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FEA Investigation of Double Circumferential U-Notch Bar under Axial Loading

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Abstract- **When a notch component is loaded, local stress and strain concentrations are generated in the notch area. The stresses often exceed the yield limit of the material in the small region around the notch root, even at relatively low nominal elastic stresses. When a notch component is subjected to cyclic loading, cyclic inelastic strains in the area of stress and strain concentrations may cause formation of cracks and their subsequent growth could lead to component fracture. Stress-strain concentration result at axial loading case for U Shape notch shaft is found by analytically and FEA investigation. In this studies have been presented in graphical representation of analytical results and FEA results on the U shape double circumferential notch bar.**

Index terms- Axial load, FEA, Stress-Strain concentration notch.

I. Introduction

Most of the engineering components contain geometrical discontinuities, such as shoulders, keyways, and grooves, generally termed notches. When a notch component is loaded, local stress and strain concentrations are generated in the notch area. When a notch component is subjected to cyclic loading, cyclic inelastic strains in the area of stress and strain concentrations may cause formation of cracks and their subsequent growth could lead to component fracture. In this studied results have been published on stress-strain concentration for U Shape Notch shaft at axial loading and this result is studied by analytical investigation and FEA investigation.

II. Problem Definition

The problem under consideration is to investigate the interference effect of U notch at fix parameters such as, Notch width, Notch inclination, Notch depth, Notch centre distance and Notch root shape (U-shaped)of double circumferential notch shaft on stress-strain concentration for various (Multi) axial loading conditions.

The detail work is carried out with the help of Numerical method and the results are validated analytically (in some cases through redefining the existing mathematical models for our problem).

Terminology used in Figure 1.1 as,

d_o= initial net-section diameter,

D_o = initial gross diameter

ρ_o= initial notch radius

$2L_o$ = the un-notch length from the notch centre to the loaded end,

$2l_o$ = the notch pitch or the distance between the centers of the two notches.

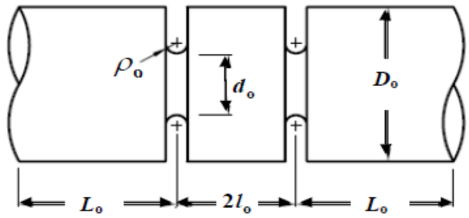

Figure 1: Cylindrical bar with double-slant circumferential U notches

III. Analytical Investigation

A. Sample calculation

Consider the shaft having symmetrical circumferential notch with un-notch diameter as 50mm, notch depth 6mm, notch root radius 1.5mm, hence notch diameter of shaft is 38mm which is subjected to various axial load of 2.5KN, 5KN, 7.5KN, 10KN, 12.5KN and 15KN.

Stress concentration factor of U-shaped circumferential groove in circular shaft under axial loading is calculated by,

$$K_t = C_1 + C_2\left(\frac{2h}{D}\right)^1 + C_3\left(\frac{2h}{D}\right)^2 + C_4\left(\frac{2h}{D}\right)^3$$

Where,

	$0.1 \le h/r < 2.0$	$2.0 \le h/r \le 50.0$
C_1	$0.89 + 2.208\sqrt{h/r} - 0.094h/r$	$1.037 + 1.967\sqrt{h/r} + 0.002h/r$
C_2	$-0.923 - 6.678\sqrt{h/r} + 1.638h/r$	$-2.679 - 2.980\sqrt{h/r} - 0.053h/r$
C_3	$2.893 + 6.448\sqrt{h/r} - 2.516h/r$	$3.090 + 2.124\sqrt{h/r} + 0.165h/r$
C_4	$-1.912 - 1.944\sqrt{h/r} + 0.963h/r$	$-0.424 - 1.153\sqrt{h/r} - 0.106h/r$

$$\frac{h}{r} = \frac{6}{1.5} = 4$$

Hence, should select the range $2.0 \le h/r \le 50.0$

$$C_1 = 1.037 + 1.967\sqrt{h/r} + 0.002h/r$$
$$= 1.037 + 1.967\sqrt{4} + 0.002 \times 4$$
$$= 4.974$$
$$C_2 = -2.679 - 2.980\sqrt{h/r} - 0.053h/r$$
$$= -2.679 - 2.980\sqrt{4} - 0.053 \times 4$$
$$= -10.71$$
$$C_3 = 3.090 + 2.124\sqrt{h/r} + 0.165h/r$$
$$= 3.090 + 2.124\sqrt{4} + 0.165 \times 4$$
$$= 8.808$$
$$C_4 = -0.424 - 1.153\sqrt{h/r} - 0.106h/r$$
$$= -0.424 - 1.153\sqrt{4} - 0.106 \times 4$$
$$= -3.154$$

