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Finite Element Analysis of Investigation of Bars with Semi-Circular Notches

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ABSTRACT

In this thesis the effect of semicircular notches under bending in a bar and the stresses are investigated for different materials using finite element analysis. The notch radius taken are 2mm and 3mm. The notches are taken at end of bar and at 3mm from end of the bar. The different materials considered for the analysis are Aluminum alloy 7075, composite materials S2- Glass Epoxy, Kevlar 29. The model is created by using CREO 2.0 and structural, fatigue and modal analysis results are obtained by using ANSYS.

INTRODUCTION

Notches:

Notches cannot be avoided in many structures and machines. so, notch effects are a key problem in the study of fatigue.

Examples:

1.) Thread roots and the transition between the head and the shank.
2.) Rivet holes in sheets.
3.) Welds on plates, Keyways on shafts

Although notches can be very dangerous they can often be rendered harmless by suitable treatment.

To understand the effects of notches one must consider five parameters:

1. Concentrations of stress and of strain.
2. Stress gradients.
3. Mean stress effects and residual stresses.
4. Local yielding.
5. Development and growth of cracks.

The degree of stress and strain concentration is a factor in the fatigue strength of notched parts.

It is measured by the **elastic stress concentration factor**, K_t

$$K_t = \sigma_{max}/\sigma_{nom}$$

Where, σ_{max} = maximum stress

σ_{nom} = nominal stress

Elastic stress concentration factors are obtained from:

1.) Theory of elasticity.
2.) Numerical solutions.
3.) Experimental measurements.

The most common and flexible numerical method is the finite element method. A Mode l with relatively fine mesh in the areas of steep stress gradients is required.

Problem definition

The problem under consideration is to investigate the stress, strain, Total deformation and effective stress concentration factor of U – shaped circumferential notch shaft under axial loading conditions.

Notch is taken from one end of the bar. The different materials considered for analysis are Aluminum alloy 7075, composite materials S 2– Glass epoxy, Kevlar 29.

The parameters taken are

Radius of the Notch	– 2 and 3mm
Distance of the Notch from one end of the bar	– 3mm
Length of the bar	– 24mm
Diameter of the bar	– 18mm

LITERATURE SURVEY

In the paper by Hitham M. Tlilan, etal [1], the interference effect on the new strain concentration factor (SNCF), which has been defined under triaxial stress state; is studied using the Finite Element Method (FEM). To this end, cylindrical bars with double circumferentially U-notches under static tension are employed. The new SNCF is constant in the elastic deformation and the range of this constant value increases with increasing notch pitch (lo) in the range 0.0 <lo≤ 0.5 mm, then it decreases with increasing lo, and reaches a value nearly equal to that of the single circumferential U-notch. This becomes prominent with decreasing notch radius. As plastic deformation develops from the notch root; the new SNCF increases from its elastic value to a maximum value. On further plastic deformation, the new SNCF decreases with plastic deformation. The current results indicate that the notch pitch, where the interference effect is more pronounced on the new SNCF, is $0.0 \leq l_o \leq 5$ mm.

In the paper by Hitham M. Tlilan, etal [2], The interference effect on the new strain-concentration factor (SNCF), defined under the triaxial stress state, is studied for circumferentially notched cylindrical bars with double-slant notches under static tension. The material employed is Austenitic stainless steel. The results indicate that the new SNCF ($K\varepsilon$ new) for a certain *l*o is constant during elastic deformation and increases with decreasing pitch *l*o. It also increases with increasing notch radius. The elastic $K\varepsilon$ new for *l*o = 0.5 mm is the minimum.

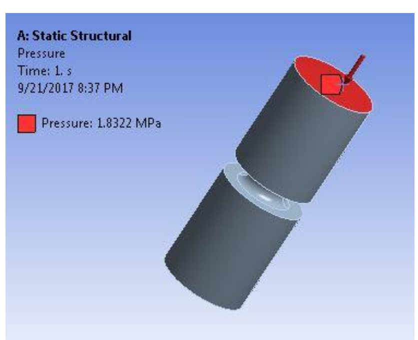
This becomes prominent with decreasing notch radius. The new SNCF increases from its elastic value to a peak value as the plastic deformation develops from notch root. On further plastic deformation, the new SNCF increases to the maximum value for $lo = 0.0$ and $lo \geq 2.5$ and then decreases with plastic deformation. This peak value is the maximum $K\varepsilon$ new for $0.0 < lo \leq 2.0$.

