimens were fabricated for strain-controlled fatigue testing as specified by ASTM E606 standard. The gauge lengthis 15 mm for the specimen UNS S32760 undertaken and the drawing of the specimen ispresented in Figure

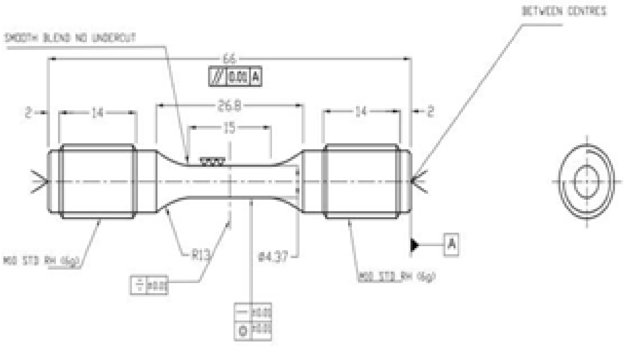

Fig. : Standard Fatigue Specimen.

Specimen Fabrication

The material UNS S32760 was bought in the form of 2M long solid rods of 14mm diameter. These rods were transported from Mumbai to Hyderabad and thensent for fabrication. These rods were first sent to test the straightness of the material to check the dimensions and any deformations and kinks in the material.

The specimens are fabricated on a CNC Lathe Machine (Figure) and the notches are made using a 4th axial CNC Milling machine. The CNC operations used were facing, turning and chamfering. These operations were all calibrated through the CNC program.

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Fig: Super Jobber CNC Lathe Machine that was operated to fabricate un-notched and notchedspecimens.

Fig. : Specimen After complete fabrication on one side

Fig.: Specimen after complete fabrication on bothsides without the notch.

fig: Different views of a typical notched specimen

2. EXPERIMENTATIONFatigue Testing

Low cycle fatigue testing is carried out with a 25

KN capacity Servo Hydraulic Nano UTM that is of ITW – BISS make (figure 4.1). strain controlled fatigue testing is undertaken as it is the most suitable method in particular when there are notches grooved on geometry.to two repeats are executed for one experimental situation as consistent with ASTM E606 standard and the average of the nearest values is offered as fatigue life for error reduction and consistency within the results.

Fig. : Servo Hydraulic Nano UTM (Capacity: 25 KN)used for fatigue testing

Design of Experiments

Taguchi Technique for Notch Analysis

The three elements chosen for Taguchi evaluation of notch fatigue strength together with their high, medium and low levels are referred to in table 4.1. The experimental matrix given in table 4.2 is a 9-trial orthogonal array (OA) of Taguchi matrix i.e. L9. This OA provides complicated enough array to illustrate the amount of confounding that can occur in an experiment.

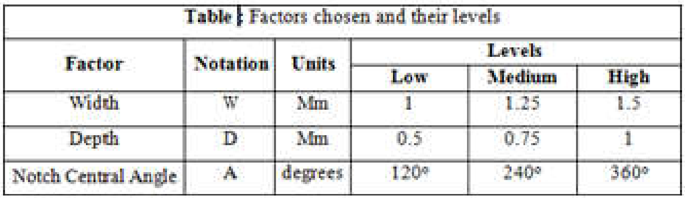


Table : Factors chosen and their levels

Factor	Notation	Units	Levels		
			Low	Medium	High
Width	W	Mm	1	1.25	1.5
Depth	D	Mm	0.5	0.75	1
Notch Central Angle	A	degrees	120°	240°	360°

