

Effect of V Notch Shape on Fatigue Life in Steel Beam Made of AISI 1037

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Abstract

The present work encompasses effect of V notch shape with various geometries and dimensions on fatigue life behavior in steel beam made of Medium Carbon Steel AISI 1037 which has a wide application in industry. Fatigue life of notched specimens is calculated using the fatigue life obtained from the experiments for smooth specimens (reference) and by use Numerical method (FEA). The fatigue experiments were carried out at room temperature, applying a fully reversed cyclic load with the frequency of (50Hz) and mean stress equal to zero ($R = -1$), on a cantilever rotating-bending fatigue testing machine. The stress ratio was kept constant throughout the experiment. Different instruments have been used in this investigation like Chemical composition analyzer type (Spectromax), Tensile universal testing machine type (WDW-100E), Hardness tester type (HSV-1000), Fatigue testing machine model Gunt WP 140, Optical Light Microscope (OLM) and Scanning Electron Microscope (SEM) were employed to examine the fracture features. The results show that there is acceptable error between experimental and numerical works.

Keywords: AISI 1037, Notches, Fatigue Life, S-N curve, FEA

I. INTRODUCTION

It has been estimated that 90 % of all service failures of metal parts are caused by fatigue. Fatigue is the process of progressive localized permanent structural changes occurring in a material subjected to conditions that produce fluctuating stresses at some point or points and that may culminate in cracks or complete fracture after a sufficient number of fluctuations [1]. A fatigue failure is one that occurs under cyclic or alternating stress of an amplitude that would not cause failure if applied only once. Fatigue is by far the most common cause of mechanical failure in engineering components; the prevention of fatigue failure is a major preoccupation of designers in many industries, such as power generation and transport [2]. The term "notch" in a broad sense is used to refer to any discontinuity in shape or non-uniformity in material such as the V-shape threads on nut-bolt connections, the square-shape key washer's grooves on shafts, scratches, nonmetallic inclusions and corners, fillets and geometry discontinuities. The failure usually originates in the formation of a crack at a localized point on the notches. Presentation of notches in structural components causes stress intensification in the vicinity of the notch [3]. A. Fatemi, and Z. Zeng, [4] modeled fatigue behavior and life predictions of notched specimens made of QT and forged micro-alloyed steels, they have been used notched circumferentially notched round bar and double-notched flat plate geometries, each with different stress concentration factors. Reference [5], described notch effects in fatigue and fracture and

explained that the notch effect in fracture is characterized by the fact the critical gross stress of a notched structure is less than the critical net stress which acts on the remaining alignment area under notch tip, the notch effect in fracture is sensitive to structure geometry and the Wohler curve for the notched specimen is below the smooth specimen curve. The Notch Effect On The Fatigue strength of 51CrV4Mo spring steel", has been described in Reference [6]. The determination of Wohler's (S-N) curves using a resonant pulsator is relatively fast and simple.

Reference [7], studied the failure (fracture) of an agitator shaft with a circumferential notch was selected as investigation topic. However, this study is intended for introducing fracture mechanics from an application viewpoint. It essentially focuses on both stress and fatigue analyses

Nasim Daemi & Gholam Majzoobi [8], developed experimental and theoretical life on notched specimens under bending, fatigue life of notched specimens with various notch geometries and dimensions was investigated by experiment and Manson-Coffin analytical method.

An experimental investigation was achieved by [9], this study used cantilever rotating-bending fatigue testing machine to explain the effect of surface roughness on the fatigue life of low carbon steel. There are numerous evidences in the literature that the presence of notch can reduce the fatigue life of components dramatically in some circumstances. The fatigue life of V-shape notch specimens under

rotating bending by analytical method was examined [10], Reference [11] also shows failure cycles of notched round specimens under strain controlled cyclic loading by using strain life relations obtained from experiment for plain fatigue round specimens. The maximum strain is computed by appropriate Finite element analysis using the FE software ABAQUS. They obtained that the total strain life curve generated from fatigue test of round specimen can also be used for the prediction of life for notched specimens based on actual strain developed at notch tip , the results shows that in most of the cases the predicted life is found to be less compared to experimental values for all the types of notched specimens.

