Determination of Stress Concentration Factor by Different Methods

Stress Concentration Factor

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Abstract— **In this modern day, FOS (Factor of Safety) considered is kept low to avoid unnecessary wastage of material due to which the degree of precision of stress value should be greater. The value of stress gets deviated from its precise value due to stress raisers (grooves notches etc.). So it is very important to analyze and find out the stress concentration factor. In this paper we discuss about the methods to determine the stress concentration factor.**

INTRODUCTION

What is stress concentration and stress concentration factor?

A stress concentration often called as (stress raiser) is location where stress is concentrated. When a body of discontinuity is subject to different types of loading then more stress is concentrated at the discontinuities. The structure can fail due to such stress concentration, when concentration stress exceeds Material strength. Stress concentration factor K_t is a dimensionless factor that is used to qualify how concentrated the stress is in material. It is defined as the highest stress element to nominal stress in element.

$$K_t=\sigma Max/\sigma Nom$$

The experimental, numerical and analytical studies were conducted to investigate the stress concentration around a U-notch grooved on a shaft.

The tension test was carried out on the grooved shaft using UTM (universal testing machine) and maximum stress is calculated using experimental approach and stress concentration factor was calculated

$$K_t=\sigma Max/\sigma Nom$$

Where,

$$\sigma Nom =Force/Original\ area$$

The stress concentration factor was calculated from the graph of stress concentration factor of grooved shaft in tension.We used the graph from DDHB VOLUME 1 by DR. K LINGAIAH. K_t values are also calculated using Matlab coding and using software.

For Analytical approach FEA software ANSYS is used where shaft is loaded axially and maximum stress is calculated for calculation of K_t.
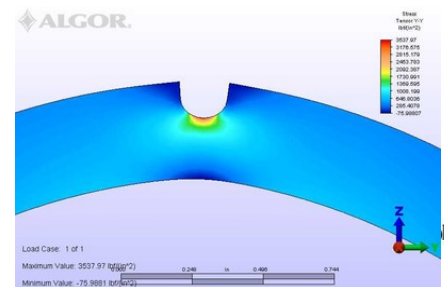
METHODS TO DETERMINE STRESS CONCENTRATION FACTOR

NUMERICAL APPROACH

We can find the value of stress concentration factor by using the stress concentration factor graph for respective element , type of discontinuity and the loading condition (Axial,Bending or Torsional) .Here we have a solid shaft with a U-groove on the circumference and axial loading is given.Thus from the graph we have ;
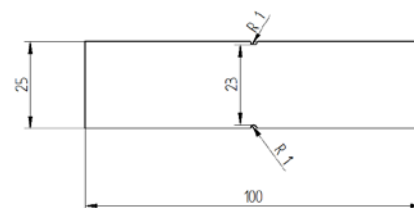

Fig: Grooved shaft

Diameter of shaft(D)=25mm
Diameter at the fillet part(d)=23mm
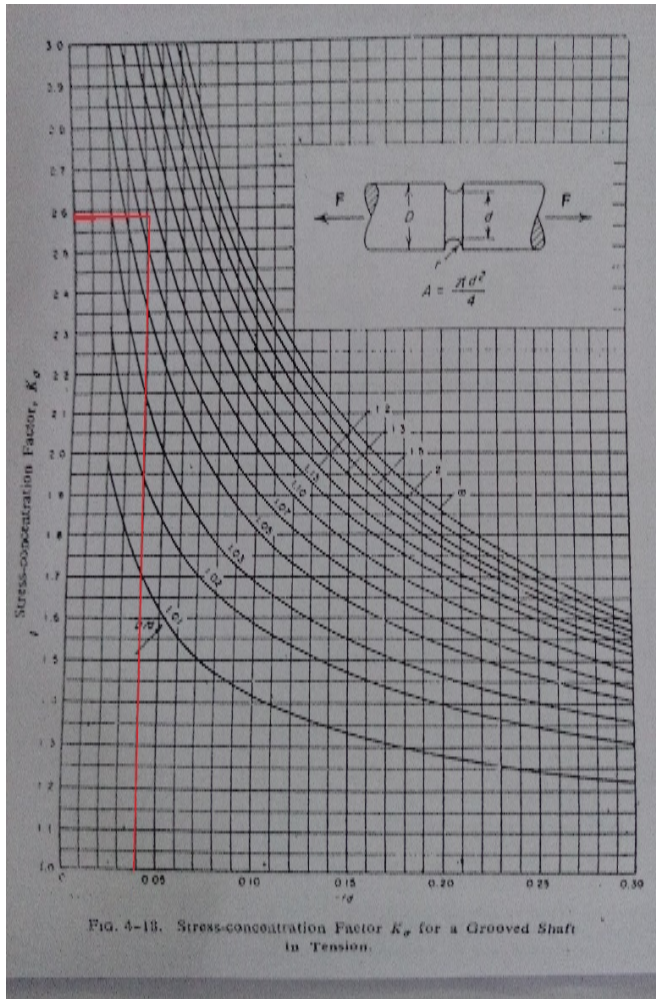Fillet radius(r)=1mm
Now,