In the paper by C. S. YEN [3], It is the purpose of this bulletin to summarize and to appraise critically the numerous interpretations or correlating methods that have been proposed in the technical literature to compare the endurance limits of notched rotating beam fatigue specimens with those of unnotched specimens. The interrelation of the ideas proposed by several investigators was studied. The discrepancy between theoretical and effective stress concentration factors is attributed to the fact that the structural action in real materials is different from that of homogeneous, isotropic, elastic, "idealized material" commonly assumed in the theoretical analysis of stresses.

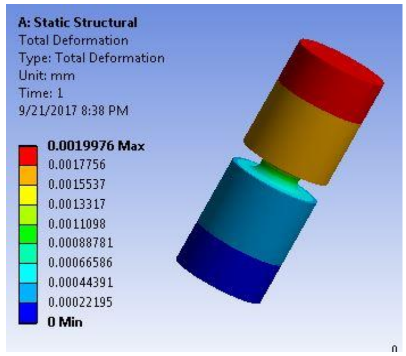
In the paper by M. Bijak-Zochowski, etal [4], The photo elastic method is used to investigate the possibility of relieving the large local stresses that develop in the corners of a right-angled indenter compressing a semi-infinite body by inducing geometric changes to the indenter/ semi-infinite body configuration. It is shown that a circular notch cut along the free edges of the indenter can eliminate the large corner stresses. The notch, if placed along the interface edge of the half plane, can reduce the stress concentration, but never eliminate it. The results obtained have wide practical application.

The Modelling and analysis in this thesis is based on the journal paper “Strain-Concentration Factor of Cylindrical Bars with Double Circumferential U-Notches under Static Tension BY Hitham M. Tlilan, Ali M. Jawarneh, Ahmad S. Al-Shyyab, Jordan Journal of Mechanical and Industrial Engineering, Volume 3, Number 2, June. 2009 ISSN 1995-6665 Pages 97 – 104”, specified as [1] in References chapter.

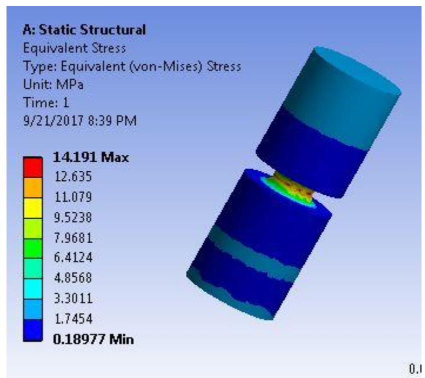
ANALYSIS OF ALUMINUM ALLOY 7075, 2 MM RADIUS AT 3MM DISTANCE



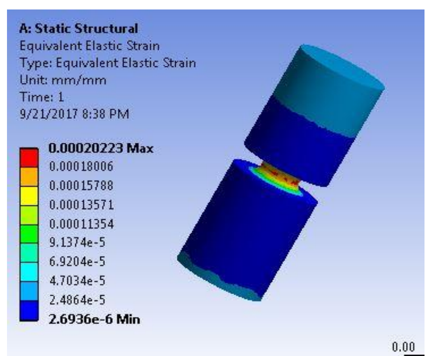
Pressure is applied on other end of R 2mm notch at 3mm distance.



Deformation of R2mm notch at 3mm distance for Aluminum alloy 7075



Stress of R 2mm notch at 3mm distance for Aluminum alloy 7075

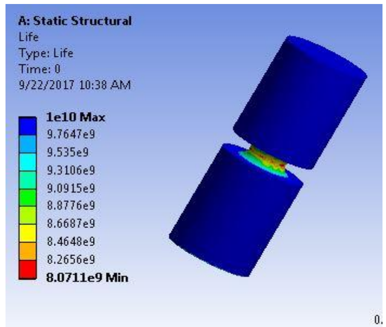


Strain of R 2mm notch at 3mm distance for Aluminum alloy 7075.