II. EXPERIMENTAL WORK

The first The experimental work included assessment of fatigue life specifications by using stress life approach for Medium Carbon Steel AISI 1037 supplied from the local market with and without notches and the effect of angle orientation , depth of notch on the fatigue limit .The experimental procedure consist of four parts. The first one deals with the selection of materials used and the specimens preparation, the second part deals with different mechanical tests, the third includes details of fatigue test and finally the details of Microscopic inspection. A Brief description for the different equipment used in this study had mentioned. Figure (1) states clearly specimens distribution have been used in this work.

A. MATERIAL SELECTION:

In this work, Medium carbon steel alloy AISI 1037 treated commercially , was used in this investigation, due to its relatively low price and better mechanical properties such as high strength and toughness this type of steel alloy has a wide application in industry and many engineering applications like railway wheels, gears, toll shanks ,crankshafts, and other machine parts.

The chemical composition test of the alloy was done by use the device Spectrometer type (ARC. MET 8000) as shown in figure (2). the results was within the specification limits and as shown in Table (1).

Table 1: Chemical composition of the AISI 1037 (wt%)

C%	Si%	Mn%	P%	S%	Fe%
0.369	0.303	0.738	0.009	0.023	Bal.

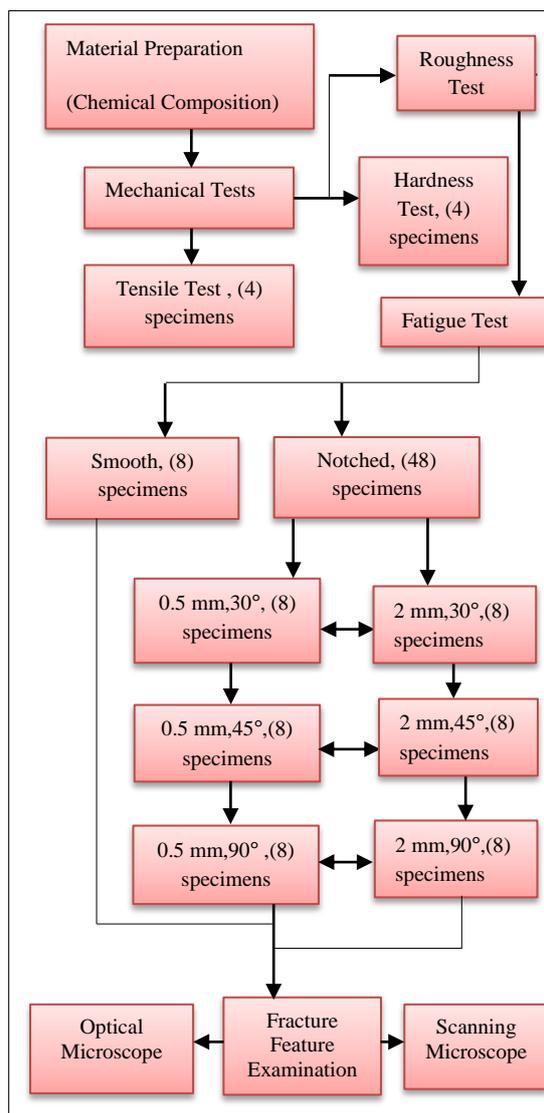


Fig. 1: Specimens distribution diagram

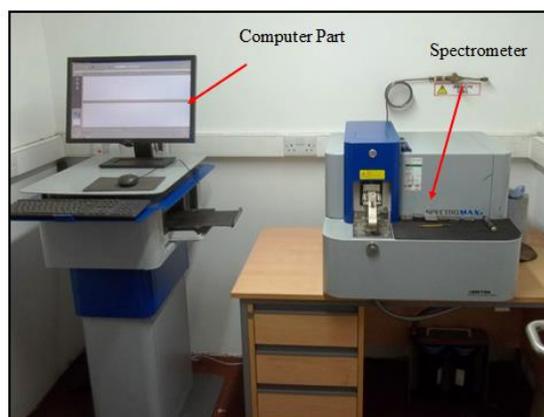


Fig.2: Spectrometer Instrument

B. MECHANICAL TESTS:

- TENSILE TEST

The tensile test is a standard test which was conducted using the microcomputer controlled electronic universal testing machine type (WDW-100E - 100KN) as shown in Fig. (4), The load was applied at a constant rate of (2 mm/min) during all tests until failure of specimen occurred. The specifications of the tensile test have been restricted according to the American Society for Testing and Materials specifications (ASTM) [12], at room temperature; the tensile specimen geometry and dimensions are shown in Fig. (3) and was prepared according to standards of ASTM A 370. Average value of four readings for the test have been taken to satisfy an additional accuracy; the results are given in table (2).