$r/d = 1/23 = 0.0434$

$D/d = 25/23 = 1.086$

Stress concentration factor for grooved shaft in tension graph {From DDHB Vol-1 Page no:64 (By Dr. K. LINGAIAH)},

FIG. 4-13. Stress-concentration Factor K_g for a Grooved Shaft in Tension.

Stress Concentration factor is,

K_t= 2.57

We obtained stress concentration factor from this method as 2.57.

EXPERIMENTAL APPROACH

Experimentally, the stress concentration factor can be found by using Universal Testing Machine, Instron test machine, polar scope system, etc. Although the most preferred method is by using the UTM. Though according to requirement of precision and availability of resource the other method also can be used.

OBJECTIVE

The purpose of the experiment is to determine the existence of the stress concentration in the vicinity of the geometric discontinuity (here U-groove) in a solid shaft.

MACHINES USED

1. Universal testing machine
2. Extensometer
3. Mild steel rod

SPECIFICATION OF SOLID MILD STEEL ROD

a) Material=Mild Steel
b) Young's Modulus=210GPA
c) Initial diameter (D)=25mm
d) Diameter of U-groove=25mm
e) Maximum Load=1000N

STEEL PROPERTIES

- Standard grade for High Speed Steel, owing to its balanced composition has good toughness and cutting performance, hence many applications.
- HSS containing Cobalt content is a high performance steel with good cutting capability and ensures high red hardness and tempering retention. It is particularly suitable in thermal stress situations and for intermittent cutting.
- HSS containing high Molybdenum and Carbon has a wear resistance, high red hardness and good toughness.
- HSS containing low Vanadium has a very good grind ability.

RAW MATERIAL SPECIFICATION

The material we used for determination of the stress concentration factor is mild steel which is also known as low carbon steel. It is the most generally used type of steel. This is also the cheapest of its category and its application is almost everywhere. Mild steel has relatively low tensile strength but it is very cheap and easy to form. The surface hardening can also be increased by carburizing

CHEMICAL COMPOSITION OF RAW MATERIALS

Element	Content(%)
Carbon, C	0.25-0.29
Iron, Fe	98
Copper, Cu	0.2
Manganese, Mn	1.03
Phosphorous, P	0.04
Silicon, Si	0.28
Sulfur, S	0.05

MECHANICAL PROPERTIES

PROPERTIES	METRIC	IMPERIAL
Density	7.85 g/cm^3	0.284 lb/in^3
Tensile strength	400-500 Mpa	58000-79800 psi
Yield strength	250 Mpa	36300
Elongation at break in 200 mm	20%	20%
Elongation at break in 50 mm	23%	23%
Modulus of elasticity	210 Gpa	30450 ksi
Poisson's ratio	0.3	0.3
Bulk modulus	140 Gpa	20300 ksi
Shear modulus	79.3 Gpa	11500 ksi

CUTTER SPECIFICATION

The material we used for cutter is high speed steel. The reason behind we use high speed steel for cutter was these material made cutters can be re sharpened repeatedly throughout the entire life of cutter, without changing the original cutting form.

CUTTER MATERIAL SPECIFICATION

It is a high performance steel with high hardness and good wear resistance properties. It is often used as a cutting tool as it can cut metal at very high rate than any other carbon too steel due to presence of tungsten and cobalt that gives it much higher strength.

CHARACTERISTIC PROPERTIES

- working hardness
- excellent toughness
- high wear resistance
- high retention of hardness

Alloying Elements Present in HSS Properties

1. Carbon: Forms carbides, increases wear resistance, is responsible for basic matrix hardness.
2. Tungsten and molybdenum: Improved red hardness, retention of hardness and high temperature strength of matrix, forms special carbides of great hardness.
3. Vanadium: Forms special carbides of supreme hardness, increase high temperature wear resistance
4. Chromium: Promotes depth hardening, produces readily soluble carbides.
5. Cobalt: Improves red hardness and retention of hardness of the matrix.

