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Fatigue Failure Analysis of Notched Specimen with En19, En354 and En36c Materials

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Abstract:- In order to prevent failures, a mechanical machine must take into account the impact of cyclic stress. The rotating-beam fatigue tester used in this work determines the fatigue life of EN19, EN354, and EN36C alloy materials. Although probabilistic fatigue evaluation is essential for guaranteeing the service integrity of big mechanical equipment, the combination of multiaxial stress circumstances, limited sample information characteristics, and probabilistic fatigue models remains inadequate in actual engineering. Therefore, a generic probabilistic fatigue evaluation procedure is proposed by efficiently combining the virtual subsample augmentation approach with the enhanced Bootstrap method. Specifically, the random sample regeneration method is first used to expand the small sample fatigue data, and then life distribution information under different stress levels is fused based on the backwards statistical inference method, the S- N curve is fitted with the integrated life dispersion information. Secondly, a new fatigue damage parameter based on the inhibition function is proposed to modify the S-N curve and predict fatigue life. Meantime, the fatigue test of alloy steel with different notch sizes is to be carried out, for different materials EN19, EN354, EN36C alloy. The results show that the impact of notch and size effects on fatigue damage of proposed specimens.

***Keywords**: Fatigue, Failure Cycle, Notched Specimen, Strain Life Equation.*

I. INTRODUCTION

Examining the broken pieces in nearly every scrap will reveal that many failures happen at stresses lower than the part's material yield strength. "Fatigue" is the term for this intricate occurrence. Up to 90% of in-service part failures that occur in industry are caused by fatigue. The fact that a fatigue fracture did not exhibit obvious plastic deformation was seen as odd in the 19th century, which led to the mistaken assumption that fatigue was only an engineering issue. They were not entirely incorrect, though, as the power of the microscopic equipment available at the time was quite restricted, and few renowned researchers conducted fatigue testing during this century; the most well-known of these was the work of August Wöhler, who would go on to come up with the idea of stress-lifetime curve (S-N Curve. The 20th century saw a significant advance in our knowledge of the fatigue failure process. Fatigue started to be seen as a material and design phenomenon rather than an engineering issue because of more powerful tools like computers, powerful microscopic instruments, sophisticated numerical analysis techniques, and a great deal of research (John Mann cited up to 100,000 references in one of his works).

Even while fatigue failure has been extensively studied, its actual nature is still unknown, and reports of damage, cracks, or even total failure brought on by cycle loads are common. Something has to be explained if the issue persists after a century of research was conducted.

Components of machines are usually subjected to the cyclic loads and the resulting cyclic stresses can lead to microscopic physical damage to the materials involved. Fatigue fractures usually occur at the notches such as holes, grooves, etc. The geometry of notch and other notch properties affect on the predictions of fatigue life. Stress at the notch is equal to the nominal stress multiplied by the elastic stress concentration factor, t k . This stress rise will of course be very harmful with respect to fatigue damage, but it can not give directly the effective stress range in fatigue. Therefore, the fatigue strength reduction factor f k should be introduced.

II. DIFFERENT PHASES OF FATIGUE LIFE

Microscopic investigation in the 20th century has revealed that the nucleation of fatigue cracks occurs at a very early stage of fatigue life. The crack starts as a slip band within a grain. The cyclic slip occurs as a result of cyclic shear stress, this slip leads to formation of slip steps, in the present of oxygen, the freshly exposed surface of the material in slip steps get oxidized, which prevents slip reversal. The slip reversal in this case occurs in some adjacent slip plane, thereby leading to formation of extrusions and intrusions on the surface of the material as shown in the figure below.

The fatigue life is generally divided into three stages/periods Figure 3 Different phases of the fatigue life The fatigue life (Nf) of a component is defined by the total number of stress cycles required to cause failure. Fatigue life can be separated into three stages where:

f = Ni +Np

III. MATERIALS

Assurance of failing attributes is basically through the stress versus no. of cycles to failure curve, which is commonly known as S-N curve. The fatigue test was directed according to IS 5075: 1975. The samples for the test were machined on a CNC lathe machine from EN19, EN354 and EN36C steel bars to the shape as appeared in Figure 1.