Table. 2 :Tensile Test Results

Property	Value
Tensile Strength σ_u (MPa)	575
Yield strength σ_y (MPa)	480
Elongation [%]	18
Modula's of Elasticity (Gpa)	206
Modula's of Elasticity Gpa)	200

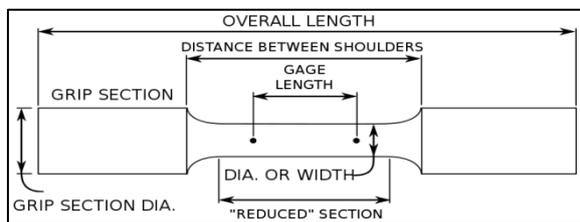


Fig. 3 :Tensile test specimen according to specification A 370

- HARDNESS TEST

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting .

There are two tests have been done in this investigation Brinell's and Vicker's hardness test. The average value of four readings was recorded and the results are shown in table 3.

Table 3: Hardness Test Results

Property	Value
Brinell Hardness (HB)	172
Vickers Hardness (HV)	180

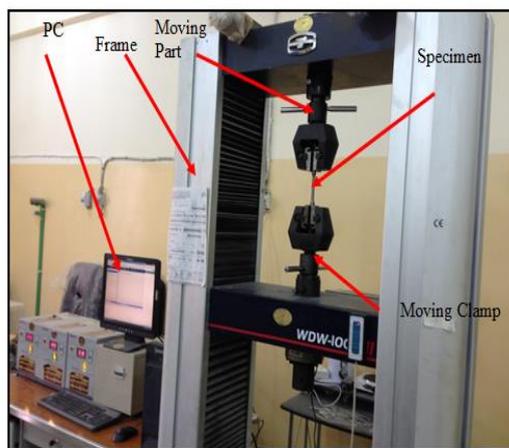


Fig. 4:Tensile testing machine

- ROUGHNESS INSPECTION

Surface roughness and surface integrity resulting from manufacturing processes are both important considerations in fatigue design. Fatigue damage on the surface of a component typically develops due to the surface integrity resulting from manufacturing, and the presence of stress concentrations originating from the surface topography. The specimens were first polished with different wet oxide aluminum papers by different degrees ,then followed by polishing with a string cloth soaked in alumina [11] . Once the manufacturing process of the specimens was done the surface roughness was measured by using a portable surface roughness tester type (SADT) as shown in figure (5) and in order to reduce human errors during the measurement, the reading was taken for three times at different points and for all notched and smooth specimen. Then, the average and total surface roughness, R_a and R_t are calculated and summarized in table 4.

Table 4: Values of surface roughness.

Ra [μm]	Rt [μm] max.
1.75	3.25
1.85	3.31



Fig. 5: Portable Surface Roughness Tester

C. FATIGUE TEST :

- FATIGUE TEST OF SPECIMENS

Fatigue specimens were machined in suitable dimensions to satisfy the requirement of the machine test that suited cylindrical specimens. Two types of fatigue specimens smooth and notched were prepared according to machine specifications. All the smooth and notched cylindrical fatigue specimens were machined from alloy steel with different content of carbon by using a programmable CNC machine adopting standard manufacturing procedure and circumferential V notch of angle of (30° , 45° and 90°) to a depth of notch was (0.5&2) mm respectively [12] with a notch radius as small as possible ($< 0.075\text{mm}$) [13] and was introduced at the portion of maximum bending. A Grinding process has been done for the cylindrical fatigue specimens by use emery papers from Silicon Carbide with different ASTM grades , (#600,800,1000,1200,2000),then polishing process done by use Alumina solution with cloth, and the residual stresses were minimized by the heating process to (350) centigrade for one hour inside furnace and then cooling by air. The minimum diameter of each specimen was measured at positions around the circumference on a toolmaker's microscope at (30) magnification. Specimens having a variation of more than (0.05 mm) in diameter were discarded. The fillet radii of the stress concentration specimens were checked at the same time that the diameter was measured. The geometry and a schematic view specimen are given in Fig. (7) .