APPLICATONS

High performance gear cutting hobs, shapers, milling cutters, Bevel tools, all kinds of highly stressed twist bits & taps, shaped shear blades, for working high strength materials, broaches, cutting tools for roughing and finishing such as helical bits, milling cutters of all types, taps, dies, spindles, reamers, thread cutting tools, drill bits, circular saw segments. Cold forming tools such as dies & punches for cold extrusion & fine cutting tools.

MACHINE SPECIFICATION

LATHE MACHINE SPECIFICATON\

Type	Stepped Cone Pulley Engine Lathe
Power Supply	3 Phase 440-440 Volts
Motor	1 HP 1440 RPM
No. of Spindle Speeds (without back gear)	04
No. of Spindle Speeds (with back gear)	08
Size of Machine (L*B*H) in mm	1400*450*1270
Swing Over Bed	165mm
Max Centre Distance	620mm

LATHE MACHINE

Used to cut groove in the mild steel specimen for conduction of required specimen.

		Capacity	Up to 100KN
1.	Maximum force at full speed		Compatible with full speed
2.	Width		Preferably in the range of 1000-1200mm
3.	Depth		Preferably in the range of 500-600mm
4.	Height		Preferably in the range of 1600-2000mm
5.	Total Crosshead travel		Preferably in the range of 1200-1400mm
6.	Total Vertical Test space		Preferably in the range of 1200-1400mm

7.	Mechanical test to be carried on UTM
	  a) Tensile Test
	  b) Compressive Test
	  c) Ductility Test
	  d) Fatigue/Cyclic Test
	  e) Flexure/Bending
	  f) Shear/Torsion Test
			Must able to perform all mentioned test

8.	Accuracy		~0.5µm
9.	Repeatability		~0.25 µm

10.	Should be suitable for mechanical testing of following material:
	  • Stainless steel
	  • Modified stainless steel such as SS 316, SS 316 LN
	  • Polymers such FRP, Polyamides, Epoxy esters
	  • Different Metals such as Copper, Aluminium alloys etc
			UTM must be suitable for testing all mentioned materials

TECHNICAL SPECIFICATION OF UNIVERSAL TESTING MACHINE

Universal Testing Machine

Universal testing machine is used to conduct the tensile test experiment on the specimen. The specimen with given dimension is clamped between the jaws of UTM and tensile force was applied and results were calculated.

TESTING PROCEDURE

1. Install the specimen in the UTM machine in tensile test setting
2. Load the solid steel rod till 1000N
3. Plot stress strain graph
4. Find : σ max and σmin

GRAPH

OUTPUT

From Graph,

σMax=5.59MPA

σNom=Force/Original area (area before tensile test)

=2.41MPA

Stress concentration factor (K) =σMax/σNom

=5.59/2.41

=2.32

RESULT

The stress concentration factor was obtained by a tensile test on mild Steel Specimen with a U-Groove of standard dimension and value was obtained as 2.32.

CONCLUSION

The value obtained from experimental approach is 2.32 and from theoretical approach (from graph and software), it is 2.57. So the variation is (2.57-2.32)=0.25

This variation may be due to

1. Improper gripping of specimen in UTM
2. Improper taking of readings
3. Manual errors of considering value in graph

CALCULATION OF STRESS CONCENTRATION FACTOR USING ANSYS FOR ANALYTICAL APPROACH

Ansys software is used for analytical approach. The shaft with groove is designed using Catia V5 software and imported in geometry section of Ansys static structural work bench then the shaft is meshed using triangular meshing of mesh size 0.5mm and mesh refinement is inserted in grooved area then axial force of 1000N is applied on both ends of shaft causing tension in shaft then solver is run and solution is obtained.