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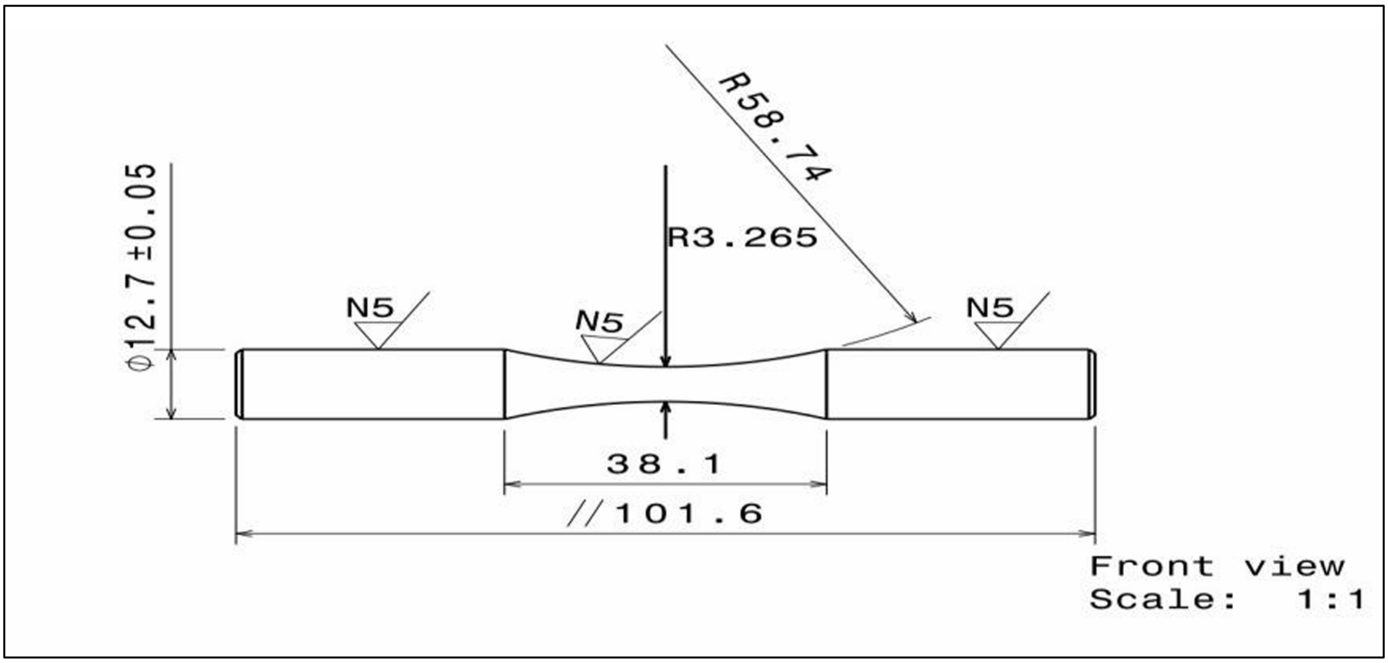

Fig 1: Sample Drawing

Table 1, 3, 5 give an idea about the composition of the EN19, EN354, EN36C material and Table 2, 4, 6 the mechanical properties of EN19, EN354, EN36C.