- ROTATING BENDING MACHINE

The fatigue behavior of different materials can be determined from laboratory tests. The type of fatigue testing machine is revolving fatigue testing machine type WP 140, (a single cantilever rotating

bending model) with a constant amplitude (fully reversed bending). A rotating sample is clamped which on one side is loaded with a concentrated force with a maximum capacity of (0.3 KN) as shown in Fig.(8). A sinusoidal cyclic load with a stress ratio $R = -1$ (minimum load/maximum load) was applied throughout the experiment . As a result, an alternating bending stress is created in the cylindrical sample following a certain number of load cycles, the sample will rupture as a result of material fatigue. Tests were carried out at room temperature ($20 -24^\circ\text{C}$), and environmental humidity comprised between (54-58%). The machining process for all specimens was maintained as constant as possible in order to avoid significant variation in the surface polish. High temperature is expected at the narrow section when the specimen is tested under loading close to elastic limit. A cooling system with cool air was employed in the lab building to maintain the temperature in this zone below 100°C in order to restrict the highest testing temperature. Under this condition, it is assumed that there is no variation in the specimen microstructure .The experiment was conducted by repeating so many similar procedure tests for all specimens. Bending moment values were used to determine the alternating bending stress, which can be determined directly from equation (5) .For constant amplitude load histories can be represented by a constant load (stress) range, ($\Delta\sigma$); a mean stress, σ_m ; an alternating stress or stress amplitude, σ_a , and a stress ratio, R , as shown in figure (6). There are many parameters concerning to the relations in fully reversed loading [14].

Below some important relations used in the fatigue life analysis :

$$\text{Stress range : } \Delta\sigma = \sigma_{\max} - \sigma_{\min} \quad (1)$$

$$\text{Mean stress: } \sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2} \quad (2)$$

$$\text{Stress amplitude: } \sigma_a = \frac{\Delta\sigma}{2} = \frac{\sigma_{\max} - \sigma_{\min}}{2} \quad (3)$$

$$\text{Stress ratio: } R = \frac{\sigma_{\min}}{\sigma_{\max}} \quad (4)$$

The bending moment is calculated with the load and the lever arm as follows :

$$M_b = F \cdot a \quad (5)$$

$$W_b = \frac{\pi d^3}{32} \quad (6)$$

By using the section modulus of the sample it is possible to calculate the alternating stress amplitude.

$$\sigma_a = \frac{M_b}{W_b} = \frac{32 F \cdot a}{\pi d^3} \quad (7)$$

$$= 2 F \quad \text{MPa} \quad (8)$$

Where;

σ_a : Stress amplitude which is equal is the maximum alternating stress (MPa)
 F : Applied Force (N)
 a : bending arm = 106 ± 0.1 mm
 d : diameter of the specimen = 8 ± 0.1 mm
 M_b : bending moment (N.mm)
 W_b : Moment of inertia (for hallow cylinder)

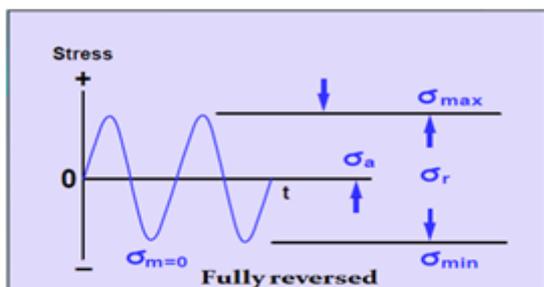


Fig. 6 : Fully Reversed Loading

A series of tests was commenced by acting a specimen to the stress cycling, and the number of cycles to failure was counted. This procedure was repeated on other specimens at progressively decreasing stress amplitudes. Data were plotted as stress σ_a versus the logarithm of the number N of cycles to failure for each of the specimens. It is important to know that each S-N curve obtained by this study has at least 8 specimens in both cases with and without notches. S-N curves are plotted by using software of Fatigue instrument present in PC which is connected directly to instrument as shown in Fig.(9).