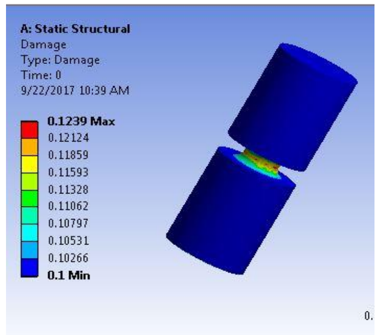
Fatigue Analysis

	B	C
1	Cycles	Alternating Stress (MPa)
2	10	255
3	100	200
4	200	150
5	300	100
6	400	50
7	500	20
*		

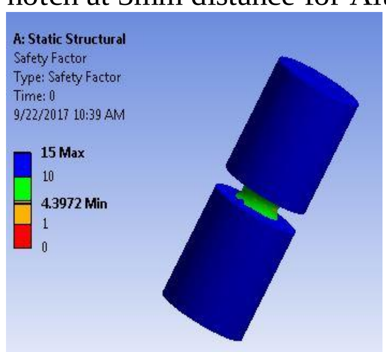
SN values



Life of R 2mm notch at 3mm distance for Aluminum alloy 7075.

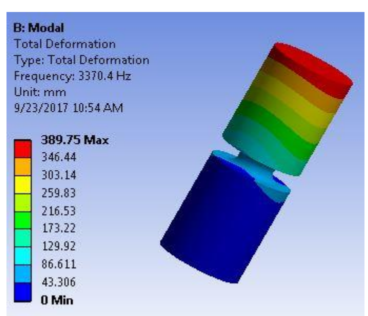


Damage of R 2mm notch at 3mm distance for Aluminum alloy 7075



Safety factor of R 2mm notch at 3mm distance for Aluminum alloy 7075

Modal Analysis



Total Deformation of R2mm notch at 3mm distance at Mode 3 for Aluminum alloy 7075

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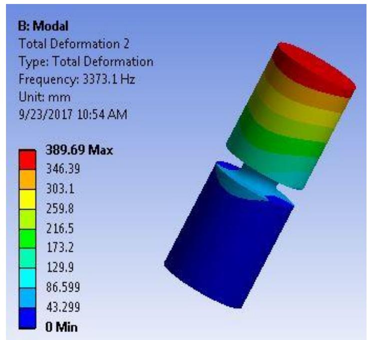
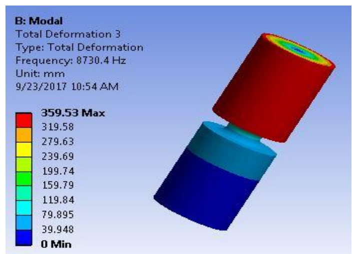


Total Deformation of R2mm notch at 3mm distance at Mode 3 for Aluminum alloy 7075



Total Deformation of R2mm notch at 3mm distance at Mode 3 for Aluminum alloy 7075

RESULTS TABLE

Analytical Results

Static structural analysis for Aluminum Alloy 7075

	2mm at end	2mm at 3mm distance	3mm at end	3mm at 3mm distance
Deformation(mm)	0.0013176	0.0019976	0.0012602	0.002778
Stress (MPa)	5.9145	14.191	3.4835	21.158
Strain	8.2528e-5	0.00020223	4.8585e-5	0.00029513

Static structural analysis for Kevlar 29

	2mm at end	2mm at 3mm distance	3mm at end	3mm at 3mm distance
Deformation(mm)	0.0011344	0.0017103	0.0010862	0.0023773
Stress (MPa)	5.8727	14.13	3.6603	21.047
Strain	7.079e-5	0.00017347	4.4101 e-5	0.0002537

Static structural analysis for S2- Glass Epoxy

	2mm at end	2mm at 3mm distance	3mm at end	3mm at 3mm distance
Deformation(mm)	0.0010981	0.0016959	0.0010463	0.002364

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Stress (MPa)	6.0918	14.527	3.5699	21.629
Strain	7.0133 e-5	0.00017148	4.1084e-5	0.00024892