And,

$$\frac{2h}{D} = \frac{2 \times 6}{50} = 0.24$$
$$K_t = C_1 + C_2\left(\frac{2h}{D}\right)^1 + C_3\left(\frac{2h}{D}\right)^2 + C_4\left(\frac{2h}{D}\right)^3$$
$$K_t = 4.974 - 10.71\,(0.24)^1 + 8.808\,(0.24)^2 - 3.154\,(0.24)^3$$
$$K_t = 2.8697$$

Calculate Nominal and Maximum stress in Notch shaft for axial load 2.5KN

Nominal stress can be calculated as,

$$\sigma_{nom} = \frac{4P}{\pi d^2} = \frac{4 \times 2.5 \times 10^3}{\pi (38)^2} = 2.2043 N/(mm)^2$$

Maximum stress is calculated by,

$$\sigma_{max} = K_t \sigma_{nom}$$
$$\sigma_{max} = 2.8697 \times 2.2043$$
$$\sigma_{max} = 6.3256\ N/(mm)^2$$

IV. FEA INVESTIGATION

A typical ANSYS analysis has three distinct steps:

1. Build the model.
2. Apply loads and obtain the solution.
3. Review the results.

These steps are performed using pre-processing, solution and post-processing processors of the ANSYS program. Actually, the first step in an analysis is to determine which outputs are required as the result of the analysis, since the number of the necessary inputs, analysis type and result viewing methods vary according to the required outputs.

After determining the objectives of the analysis, the model is created in pre-processor. The next step, which is to apply loads, can be both performed in pre-processor or the solution processor. However, if multiple loading conditions are necessary for the required outputs and if it is also necessary to review the results of these different loading conditions together, solution processor must be selected for applying loads. The last step is to review the results of the analysis using post-processor, with numerical queries, graphs or contour plots according to the required outputs.

A. Specimen Geometries

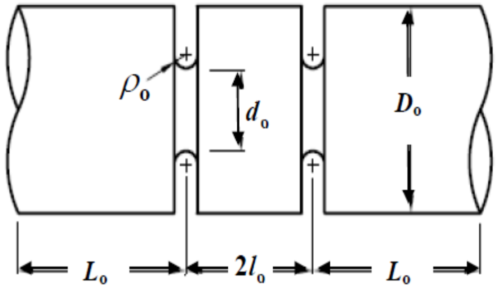

Figure 2: Specimen Geometry

The employed cylindrical bar with double circumferential U-notches is shown in Figure 1.2 The net-section diameter is denoted by d_o (in mm), the gross diameter is denoted by D_o (in mm), D_o=50mm, $2L_o$= the un-notch length from the notch center to the loaded end, $2l_o$= the notch pitch or the distance between the centers of the two notches. The specimen length is expressed as, Specimen length=$2L_o+2l_o$.The un-notch length is held constant, while the half notch pitch l_o is varied from 0.0 to 25 mm to examine the interference effect of the double circumferential U-notches. It should be noted that the notch angle $\gamma = 0^0$ represents the cylindrical bar with a circumferential U-notch, perpendicular to the axial direction.

B. FE modeling

The effect of notch parameters such as various loads on U shaped notches for axial loading is performed and investigation of stress distribution at notch surface is obtained by FEA (ANSYS 12).

The output of FEA are used deriving the characteristic curves & comparative statistics of various notch loads as an attempt to set the standard load and notch selection for specific application in future.

The effect on U shape notch at various loads such as 2500N, 5000N, 7500N, 10000N, 12500N and 15000N are observed for stress and strain distribution and check for stress concentration over the notch surface. The FE analysis of bar for various loading condition are shown in figure 3 to 9.