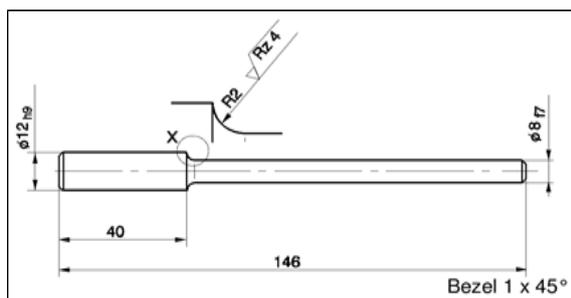


Fig. 7: Schematic dia. for fatigue test specimen (mm)

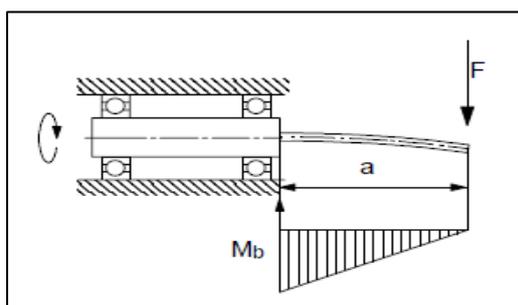


Fig. 8 : Loading of the sample

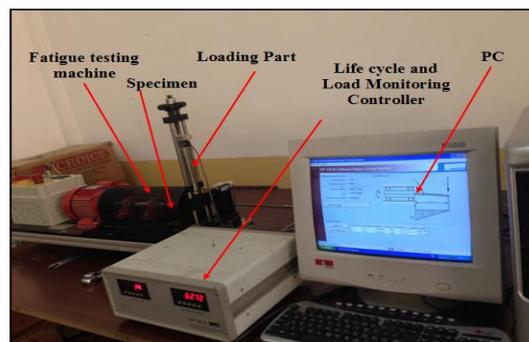


Fig. 9 : Fatigue testing machine WP 140

D. EXAMINATION FRACTURE FATIGUE:

The process of achieve test fracture for the different fatigue specimens has been done to check the nature of fracture. Fracture surfaces of failed specimens have been analyzed using Optical Microscope (OM) and Scanning Electron Microscope Zeiss type (EVO 50). Samples for microstructure examination were ground using different grades of wet silicon carbide papers (260, 500, 800, 1200 and 2000), then the samples were polished using two type of alumina (0.5 micron and 0.3 micron). Distilled water and alcohol were used to clean the samples in succession. Etching was carried out with naital (2 % HNO3) in alcohol followed by washing them with water and alcohol. Figure (10) illustrates the photo digital system.

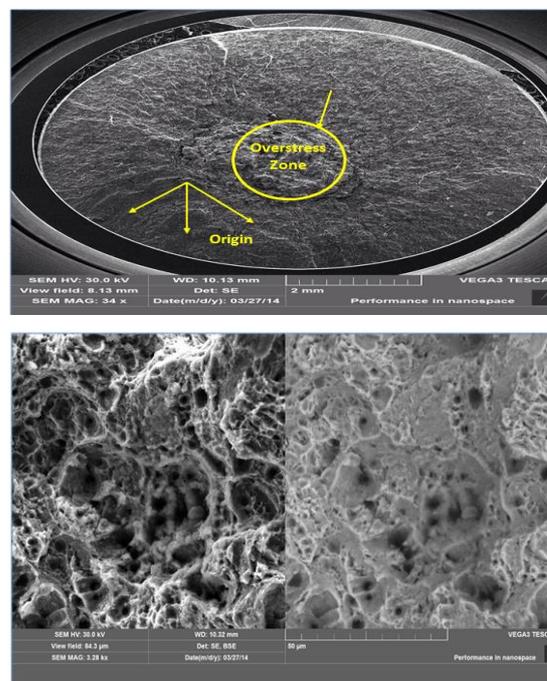


Fig. 10 : Fracture surface of a specimen AISI-1037 steel) tested on rotational bending machine by use Optical Microscope.