Fatigue analysis for Aluminum Alloy 7075

	2mm at end	**2mm at 3mm distance**	**3mm at end**	**3mm at 3mm distance**
Life	$1e^{10}$	$1e^{10}$	$1e^{10}$	$1e^{10}$
Damage	0.1239	0.12231	0.11272	1.238
Safety Factor	15	15	15	15

Fatigue analysis for Kevlar 29

	2mm at end	**2mm at 3mm distance**	**3mm at end**	**3mm at 3mm distance**
Life	$1e^{10}$	$1e^{10}$	$1e^{10}$	9.9241e9
Damage	0.13838	0.1462	1.3497	0.12526
Safety Factor	15	15	15	15

Fatigue analysis for S2- Glass Epoxy

	2mm at end	**2mm at 3mm distance**	**3mm at end**	**3mm at 3mm distance**
Life	$1e^{10}$	$1e^{10}$	$1e^{10}$	$1e^{10}$
Damage	0.10111	0.116	0.69022	0.10933
Safety Factor	15	15	15	15

Total Deformation of R2mm from end

		Aluminum 7075	**KEVLAR 29**	**S2- GLASS EPOXY**
Mode 1	**Frequency (Hz)**	5033.2	7586.6	5880.4
	Deformation (mm)	348.84	487.19	373.35
Mode 2	**Frequency (Hz)**	5034.6	7589.4	5880.6
	Deformation (mm)	348.87	487.23	373.37
Mode 3	**Frequency (Hz)**	15323	22775	18825
	Deformation (mm)	356.07	497.4	380.55

Total Deformation of R2mm at 3mm distance

		Aluminum 7075	KEVLAR 29	S2- GLASS EPOXY
Mode 1	Frequency (Hz)	3370.4	5081.9	3949.3
	Deformation (mm)	389.75	544.2	416.92
Mode 2	Frequency (Hz)	3373.1	5082.9	3958.5
	Deformation (mm)	389.6	544.19	416.71
Mode 3	Frequency (Hz)	8730.4	12944	10876
	Deformation (mm)	359.53	502.18	384.51

Total Deformation of R3mm at 3mm distance

		ALUMINUM 7075	KEVLAR 29	S2- GLASS EPOXY
Mode 1	Frequency (Hz)	2198.1	3328.4	2531.5
	Deformation (mm)	398.43	556.41	426.38
Mode 2	Frequency (Hz)	2198.7	3329.1	2534.4
	Deformation (mm)	398.41	556.27	426.38
Mode 3	Frequency (Hz)	5420.5	8064.2	6645.7
	Deformation (mm)	377.69	497	379.97

Total Deformation of R3mm from end

		ALUMINUM 7075	KEVLAR 29	S2- GLASS EPOXY
Mode 1	Frequency (Hz)	4989.7	7517.8	5837.6
	Deformation (mm)	336.97	470.79	360.19
Mode 2	Frequency (Hz)	4991.4	7720.9	5838.5
	Deformation (mm)	336.99	470.83	360.19
Mode 3	Frequency (Hz)	15721	23367	19314
	Deformation (mm)	342.83	478.9	366.14

COMPARISON OF THEORETICAL AND ANALYTICAL RESULTS

Comparison of theoretical and analytical results of stress and strain for Aluminum Alloy 7075

	2mm at end	2mm at 3mm distance	3mm at end	3mm at 3mm distance
Stress (MPa) (Theoretical)	6.0097749	15.29924273	6.874588415	23.60738455

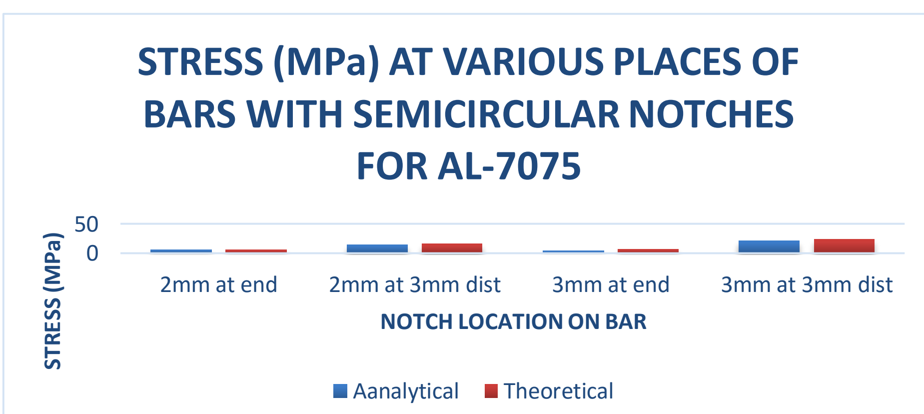
Stress (MPa) (Analytical)	5.9145	14.191	3.4835	21.158
Strain (Theoretical)	8.3818339 e-5	2.133785596e-4	9.587989421e-5	3.292522253e-4
Strain (Analytical)	8.2528e-5	0.00020223	4.8585e-5	0.00029513