C. Sample Results

a) Effect on U shaped notch at 2500N axial load.

For notch depth 6mm, notch diameter 38mm and un-notch diameter 50mm, angle of notch inclination 0^o, notch root radius 1.5mm and axial load 2500N, FEA steps and output are discuss as per following figures.

In order to take the advantage of geometrical symmetry, modeling geometry is done as shown in Figure 1.3. And Figure 1.4 gives the loading condition on geometry. The material of the specimen is considered as Structural Steel having S_{yt}=S_{yc}=2.5E+08Pa, S_{ut} =4.6 E+08Pa, Density=7850kg/m^3.

FEA Results give complete idea of the interference effect of stress concentration and strain concentration. In Figure 1.5 FEA gives Equivalent Stress. From Figure No. 1.5, we can understand the concept of the stress concentration at the notch root. Also stress interference is occurred at the notch length of double circumferential inclined notch. In Figure 1.6 FEA gives Equivalent Strain which elaborates the concept of strain concentration at notch root and strain interference at notch length.

Stress intensity is maximum at notch root and interference of stress intensity is occurred at the notch length. Figure 1.7 and Figure 1.8 shows the Maximum Principal Stress (MPa) and Maximum Principal Strain and both indicate the interference of same clearly and Figure 1.9 gives the total maximum deformation (in mm).