III. NUMERICAL INVESTIGATION:

To study the stress analysis at the fracture surface, finite element method (FEM) was employed. ANSYS program version 14 was used to check the calculated fatigue results. A fatigue analysis can be separated into 3 areas: materials, analysis, and results. A stress-life approach has been adopted for conducting a fatigue analysis where smooth and notched fatigue specimens with different notch angles and depths are modeled, the element meshes were generated, boundary condition corresponding to maximum loading condition was given and stress analysis through ANSYS also show that maximum value of stress occurs at the vicinity of change in cross section of the specimens where a V notch with different geometry is present. Fig. (11) shows model with mesh ,deformation and maximum stresses generated in the model.

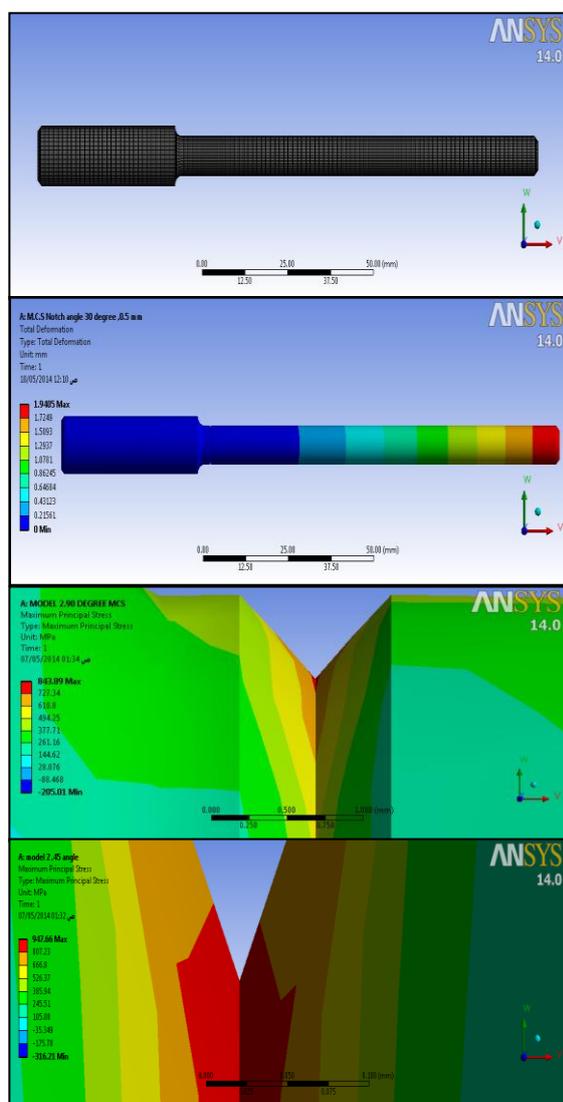
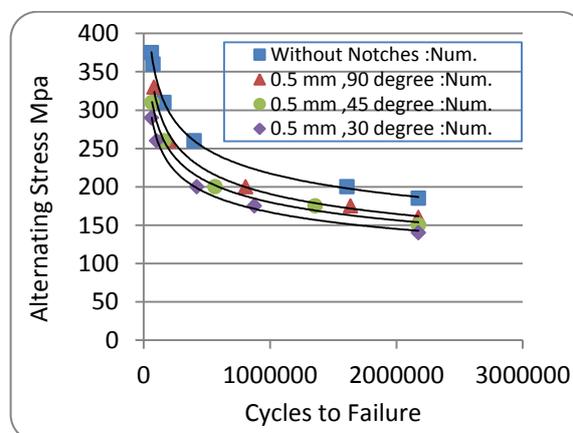
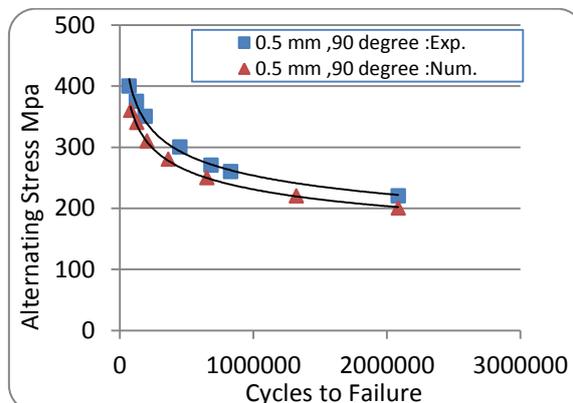
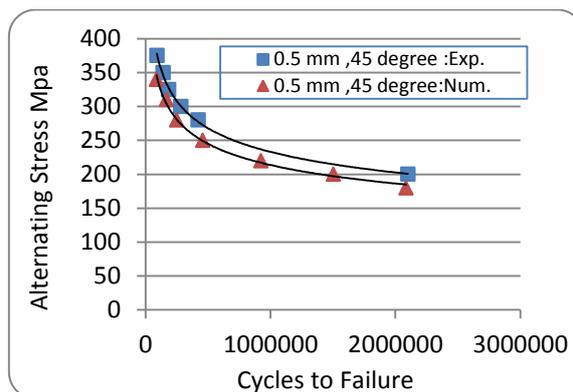
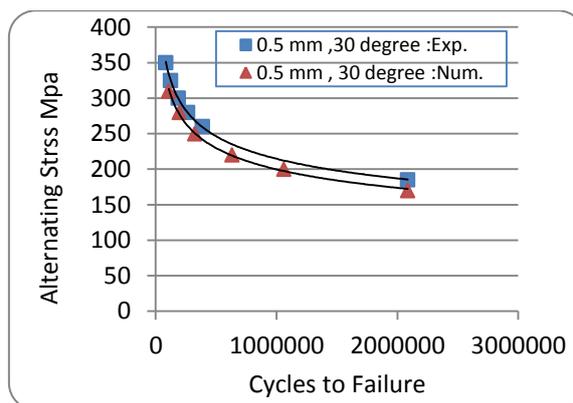