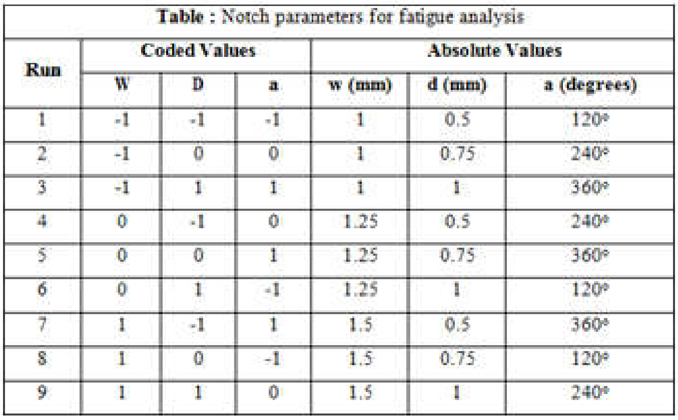


Table : Notch parameters for fatigue analysis

Run	Coded Values			Absolute Values		
	W	D	a	w (mm)	d (mm)	a (degrees)
1	-1	-1	-1	1	0.5	120°
2	-1	0	0	1	0.75	240°
3	-1	1	1	1	1	360°
4	0	-1	0	1.25	0.5	240°
5	0	0	1	1.25	0.75	360°
6	0	1	-1	1.25	1	120°
7	1	-1	1	1.5	0.5	360°
8	1	0	-1	1.5	0.75	120°
9	1	1	0	1.5	1	240°

It is also included in the output response as per Taguchi L9 orthogonal.

The experimental outcomes are analyzed by using the Chauvenet's criterion for their deviations in a waywhich illustrates the percentage contribution of every parameter with 0% error. by means of using additive model, the difference because of the inclusion and exclusion of the fictitious parameter (p) is estimated. With this perturbation, the correction values are computed for the experiment under consideration. The corrections are added/ subtracted from the estimated values to reach at the lower and upper bounds. The regression equation developed from this method is used to estimate the fatigue life of complete factorial matrix along side the lower and top bounds of the fatigue life.

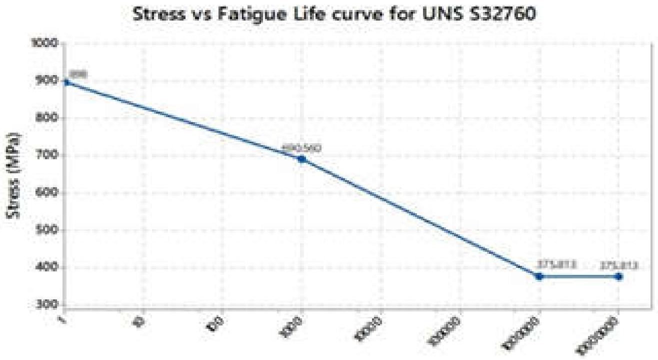
EMPIRICAL METHODS

Different empirical methods are adopted to estimate the fatigue/endurance limit and to approximate the „Stress (vs) Fatigue Life" and „Strain Amplitude (vs) Fatigue Life" curves for the chosen materials. Marin"s equation is employed to find the endurance limit. Further, a method proposed by Shigley is employed to approximate the „Stress (vs) Fatigue Life" curves. Strain based fatigue life prediction is done using the Muralidharan-Mansion method and the

„Strain Amplitude (vs) Fatigue Life" curves are approximated for the chosen materials.

Table : Data for interpolation of k_c

S_u (MPa)	k_c
344.738	0.907
689.476	0.859
1034.21	0.822
1378.95	0.814



Graph: Stress vs Fatigue Life curve for UNS S32760 The fatigue life of the materials and their weldments undertaken are computed at different strain amplitudesusing the Muralidharan-Mansion method and the results are presented in Table

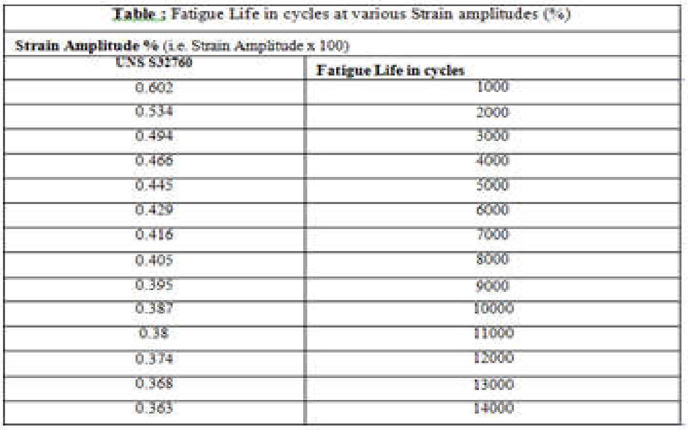
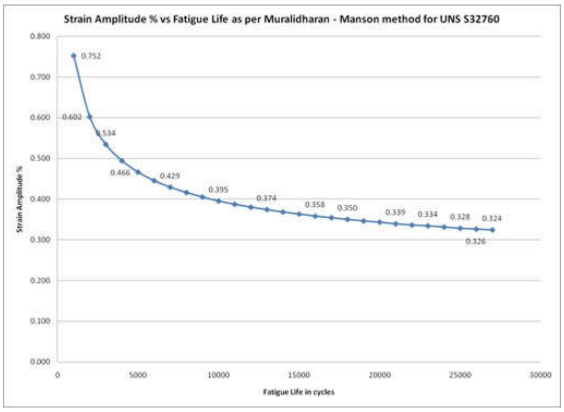