Comparison of theoretical and analytical results of stress and strain for Kevlar 29

	2mm at end	**2mm at 3mm distance**	**3mm at end**	**3mm at 3mm distance**
Stress (MPa) (Theoretical)	6.0097749	15.29924273	6.874588415	23.60738455
Stress (MPa) (Analytical)	5.8727	14.13	3.6603	21.047
Strain (Theoretical)	7.240692651e-5	1.843282257e-4	8.282636645e-5	2.844263199e-4
Strain (Analytical)	7.079e-5	0.00017347	4.4101 e-5	0.0002537

Comparison of theoretical and analytical results of stress and strain for S2- Glass Epoxy

	2mm at end	**2mm at 3mm distance**	**3mm at end**	**3mm at 3mm distance**
Stress (MPa) (Theoretical)	6.0097749	15.29924273	6.874588415	23.60738455
Stress (MPa) (Analytical)	6.0918	14.527	3.5699	21.629
Strain (Theoretical)	6.915736364e-5	1.760557276e-4	7.910918774e-5	2.716615023e-4
Strain (Analytical)	7.0133 e-5	0.00017148	4.1084e-5	0.00024892



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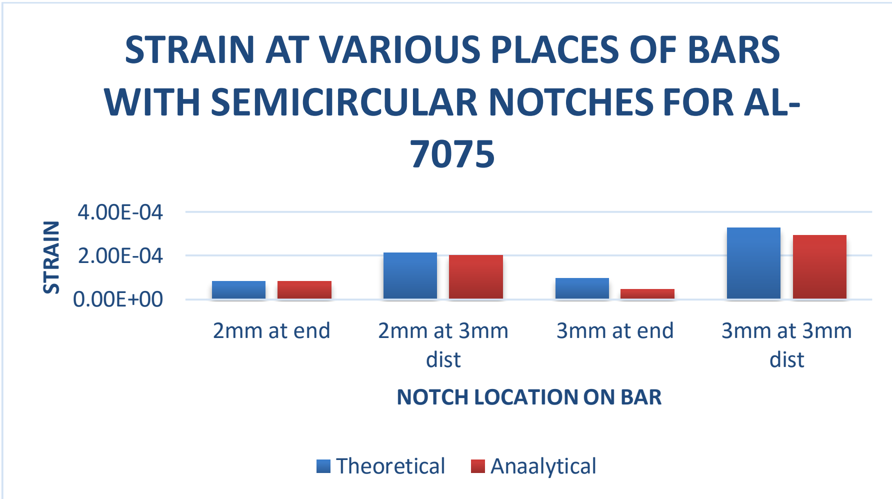
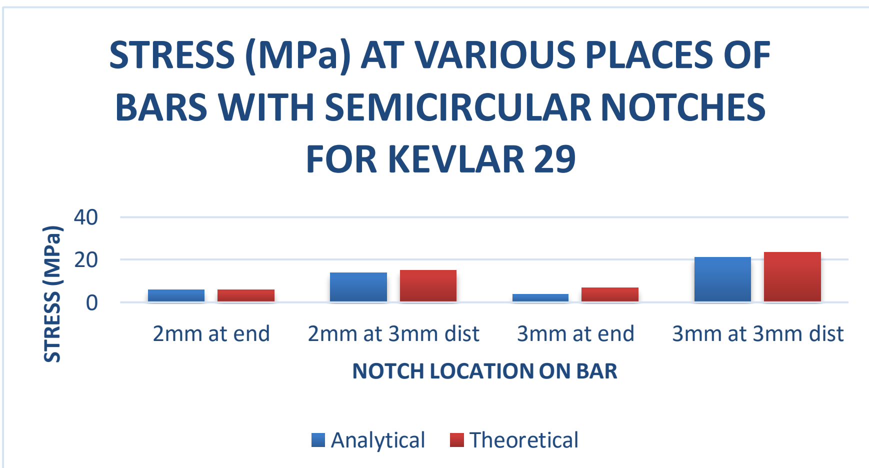
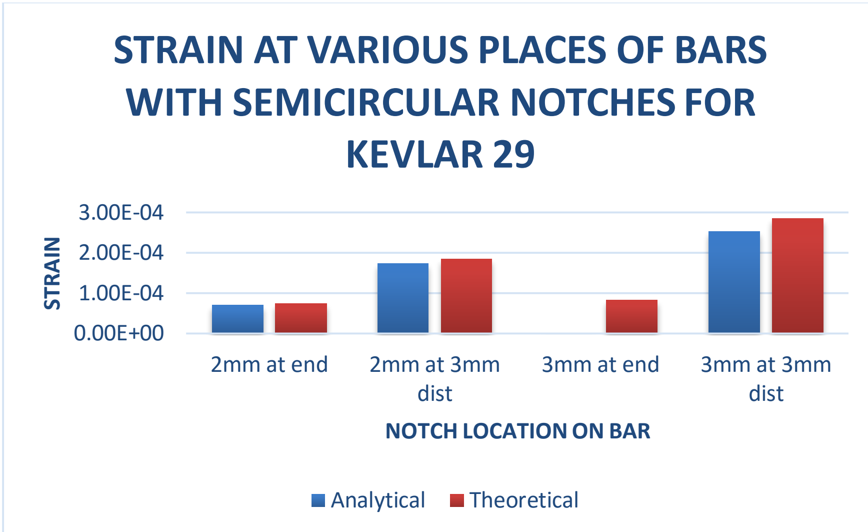
Stress (Mpa) at various places of bars with semi-circular notches for Al-7075