Fig. 11: FE model with mesh, deformation and principle stresses for notched bar



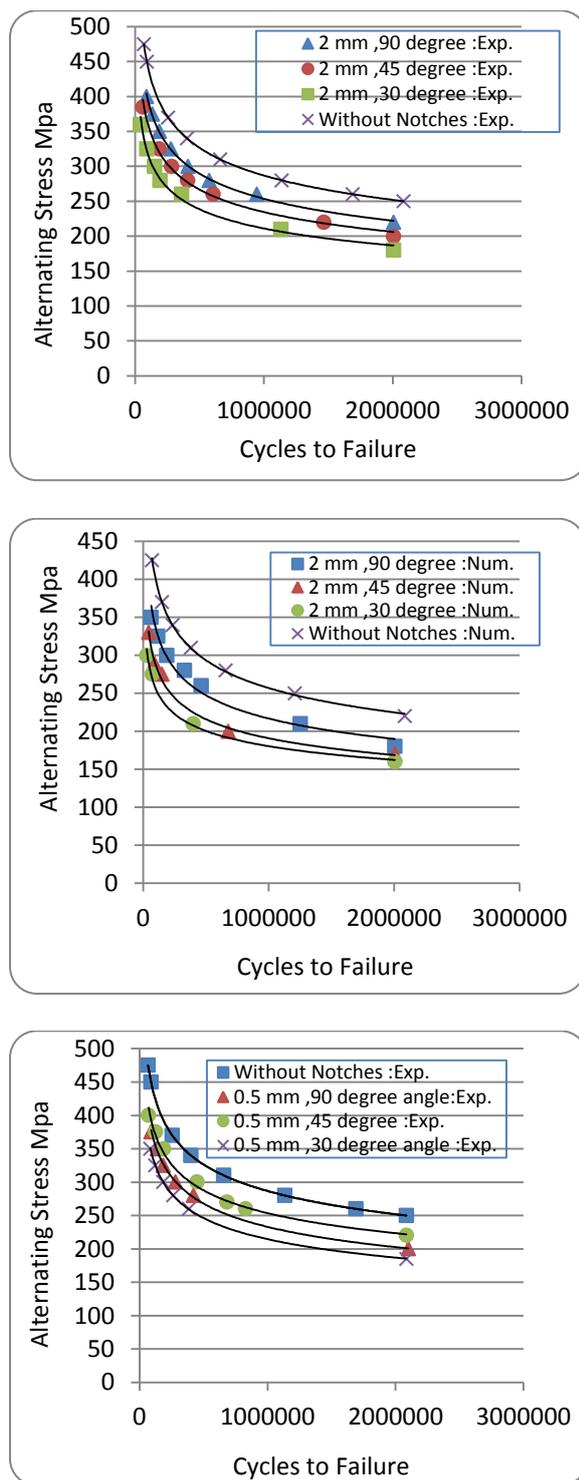


Fig. 12 : Numerical and Experimental S-N curves for V notched Specimens with different angle orientation