Table : Fatigue Life in cycles at various Strain amplitudes (%)

Strain Amplitude % (i.e. Strain Amplitude x 100) UNS S32760	**Fatigue Life in cycles**
0.602	1000
0.534	2000
0.494	3000
0.466	4000
0.445	5000
0.429	6000
0.416	7000
0.405	8000
0.395	9000
0.387	10000
0.38	11000
0.374	12000
0.368	13000
0.363	14000

Table : depict the „Strain amplitude (vs) Fatigue Life‟ curves developed employing the Muralidharan-Mansion method for the material.



Graph: Strain Amplitude (vs) Fatigue Life plot forUNS S32760

Fatigue Analysis Using Finite Element Approach The fatigue tool available in ANSYS 18.1 was used to approximate the fatigue life in cycles for thematerialsUNS S32760steel. 3-D model of the ASTM E606 standardFatigue specimen was created in CREO 3.0and exported to ANSYS 18.1 asIGESfile.Discretization was carried out using Tetrahedronelements maintaining mesh refinement level asthree.Finite Element Fatigue Analysis was carried out on thestandard fatigue specimen (Figure 4.2) to find out theendurance limit and subsequently to plot the „Stress(vs) Fatigue Life‟ curve. Smith – Watson – Toppermethod of the Strain – Life approach was adopted forthe analysis since it provides a conservative answer incomparison to the Morrow’s approach.

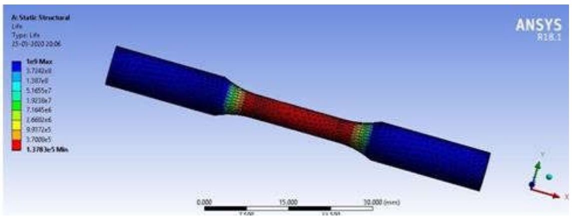


Figure : Fatigue Life in cycles

Finite element fatigue runs are carried out for 40 different loadings and the stress (vs) fatigue life curve is plotted from respective stress and fatiguelife values. Table 5.3 encompasses the stress and fatigue life values and the curve is depicted in Figure 45.3. The magnified view of the low cyclefatigue region of the stress (vs) fatigue life curve is shown in Figure 5.4. The endurance limit is found to be 321.45 MPa for as it is the stress value obtained at a fatigue life of around 10^6 cycles.

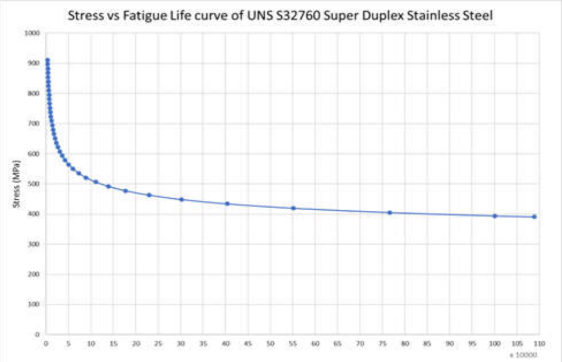


Fig : Stress (vs) Fatigue Life curve for UNS S32760 fatigue strength reduction of bearing steel in the very high cycle regime,

Impact of Notch Geometry on the Fatigue Life Specimens without notch and with various types of notches as per Taguchi L9 orthogonal array werefabricated using a CNC Lathe. Both parent materialand welded samples were used to fabricate thespecimens based on the scenario. Strain controlledfatigue runs were executed with 0.3% strain amplitudeon the specimens till there was an appreciable crackobserved on the specimen. Fatigue runs were initiallyundertaken on the specimen without any notch on itssurface and the fatigue life in cycles was recorded. Thereafter, the fatigue test runs were undertaken forthe nine specimens with various types of notchgeometries on their surfaces and the fatigue lives werenoted.