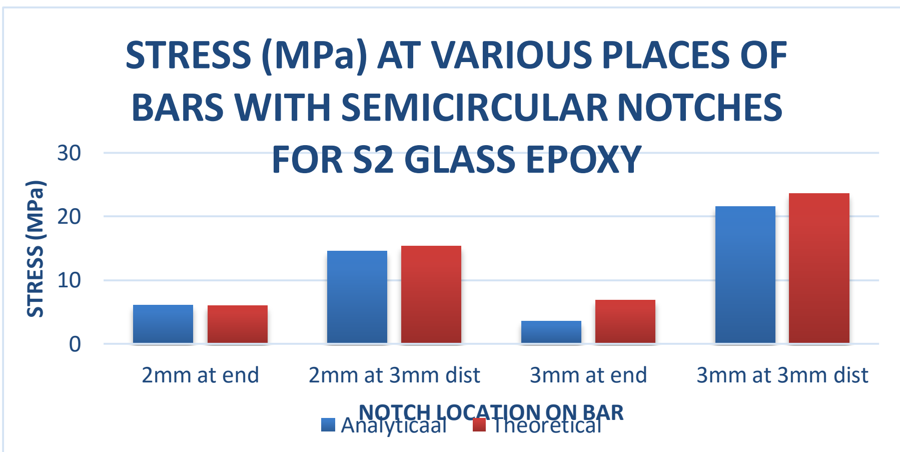
Strain at various places of bars with semi-circular notches for Al-7075



Stress (Mpa) at various places of bars with semi-circular notches for Kevlar 29



Strain at various places of bars with semi-circular notches for Kevlar 29.



Stress (Mpa) at various places of bars with semi-circular notches for S2- Glass Epoxy.