Table 1: Chemical Composition of EN19 Material

Elements	Min	Max
Carbon	0.35	0.45
Manganese	0.5	0.8
Chromium	0.9	1.5
Molybdenum	0.2	0.4
Silicon	0.1	0.35
Sulphur	0	0.05
Phosphorus	0	0.035

Table 2: Mechanical Properties of EN19

Condition	Tensile
Tensile /mm²	850-1000
Yield N/mm²	680
Elongation %	13
Izpd KCV J	50
Hardness Birnell	248-302

Table 3: Chemical Composition of EN354 Material

Elements	Min	Max
Carbon	-	0.2
Silicon	-	0.35
Manganese	0.50	1.00
Sulphur	-	0.04
Phosphorus	-	0.04
Chromium	0.75	1.25
Molybdenum	-	0.035
Nickel	1.50	2.00

Table 4: Mechanical Properties of EN354

Tensile Strength	540-700 MPa
Yield Strength	355 MPa
Elongation	16%

Table 5: Chemical Composition of EN36C Material

Elements	Min	max
Carbon	0.35	0.45
Manganese	0.5	0.8
Chromium	0.9	1.5
Chromium	0.2	0.4
Silicon	0.1	0.35
Sulphur	-	0.05
Phosphorus	-	0.035

Table 6: Mechanical Properties of EN354

Tensile Strength n/mm²	1100
Elongation%	15
Impact load	40
Hardness	341
Reduction Area %	50

IV. FATIGUE TESTING MACHINE

Generally the fatigue test is to decide the life expectancy that might be normal from a material exposed to cyclic stacking. The fatigue life of material is the absolute number of cycles that a material can be exposed to a solitary stacking condition. To carry out fatigue test, a sample is loaded into a fatigue testing machine. This cycle of loading and unloading is then repeated until the end of the test is reached. The test may run to a predetermined number of cycles or until the sample has failed depending on the parameters of the test. The type of fatigue testing machine using is Rotating beam type. The specimen function is as a single beam symmetrically loaded at two points. Fatigue testing machine details as shown in fig.2 and fig.3 respectively.

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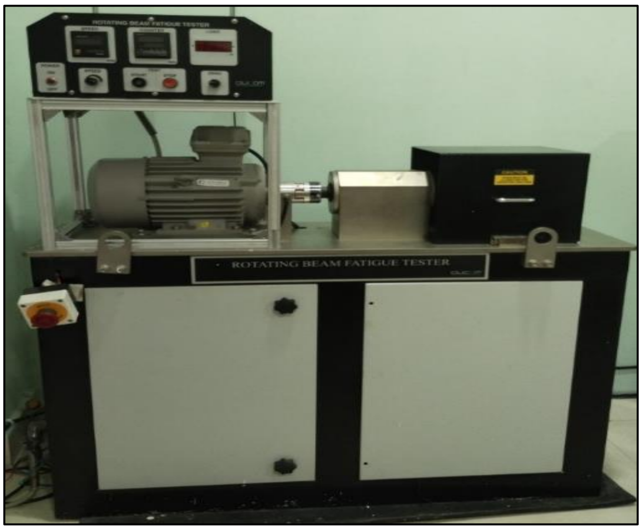