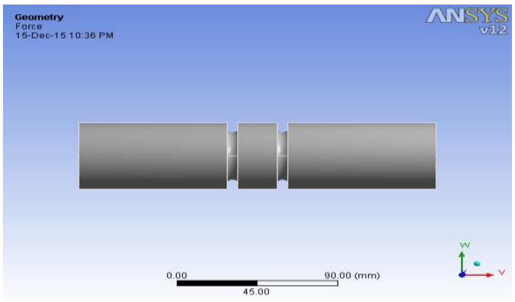

Figure 3: Model of double notch bar

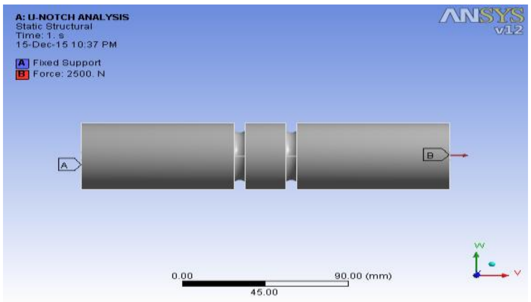

Figure 4: Load applied

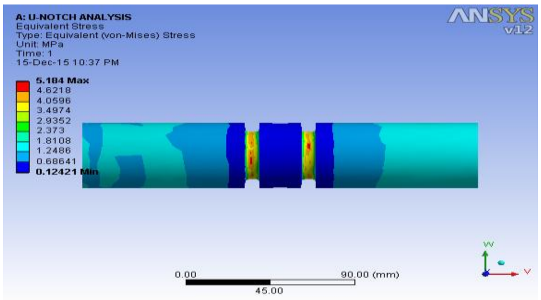

Figure 5: Equivalent Stress

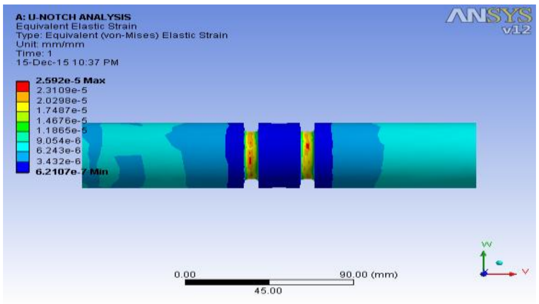

Figure 6: Equivalent Strain

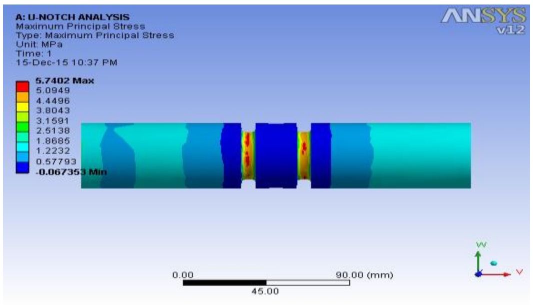

Figure 7: Maximum Principal Stress

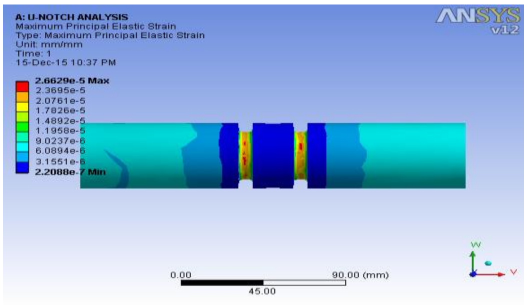

Figure 8: Maximum Principal Strain

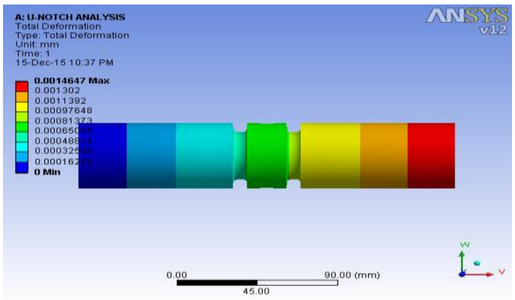

Figure 9: Total Deformations

From above FEA investigation gives the Force (N) vs Equivalent Stress (Mpa), Max Principal Stress (Mpa), Equivalent Strain, Max Principal Strain and Total Deformation (mm) results for U-Shaped Notch bar at various loads applied condition. This results indicates in Table 1 is as follows,

TABLE I
FEA RESULT FOR U- NOTCH

Force (N)	Equivalent Stress (Mpa)	Max Principal Stress (Mpa)	Equivalent Strain	Max Principal Strain	Total Deformation (MM)
2500	5.184	5.7402	0.00002592	0.00002663	0.0014647
5000	10.368	11.48	0.00005184	0.00005328	0.0029294
7500	15.552	17.221	0.000077759	0.00007988	0.0043941
10000	20.736	22.961	0.00010368	0.00010652	0.0058589
12500	25.92	28.701	0.0001296	0.00013315	0.0073236
15000	31.104	34.441	0.00015552	0.00015978	0.0087883

From above Table 1.1 shows the FEA results and find out stress results on U Shaped notch bar at different loads. So, Figure 1.10 gives the graph of Force (N) vs Equivalent Stress and Maximum Principal Stress (Mpa) respectively for U Shaped notch bar. The graph indicates the output of FEA which gives Equivalent Stress and Maximum Principal Stress (Mpa) increases with the increasing loads from 2500N to 15000N. Similarly, From Figure 1.11 gives the graph of Force (N) vs Equivalent Strain and Maximum Principal Strain respectively for U Shaped notch bar. The graph indicates the output of FEA which gives Equivalent Strain and Maximum Principal Strain increases with the increasing loads from 2500N to 15000N.

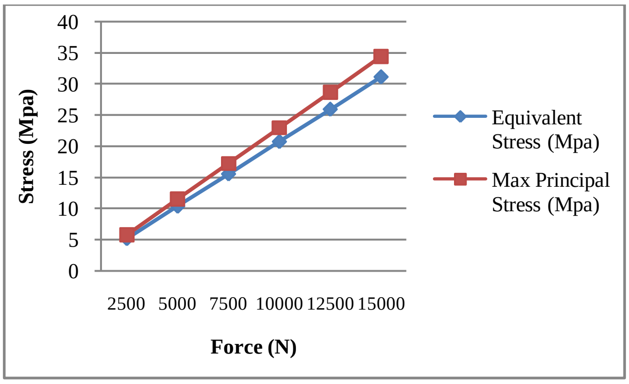

Figure 10: Force (N) vs Equivalent Stress and Maximum Principal Stress (Mpa)