IV. RESULTS

In this work it is trailed to predict the fatigue life of notched fatigue specimens under effect of cyclic loading using stress life data of smooth fatigue specimen

(reference) on the basis of maximum stress developed obtained from finite element simulated results of notched specimen under stress controlled cyclic loading. The cylindrical specimen under consideration is being subjected to bending stress due to vertical component force, so as the shaft rotates there is a fluctuation of stress, the point which is subjected to maximum stress value is found and shown in Fig. (8). The various bending (σ_{nom}) and at the failure surface is found by use analytical method. According to the accurate stress concentration factors corresponding bending stress can be found using least square method. The radii of fillet at smooth specimen was found (2) mm ,while for notched specimens ,three angle orientation (30,45 &90 degree) with two notch depths (0.5&2) mm were employed .Values of Stress concentration factor (K_t) was obtained using finite element method and the results are given in table 5,for more details of the procedure for stress concentration determination , see [15]. For dynamic loading, we need to calculate fatigue concentration factor K_f based on the notch sensitivity of the material as in below :

$$K_f = 1 + (K_t - 1) q \quad (9)$$

where q is the notch sensitivity it can be defined from the Kunn-Hardarth formula in terms of Neuber's constant (a) and the notch radius (r).

$$q = \frac{1}{1 + \frac{a}{r}} \quad (10)$$

Table 5: Values of Stress Concentration ,fatigue and notch sensitivity factors

α°	h (mm)	r (mm)	K_t	q	K_f
30	0.5	0.07	4.28	0.268	1.88
45	0.5	0.07	4.15	0.269	1.85
90	0.5	0.07	3.47	0.267	1.66
30	2	0.07	3.95	0.267	1.79
45	2	0.07	3.83	0.268	1.76
90	2	0.07	3.23	0.269	1.6

V. CONCLUSION

In this work, bending fatigue life of notched specimens with V notch geometry of various angle orientation and notch depths was investigated by experiments and by FEA method , hence the mathematical form of fatigue life equation of the specimens, were obtained. The stress concentration factor for the geometry used in this work was calculated also analytically and numerically by use FEM. The results indicate that the FEA method is applicable to the experiments .The final conclusion can be made from the results obtained that the S-N curve generated from fatigue test of round specimen can also be used for the prediction of life for notched specimens based on actual stress developed at notch tip. From the results it is also

observed that in most cases the predicted life is found to be less compared to experimental values for all the types of notched specimens. This may be due to the fact that the life has been predicted based on maximum stress in notched section [9]. It is observed that the life prediction by FEA simulation is acceptable for different stress amplitudes and also at different no. of cycles. The accuracy of the predicted life by FEA simulation depends on the selection of appropriate material model and the accuracy of the value of the material parameters used. It is very important to know that the prediction in this method depends on the correctness of the material total S-N curve (simple regression) generated from experimental results of high cycle fatigue data of cylindrical specimens and the accuracy of simulated value of maximum stress of notched specimens. The maximum error between two methods found 9%. The common stress life curve generated from specimens of several notch angles gives a better prediction, which is apparent from the figure (12). Also the results show that maximum principle stresses is greater in small angle orientation while the fatigue limit will be more with increasing of angle orientation.

The maximum value of stress occurs at the vicinity of change in cross section of the specimen where a relief groove is present.

Failure originated as the applied load exceeds the fracture strength of the material.

Fatigue limit value has strong relation with mechanical properties of metals, on the other hand it is concluded that for fatigue life equation represented by Basquin's form :

$$\sigma_a = aN_f^b$$

The coefficients a represent Stress-Life curve intercept and coefficient b is the fatigue strength exponent (Stress-Life curve slope). These coefficients after evaluated by linearizing the power law in logarithmic, it is found that the increasing of tensile stress value affects the change value of those coefficients based on certain factor. The value of this factor needs more experiments to be conducted. This remains to be done in our next investigations.

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