Fig 2: Fatigue Testing Machine

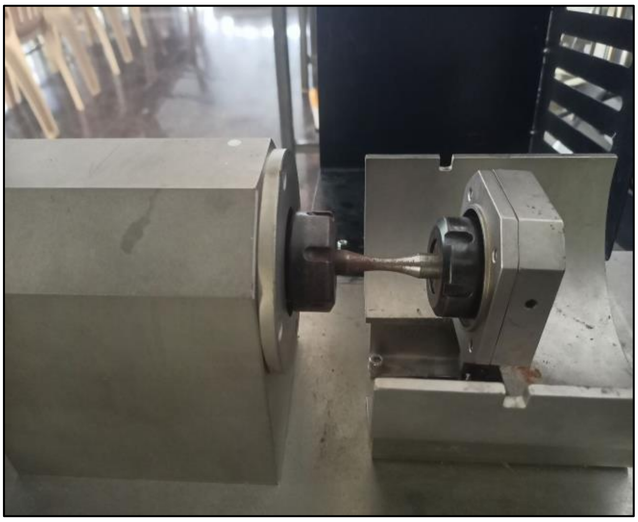
Fig 3: Specimen Holding

➢ *Machine Specifications:*

Table 7: Machine Specifications of Rotating Beam Fatigue Machine

Machine Specifications	
Specimen material and size	Non heat treated 12.7 and 101.6 mm long
Collect size	13mm
Load:	50 to 1000N (load applied with dead weights)
Loading ratio:	1.5
Specimen speed:	Min 1000 rpm, Max 5000 rpm
Setting block length	40mm
Centre of profile:	19.05mm
Bending moment distance:	Bending distance = loading distance + middle of profile centre
Loading distance	Loading point + Housing Covering plate + Collect length (9.9+9+17) = 35.95mm
Bending distance	35.95+19.05 i.e. 55mm
Counters (counts):	1 to 999999
Bending moment	3 to 55 Nm
Bending Stress	110 to 2190 Mpa

➢ *Calculations*

- Bending Moment, M = Load applied x Bending distance Bending Stress, b = 32M/ πd3
- Endurance Stress, e = Ka.Kb.Kc. σel
- Where
- Ka = a (σ out) b, Surface Finish Factor
- Kb = 1.24d-0.107, Size Factor
- Kc = Reliability Factor
- Log10N-3 = EF
- Where EF = Fatigue strength corresponding to the N cycles

➢ *EN19*

Table 8: Fatigue life Calculations of EN19

S.No	Load in N	Speed in RPM	Bending moment in Nm	Cycles
1	200	1000	11	62329
2	250	1000	13.7	54999
3	250	1500	13.7	24627
4	300	1500	16.5	19627
5	350	1500	19.25	16363

➢ *Calculations*

- Ultimate Tensile Strength for EN19 = 900 N/mm^2
- S_{ut}=900 N/mm^2
- $S_e^!$= 0.5sut
- $S_e^!$= 0.5*900
- $S_e^!$= 450 N/mm^2
- 0.9 S_{ut} =0.9*900 =810 N/mm^2
- Log_{10} (0.9 S_{ut})= 2.90
- $Log_{10}(S_e^!)$=2.653
- $Log_{10}(10^6)$=6, $Log_{10}(10^3)$=3

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- *Specimen 1*

No of Cycles at which failure taken place =62329

Log_{10}(No of Cycles)= Log_{10}(62329)=4.794

$$\text{Log10 (Sf)} = 0.9\ \text{Sut} - \frac{0.9\ S_{ut} - S_e^!}{6-3} * (\text{Log}_{10}(\text{cycles})-3)$$

Log_{10} (S_f) = 2.755

- *Specimen 2*

No of Cycles at which failure taken place =54999

Log10(No of Cycles)= Log10(54999)=4.740

$$\text{Log10 (Sf)} = 0.9\ \text{Sut} - \frac{0.9\ S_{ut} - S_e^!}{6-3} * (\text{Log}_{10}(\text{cycles})-3)$$

Log10 (Sf) = 2.760

- *Specimen 3*

No of Cycles at which failure taken place =24627

Log10(No of Cycles)= Log10(24627)=4.391

$$\text{Log10 (Sf)} = 0.9\ \text{Sut} - \frac{0.9\ S_{ut} - S_e^!}{6-3} * (\text{Log}_{10}(\text{cycles})-3)$$

Log10 (Sf) = 2.789

- *Specimen 4*

No of Cycles at which failure taken place =19627

Log10(No of Cycles)= Log10(19627)=4.292

$$\text{Log10 (Sf)} = 0.9\ \text{Sut} - \frac{0.9\ S_{ut} - S_e^!}{6-3} * (\text{Log}_{10}(\text{cycles})-3)$$

Log10 (Sf) = 2.798

- *Specimen 5*

No of Cycles at which failure taken place =16363

Log10(No of Cycles)= Log10(16363)=4.213

$$\text{Log10 (Sf)} = 0.9\ \text{Sut} - \frac{0.9\ S_{ut} - S_e^!}{6-3} * (\text{Log}_{10}(\text{cycles})-3)$$