Figure : UNS S32760 specimens post fabrication

Figure: UNS S32760 un-notched specimen afterfatigue failure.

Table : Fatigue Life (cycles) for un-notched UNS S32760 specimens

Specimen scenario	**Fatigue Life (cycles)**		
UNS S32760 Material	**Trial 1**	**Trial 2**	**Average**
	26884	25147	26016

The nine notched specimens after fatigue failure are shown in Figure 5.8 and the results are presented in Table .

Table: Fatigue Life (cycles) for notched UNS S32760 specimens

Run	**w**	**D**	**a**	**Fatigue Life (cycles)**		
				Trial 1	**Trial 2**	**Average**
1	-1	-1	-1	2783	2876	2830
2	-1	0	0	2566	2345	2456
3	-1	1	1	589	650	620
4	0	-1	0	7155	6987	7071
5	0	0	1	1513	1389	1451
6	0	1	-1	2895	2568	2732
7	1	-1	1	2387	2546	2467
8	1	0	-1	4120	3895	4008
9	1	1	0	1267	1018	1143

When the depth of the notch is at the lowest value withthe width and notch central angle at their mid values, the fatigue life is observed to be the highest to the tune of 7155 cycles (Run 4), while the fatigue life is observed to be the lowest to the tune of 589 cycles only when the depth of the notch is at the highest value (Run 3) asillustrated in Table .

Table ANOVA for Regression Analysis of UNS S32760 material

Coefficient	**Estimate**	**SS**	**DOF**	**MS**	**F**
b_0	2752.722	-	-	-	
b_1	190.222	651320.889	2	325660.444	0.04325861
b_2	-874.833	13776000.500	2	6888000.250	0.914957047
b_3	-559.056	5625776.056	2	2812888.028	0.373645707
b_4	98.444	174443.556	2	87221.778	0.011585972
b_5	74.333	99458.000	2	49729.000	0.006605676
b_6	-194.333	679778.000	2	339889.000	0.045148639
SSR		**21006777.000**	**12**		
SSE		**37641112.611**	**5**	**7528222.522**	
SST		**58647889.611**	**17**		

The data is subjected to analysis of variance usingYate‟s algorithm and the values/ coefficients are presented in Table

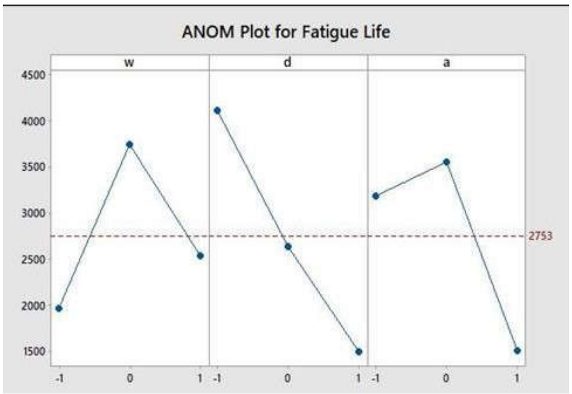
Table: ANOVA for Taguchi Analysis of UNS S32760 material

Source	SS	DOF	MS	F	% Contribution
w	9949003.11	2	4974501.56	4.00	16.96
d	20782451.44	2	10391225.72	8.36	35.44
a	14250781.44	2	7125390.72	5.74	24.30
SSR	44982236.00	6			
SSE	13665653.61	**11**	**1242332.15**		
SST	58647889.61	**17**			

From the Taguchi analysis it is evident that depth of notch has 35.44%, notch central angle has 24.30% and width of notch has 16.96% impact on the fatigue life of UNS S32760 super duplex stainless steel.

The experimental data is also subjected to Analysis of means (ANOM) and the results are presented in Table

5.9 and plotted in Figure . The grand mean of the results in terms of fatigue life is found to be 2753 cycles. Based on the ranks computed, it is clearly seen that depth of notch is predominant in governing the fatigue life while the width is contributing to a lower extent.