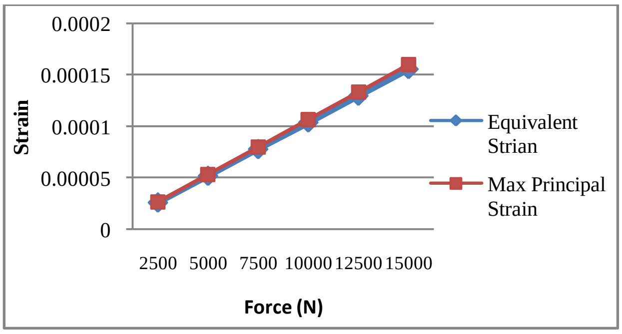

Figure 11: Force (N) vs Equivalent Strain and Maximum Principal Strain

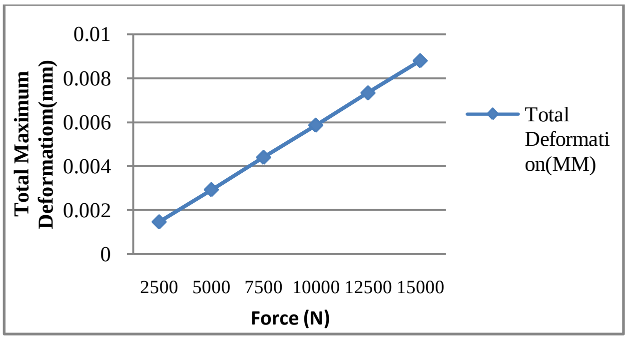

Figure 12: Total Maximum deformation (MM) vs Force (N)

Figure 1.12 Shows the graph of total maximum deformation (in mm) vs Force (N) for U Shaped notch bar. The graph indicates that total deformation increases with increasing load applied from 2500N to 15000N.

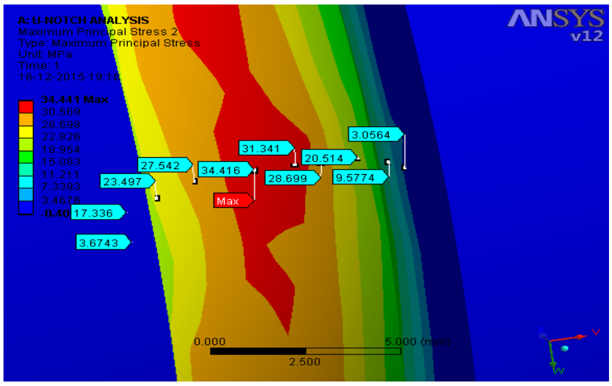

Figure 13: Maximum Principal Stress Probe (Mpa)

From, Figure 1.13 shows the Maximum Principal Stress Probe (Mpa) vs Probe point at U Notch and Figure 1.14 shows the graph between Maximum Principal Stress Probe (Mpa) vs Probe point at U Notch. So, in this graph clearly identify the maximum principal stress or stress concentration point is high at U shaped notch root.

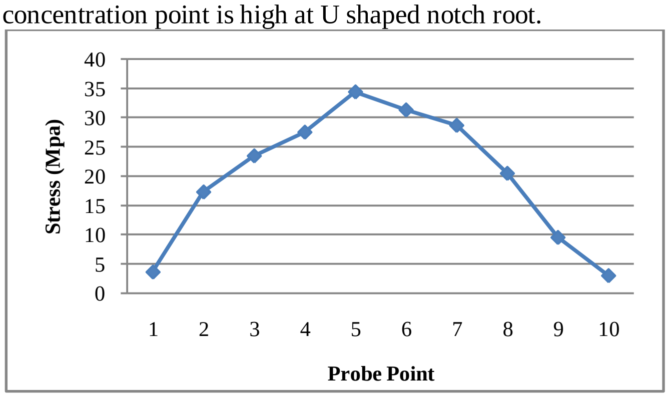

Figure 1.14 shows the Maximum Principal Stress Probe (Mpa) vs Probe point at U Notch

V. CONCLUSION AND FUTURE ENHANCEMENT

From above the investigation we studied that the stress and strain concentration is observed in U shape double circumferential notch at various axial loads. In this investigation maximum stress concentration value is observed at notch root section. Hence, we studied stress strain concentration and total deformation in U shape notch shaft at various axial loads.

In future experimental investigation of the same to validate the FEA results should be done.

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