Log10 (Sf) = 2.804

- *EN354*

Table 9: Fatigue life Calculations of EN354

S.No	Load in N	Speed in RPM	Bending moment in Nm	Cycles
1	200	1000	11	45039
2	250	1000	13.7	29939
3	300	1000	16.5	15023
4	250	1300	13.7	16955
5	250	1500	13.7	11623

- *Calculations*

Ultimate Tensile Strength for EN354= 600 N/mm^2

S_{ut}=600 N/mm^2

$S_e^!$= 0.5sut

$S_e^!$= 0.5*600

$S_e^!$= 300 N/mm^2

0.9 S_{ut} =0.9*600=450 N/mm^2

Log_{10} (0.9 S_{ut})= 2.73

$Log_{10}(S_e^!)$=2.47

$Log_{10}(10^6)$=6, $Log_{10}(10^3)$=3

- *Specimen 1*

No of Cycles at which failure taken place =45039

Log_{10}(No of Cycles)= Log_{10}(45039)=4.65

$$\text{Log10 (Sf)} = 0.9\ \text{Sut} - \frac{0.9\ S_{ut} - S_e^!}{6-3} * (\text{Log}_{10}(\text{cycles})-3)$$

Log_{10} (S_f) = 2.59

- *Specimen 2*

No of Cycles at which failure taken place =29939

Log_{10}(No of Cycles)= Log_{10}(29939)=4.47

$$\text{Log10}\,(S_f) = 0.9\,S_{ut} - \frac{0.9\,S_{ut} - S_e^{!}}{6-3} * (\text{Log}_{10}(\text{cycles})-3)$$

$\text{Log}_{10}\,(S_f) = 2.60$

- *Specimen 3*

No of Cycles at which failure taken place =15023

Log_{10}(No of Cycles)= Log_{10}(15023)=4.176

$$\text{Log10}\,(S_f) = 0.9\,S_{ut} - \frac{0.9\,S_{ut} - S_e^{!}}{6-3} * (\text{Log}_{10}(\text{cycles})-3)$$

$\text{Log}_{10}\,(S_f) = 2.62$

- *Specimen 4*

No of Cycles at which failure taken place =16955

Log_{10}(No of Cycles)= Log_{10}(16955)=4.229

$$\text{Log10}\,(S_f) = 0.9\,S_{ut} - \frac{0.9\,S_{ut} - S_e^{!}}{6-3} * (\text{Log}_{10}(\text{cycles})-3)$$

$\text{Log}_{10}\,(S_f) = 2.62$

- *Specimen 5*

No of Cycles at which failure taken place =11623

Log_{10}(No of Cycles)= Log_{10}(11623)=4.06

$$\text{Log10}\,(S_f) = 0.9\,S_{ut} - \frac{0.9\,S_{ut} - S_e^{!}}{6-3} * (\text{Log}_{10}(\text{cycles})-3)$$

$\text{Log}_{10}\,(S_f) = 2.63$

- *EN36C*

Table 10: Fatigue Life Calculations of EN36C

S.No	Load in N	Speed in RPM	Bending moment in Nm	Cycles
1	200	1000	11	11271
2	250	1000	13.7	8783
3	250	1500	13.7	7146
4	300	1000	16.5	5436
5	300	1500	16.5	5583

- *Calculations*

- Ultimate Tensile Strength for EN36C= 1100 N/mm^2
- S_{ut}=1100 N/mm^2
- $S_e^{!}$= 0.5sut
- $S_e^{!}$= 0.5*1100
- $S_e^{!}$= 550 N/mm^2
- 0.9 S_{ut} =0.9*1100=990 N/mm^2
- Log_{10} (0.9 S_{ut})= 2.99
- $\text{Log}_{10}(S_e^{!})$=2.74
- $\text{Log}_{10}(10^6)$=6, $\text{Log}_{10}(10^3)$=3