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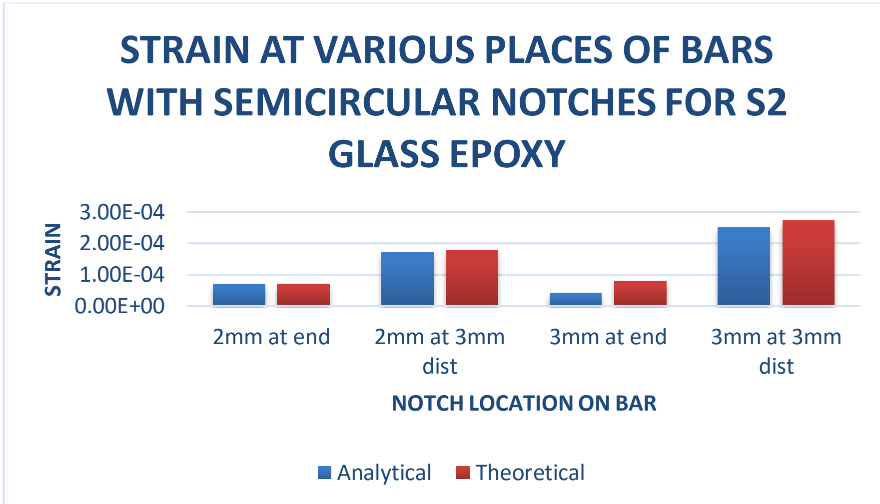

Strain at various places of bars with semi-circular notches for S2- Glass Epoxy.

CONCLUSION

In this present work the stresses, deformations of a bar having a notch are determined experimentally and analytically. The model is created by using CREO and static structural, fatigue and modal analysis results are obtained by using ANSYS.

By observing the analytical results, it can be concluded that, the stresses are maximum for S2- Glass Epoxy, when the notch is at 3mm radius at 3mm distance and minimum for Aluminum alloy 7075 at 3mm radius at end. Damage is more for 3mm radius at end when Kevlar 29 is used and less for 2mm radius at end when S2- Glass Epoxy is used. Frequencies are more for 2mm radius at end when Kevlar 29 is used but less for 3mm radius at 3mm distance when Aluminum alloy 7075 is used. Due to higher frequencies, vibrations will increase for 2mm radius at end when Kevlar 29 is used. The maximum deformations are obtained for 3mm radius at 3mm distance when Kevlar 29 is used and minimum for 3mm radius at end when Aluminum alloy 7075 is used.

By comparing theoretical and analytical results, it can be concluded that

1.) Aluminum alloy 7075
- For 2mm radius at end, the theoretical stress is 4.91% greater than analytical value.
- For 3mm radius at end, the theoretical stress is 2.48% greater than analytical value.
- For 2mm radius at 3mm distance the theoretical stress is 13.19% greater than analytical value.
- For 3mm radius at 3mm distance, the theoretical stress is 20.15% greater than analytical value.

2) Kevlar 29
- For 2mm radius at end, the theoretical stress is 4.87% greater than analytical value. For 3mm radius at end, the theoretical stress is 2.66% greater than analytical value.
- For 2mm radius at 3mm distance, the theoretical stress is 13.13% greater than analytical value.

- For 3mm radius at 3mm distance, the theoretical stress is 20.04% greater than analytical value.

3) S2- Glass Epoxy
    - For 2mm radius at end, the theoretical stress is 5.09% greater than analytical value.
    - For 3mm radius at end, the theoretical stress is 2.56% greater than analytical value.
    - For 2mm radius at 3mm distance, the theoretical stress is 13.52% greater than analytical value.
    - For 3mm radius at 3mm distance, the theoretical stress is 20.62% greater than analytical value.

FUTURE SCOPE OF RESEARCH

- The present study can be extended by considering multiple notches at fixed intervals from the end of the bar.
- As well as it can be extended by doing analysis on multiple notches at multiple intervals as per the requirements.
- Notches or holes with different depth and radius may be considered for further extension of analysis.
- The present study can be extended by considering the bars with tapered cross section.
- Comparing the results by using Finite Element Analysis will give better understanding from the experimental results.

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2) Strain-Concentration Factor of Notched Cylindrical Austenitic Stainless-Steel Bar with Double Slant Circumferential U-Notches Under Static Tension BY Hitham M. Tlilan, Ahmad S. Al-Shyyab, Tariq Darabseh, Majima Tamotsu
   A critical review of the criteria for notch-sensitivity in fatigue of metals by C. S. Yen, T. J. Dolan
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