GEOMETRY	SHAFT WITH U-GROOVE
Material properties	Mild steel
Density	7850kg/m3
Young modulus	210GPA
Poisson's ratio	0.3
Meshing information	
Element size	0.5mm
Number of node	146261
Number of element	87648
Loading information	Tensile loading of 1000N in y direction
Boundary condition	Free at both ends
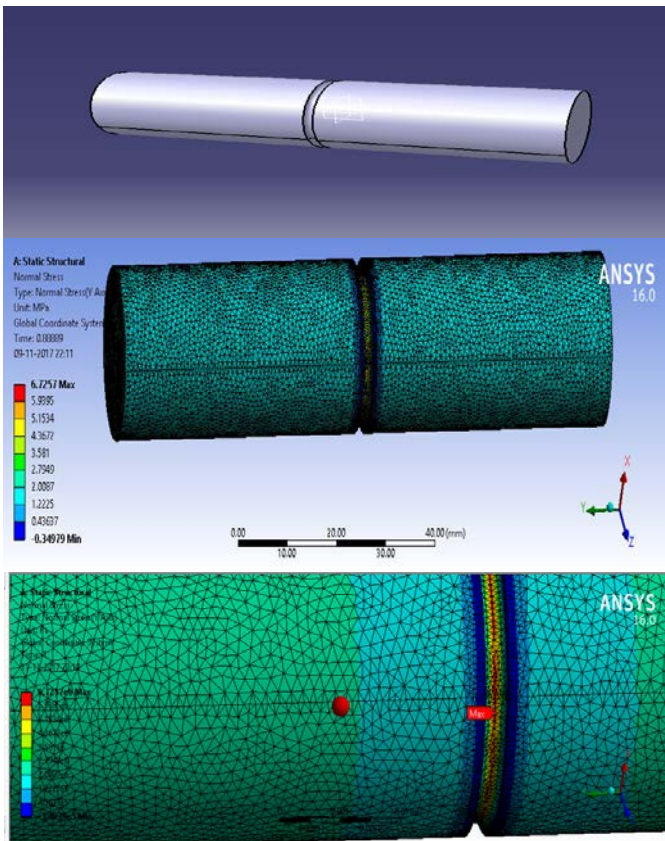
Maximum normal stress in Y –direction is calculated;

$$\sigma Max = 6.725 MPA$$

Kt was calculated by dividing the σmax value by σNom value

$$\sigma Nom = 1000 / ((\pi/4) \times 232) = 2.4068 \text{ Mpa}$$

The value of Kt from analytical approach i.e. using Ansys is 2.7944 deviates from actual value 2.575 due to following reason:

a) Due to improper mesh sizing.
b) Due to improper elemental shapes and number of nodes.
c) Due to some in accuracy in boundary condition
d) Due to consideration of less digits after decimal during calculations.

These things can be minimized by following ways:

a) Choosing smaller mesh sizing as possible leads to more accuracy in result operation.
b) Choosing element with more number of nodes leads to appropriate interpolation.
c) By applying exact boundary conditions, we can get more accurate results.

USE OF SOFTWARE

Many different types of software are used to determine the stress concentration factor. Following software can be used directly used to directly determine the stress concentration factor:

1) ALFAK SOFTWARE: A software created by faculty of Mechanical engineering Sarajevo. It is a very simple and easy to use software to determine stress concentration factor.
2) PETERSON'S METHOD: This method is explained in Walter Dr. Pikley publication from Virginia Engineering education.
3) CATIA V5 AND ANSYS: These FEA software can be used to directly find the value and nature of stress concentration in complex geometries.
4) STRESS CONCENTRATION FACTOR CALCULATOR: This is a basic and simple method of calculating the stress concentration factor. You just need to select the type of specimen and discontinuity, put the condition like load, diameter, moments, etc.

CALCULATION OF STRESS CONCENTRATION FACTOR USING MATLAB

a) Image display

A figure of the case is displayed on the screen which will aids in better understanding of the parameters entered by the user and would avoid any confusion.Specimen.jpg is the name given to figure which has to be stored in Matlab folder.

```
[P,map]=imread('specimen.jpg');
imagesc(P,[min(P(:)) max(P(:))]);colormap(map)
axis off
axis equal
```
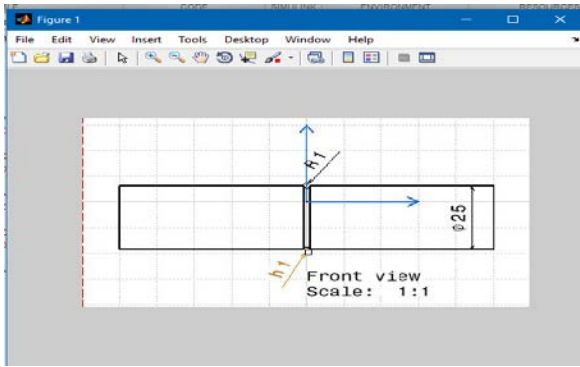
b) Prompt
This section contains a set of codes that allow the user to input the various parameters that are necessary to compute the stress concentration factor shown in the figure by means of a dialog box that pops up when the program is run.

```
prompt={'Enter the diameter of cylinder:D',....
    'Enter the depth of U notch:h',......
    'Enter the radius of curvature of U notch:r'};
dlg_title='Inputs';
num_lines=1;
answer=inputdlg(prompt,dlg_title,num_lines);

D=str2double(answer(1,1));
h=str2double(answer(2,1));
r=str2double(answer(3,1));
```