- *Specimen 1*

No of Cycles at which failure taken place =11271

Log_{10}(No of Cycles)= Log_{10}(11271)=4.05

$$\text{Log10}\,(S_f) = 0.9\,S_{ut} - \frac{0.9\,S_{ut} - S_e^{!}}{6-3} * (\text{Log}_{10}(\text{cycles})-3)$$

$\text{Log}_{10}\,(S_f) = 2.902$

- *Specimen 2*

No of Cycles at which failure taken place =8783

Log_{10}(No of Cycles)= Log_{10}(8783)=3.94

$$\text{Log10}\,(S_f) = 0.9\,S_{ut} - \frac{0.9\,S_{ut} - S_e^{!}}{6-3} * (\text{Log}_{10}(\text{cycles})-3)$$

$\text{Log}_{10}\,(S_f) = 2.911$

- *Specimen 3*

No of Cycles at which failure taken place =7146

Log_{10}(No of Cycles)= Log_{10}(7146)=3.855

$$\text{Log10}\,(S_f) = 0.9\,S_{ut} - \frac{0.9\,S_{ut} - S_e^{!}}{6-3} * (\text{Log}_{10}(\text{cycles})-3)$$

$\text{Log}_{10}\,(S_f) = 2.9188$

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- *Specimen 4*

No of Cycles at which failure taken place =5436

Log_{10}(No of Cycles)= Log_{10}(5436)=3.73

$$Log10\,(Sf) = 0.9\,Sut - \frac{0.9\,S_{ut} - S_e^{!}}{6-3} * (Log_{10}(cycles)-3)$$

Log_{10} (S_f) = 2.929

- *Specimen 5*

No of Cycles at which failure taken place =5583

Log_{10}(No of Cycles)= Log_{10}(5583)=3.74

$$Log10\,(Sf) = 0.9\,Sut - \frac{0.9\,S_{ut} - S_e^{!}}{6-3} * (Log_{10}(cycles)-3)$$

Log_{10} (S_f) = 2.928

V. RESULTS AND DISCUSSION

The S-N curvature is utilized to plot the extent of a rotating stress and the number of cycles to failure for a given case material. Both stress and the quantity of cycles are shown on logarithmic scales. The exhaustion qualities of a given material are taken by its S-N graph, a case of which is appeared. The representation of fatigue test in which an example of material is trying to failure by applying a alternate stress of extent S comprises of spots. It is rehashed for various estimations of S and number of cycles to failure then N is plotted against S. For various materials the plot of log S against log N is shown to in straight line.