From Taguchi Analysis optimal parameter condition is; w = 0, d = -1 and a = 0 in their coded forms and the absolute values are; w = 1.25 mm; d = 0.5 mm; a = 240° respectively. The predicted optimal fatigue life can be found by the equation,

Optimal predicted fatigue life, foptimum = m + $(mi{-}m)$

where; m = Grand Mean and mi = Maximum value in

each parameter at optimal condition. Therefore; foptimum = 2753+ [(3751.17-2753) + (4122.33-2753) + (3556.33-2753)] = 5924 cycles

Employing the optimal parameter condition an experiment is conducted and it is found that the optimal fatigue life is 6652 cycles and it is in consonance with the predicted value.

At this stage, modified Taguchi method which is basedon Chauvenet‟s criterion is applied for one trial values of the fatigue life and the corrections for the fictitious parameter are obtained as -954.00, -192.33, and 1146.33 respectively.

Table: ANOVA for Fatigue Life of UNS S32760 material

Parameter	1-mean	2-mean	3-mean	Mean	SS	% Contribution
w	1979.33	3854.33	2591.33	2808.33	5485338.00	18.38
d	4108.33	2733.00	1583.67	2808.33	9586450.67	32.13
a	3266.00	3662.67	1496.33	2808.33	7982064.67	26.75
p	1854.33	2616.00	3954.67	2808.33	6783564.67	22.74
				Sum	29837418.00	100

CONCLUSION

This experimentation of fatigue analysis of the Super Duplex Stainless-steel UNS S32154 has yielded the stress amplitudes and the fatigue lives of the material with different parameters such as notch angles varying from 0° to 360°, and the Notch depths varying from 0.5mm to 1mm, and the notch width varying from1mm to 1.5mm.

These variations in notches have made an interesting impact on the fatigue life of the material, It was noticed that the notch depth has an vital role in the life of the material, As the notch depth increases, the fatigue life of the material decreases.

Below are the notch parameters that were considered in the experimentation.

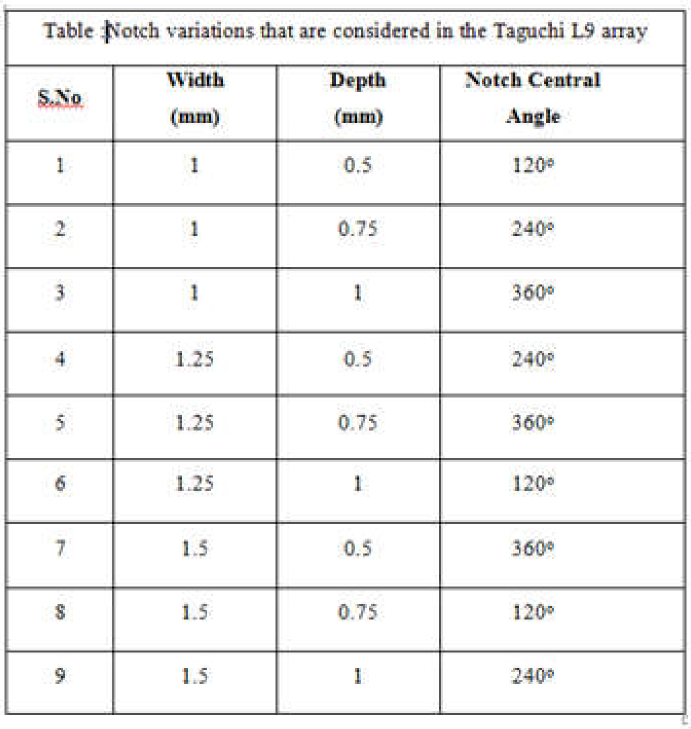


Table :Notch variations that are considered in the Taguchi L9 array

S.No	Width (mm)	Depth (mm)	Notch Central Angle
1	1	0.5	120°
2	1	0.75	240°
3	1	1	360°
4	1.25	0.5	240°
5	1.25	0.75	360°
6	1.25	1	120°
7	1.5	0.5	360°
8	1.5	0.75	120°
9	1.5	1	240°

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