c)
```
disp('This code is for elastic stress on a cylindrical section with two U notches')
disp('under elastic stress and axial tension')
disp('The output is the factor of stress concentration')
```
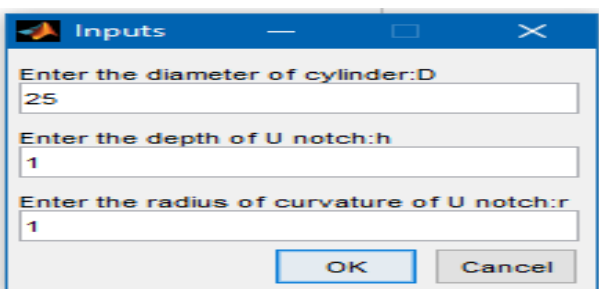

d) Logic
This section contains the coding that is required to compute the stress concentration factor. A simple if-else statement is utilized to check the conditions if there is just one condition. If the input parameters do not satisfy the conditions, then 'This code is not valid for these parameters' message is printed.

```
x=h/r;
y=(2*h)/D;
if (x>=0.1&x<=2)
  k1=0.850+2.628*sqrt(x)-0.413*x;
  k2=-1.119-4.826*sqrt(x)+2.575*x;
  k3=3.563-0.514*sqrt(x)-2.402*x;
  k4=-2.294+2.713*sqrt(x)+0.240*x;
```

```
ktheta1=k1+k2*y+k3*y^2+k4*y^3;

disp('the value of stress concentration factor is:');
disp(ktheta1);

elseif (x>2&x<=50)
  k1=0.833+2.069*sqrt(x)-0.009*x;
  k2=2.732-4.157*sqrt(x)+0.176*x;
  k3=-8.859+5.327*sqrt(x)-0.320*x;
  k4=6.294-3.239*sqrt(x)+0.154*x;

  ktheta1=k1+k2*y+k3*y^2+k4*y^3;
  disp('the value of stress concentration factor is:');
  disp(ktheta1);

else
  disp('This code is only valid for 0.1<=h/r<=50')
end;
```

e) Output
The output, which is the factor of stress concentration is printed out on the screen.
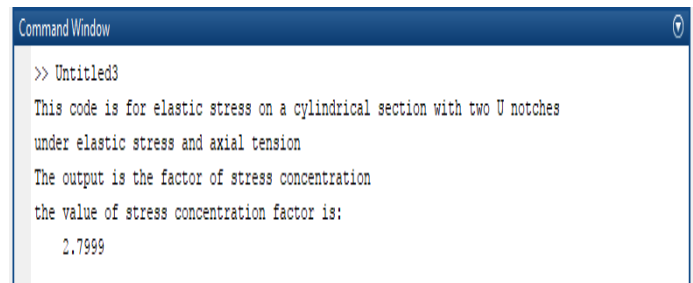
Reasons for variation in result of MATLAB with Theoretical value
• Applied boundary condition may not be exact

CREATE YOUR OWN SOFTWARE
You can make your own software as per your requirement in order to avoid expensive software. With a good knowledge of programming language, small software application can be developed. The initial approach can be to put the fundamental and relation in stress concentration topic in order to a program than process accordingly. In above method, we have used Matlab to solve a given specific problem. Similarly, that program can be expanded and can be converted into a simple software which can be used to find stress concentration.

RESULT COMPARISON

Methods used	Values of (k_t) obtained
1. Numerical approach	2.575
2. Experimental approach	2.32
3. Analytical approach (FEA) analysis using ANSYS (workbench16)	2.7944
4. Using software (stress concentration factor calculator)	2.57
5. Mat lab code	2.7999

The variation in results calculated from different method and their reasons with remedies are explained above in each consecutive approaches.

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