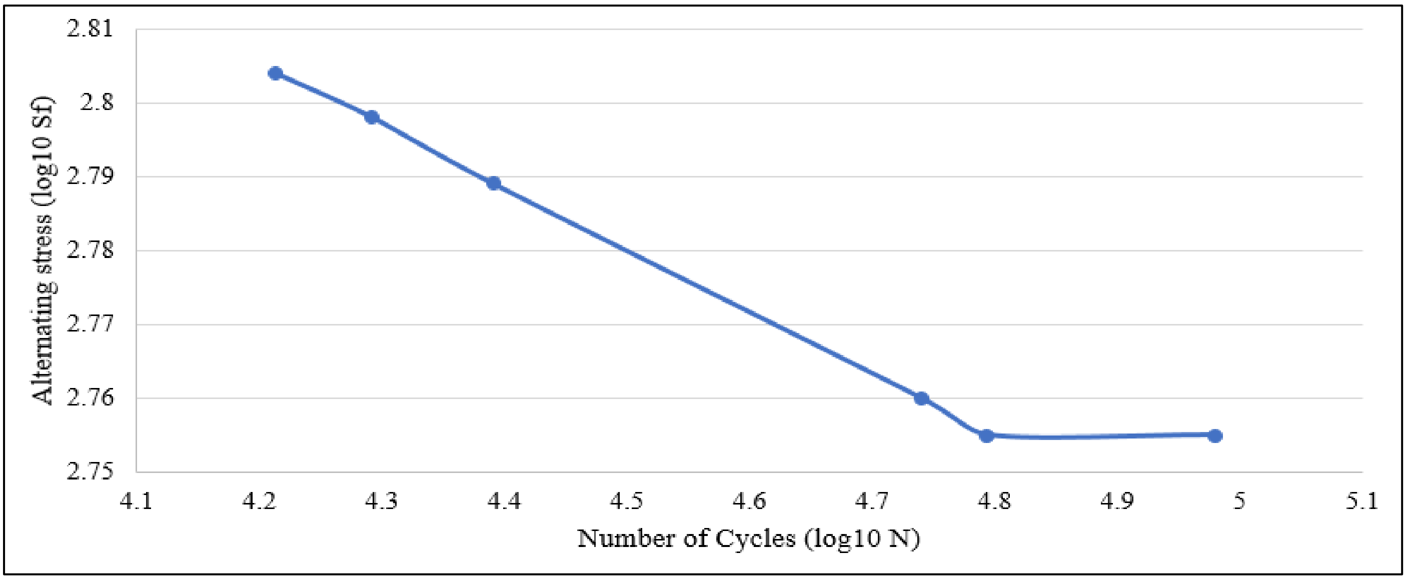

Fig 4. S-N Curve OF EN19 Specimen

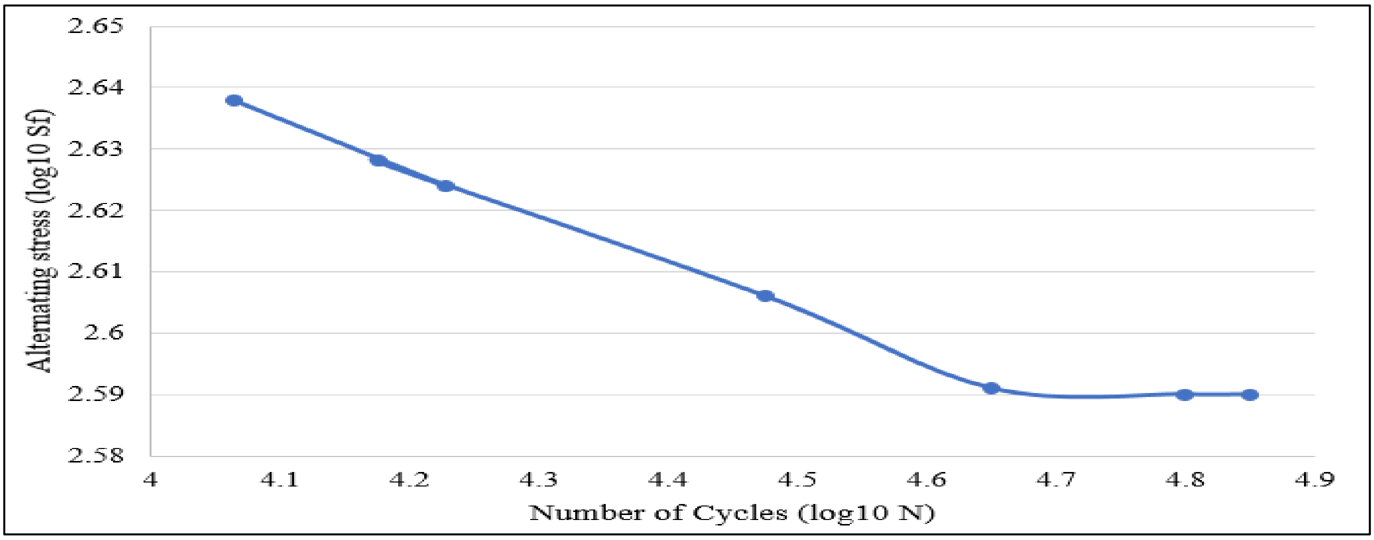

Fig 5: S-N Curve OF EN354 Specimen

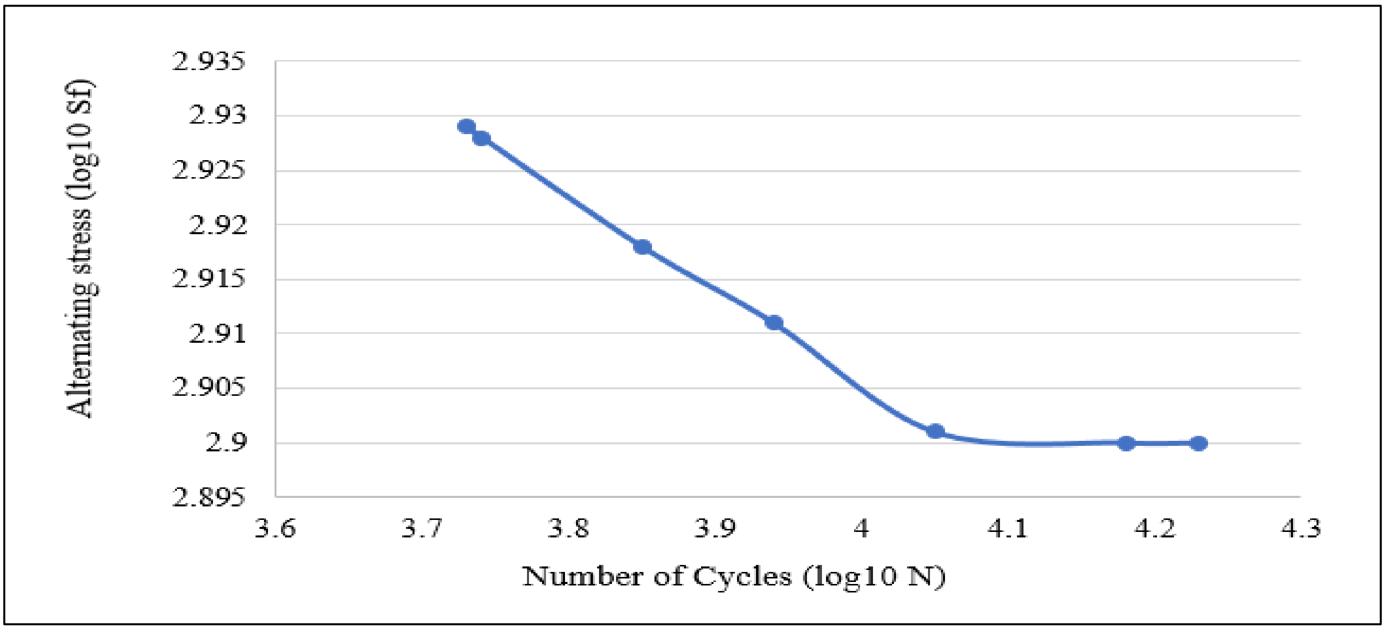

Fig 6: S-N Curve of EN36C Specimen

VI. CONCLUSIONS

- EN19: This material can tolerate larger pressures at lower cycle counts since it shows a progressive decrease in alternating stress as the number of cycles increases. But as it gets closer to a stress limit, the curve flattens out, indicating an endurance limit beyond which it can withstand several cycles without failing.
- EN354: Although at a somewhat lower stress level, EN354's alternating stress diminishes as the number of cycles increases, much like EN19. This implies that while EN354 may not be as resilient as EN19 under extreme stress, it still has an endurance limit, which makes it appropriate for uses requiring fatigue resistance under moderate stress.
- EN36C: Compared to EN19 and EN354, EN36C exhibits a more pronounced decrease in alternating stress as cycles increase, reaching a steady point somewhat sooner. This implies that EN36C is better suited for applications with lower stress levels or where a lower fatigue life is acceptable because it has a lower endurance limit than the other materials.

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