MATERIALISTIC SUITABILITY ANALYSIS FOR CUTTING DYNAMOMETERS

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ABSTRACT
Suitability of material comes forth in deciding for the right material together with the shape and size of the dynamometer to support the cutting load. Role of material strength with the size of dynamometer came into decision when fixing the maximum cutting load on the assembly parts in the same way as role of shape of deforming element came into decision when setting up the maximum permissible deformation taken up by the dynamometer. Present work aims at verifying the selection of the size, shape and material under a target cutting load that are used by various researchers in designing the cutting dynamometers successfully. Research has been done to devise cutting dynamometers with varying shapes and sizes of deforming elements made with different materials. SOLIDWORKS is employed to model the material deformation and study is conducted to compare the values obtained for the maximum deflection, strain and total von-Mises stress developed at the most heavily stressed point through SOLIDWORKS with the corresponding theoretical or experimental values obtained by the researchers.

1. INTRODUCTION
Apart from considering the type of sensing element and the shape of the deforming element, deciding for the materials of a cutting dynamometer is also an important aspect which is kept foremost in the design and construction of cutting dynamometers. A good material must be selected based on the mechanical characteristics to solve the purposes effectively and economically the devices are made for. The characteristics like natural frequency, linearity, cross sensitivity, frequency response should also be given priority along with the mechanical characteristics like deformation under the load, wear, rigidity, toughness and most importantly the material strength. The materials selected should impart sufficient strength and rigidity to the structure of the cutting dynamometer so that the dynamometer structure can safely support the cutting forces that will be coming during metal cutting. Correctly selected materials facilitate the designed and constructed dynamometers in taking up high cutting forces without being deformed beyond permissible limits. If the materials of the cutting dynamometers are not chosen wisely it may result in the breakage of the dynamometers under excessive forces during metal cutting and therefore due care should be paid to prevent the device failure (Korkut, 2003).
Cutting dynamometer materials are required to carry high strength to bear forces during metal cutting without getting deformed, good flexural rigidity to have deflection under permissible range, good heat conduction characteristics to make the material safe against thermal softening and a good corrosion resistance. Beside the material properties mentioned, a dynamometer device should possess high natural frequency, high accuracy of measurement, a good linear and cross-sensitivity, high repeatability and a wide frequency response for the dynamic characterization (Sun et al., 1982 & Khan et al., 2020).
Dynamometric systems in cutting industries are popular for being capable of measuring various forces during the metal cutting. A typical dynamometric system usually includes some deforming elements alongwith sensing elements with proper circuitry housed rigidly in a frame usually mounted on a machine tool to measure the forces during metal cutting. Measurement of forces during metal

cutting is always important as the forces during cutting are good measures for heat generated during metal cutting, quality of work surface produced and tool wear, etc (Huang et al., 2014).

2. LITERATURE SURVEY

Literature available indicates clearly that steel is at the top among the preferred materials for the cutting dynamometers by the researchers. With steel as the material for cutting dynamometers, various design has been successfully validated with targeted cutting process, employing strain-gauges as the sensing elements, through calibration and testing for the design load of 90N to as high as 6800N approximately with good uncertainty in measurement; which in some cases being ±0.025% (Hallam et al., 1962, Venkataraman et al., 1965, Hsu et al., 1970 & Kumar et al., 2011). Exhibiting a good mechanical strength, AISI 1040 carbon steel has found its application in making cutting-dynamometers under a design load of 4500N with significantly low cross-sensitivity (Korkut, 2003, Karabay, 2007 & Karabay, 2007). AISI 4130 and AISI 4140 alloy steels have been used by the researchers in developing cutting-dynamometers, with maximum force to measure in each direction limited to 3500N, as these alloy steels possess good corrosion resistance and reasonably good strength (Yaldiz et al. 2006, Yaldiz et al. 2006 & Yaldiz et al. 2007). Device to measure the forces upto a maximum of 1000N has been reported with EN24, a high strength alloy steel, with an uncertainty in measurement of ±0.10% (Kumar et al., 2013).

Different designs of simple and combined type cutting-dynamometers have been reported by the researchers with Aluminium as the material for the deforming element for a maximum load of 4000N with excellent linearity and cross-sensitivity (Oraby et al., 1990, Kim et al., 1997 & Libii, 2006). A small, three-component hole-based cutting-dynamometer of high-capacity has successfully been designed and tested with phosphor bronze for better sensitivity (Tani et al., 1983).

3. THEORY

Thin and thick rings of various shapes have been used as the deforming elements by the researchers till date. Although many researchers in designing the cutting dynamometer found it better to consider the deforming elements to be of the shape of octagonal rings. In applications for the cutting dynamometers, octagonal rings as the deforming elements have an edge over circular rings as the former offer better placement of sensing elements (strain gauges in most of the studies conducted) and are stiffer with the same section. Figure 1(a) and (b) can be referred as to have an understanding of the comparative dimensions of octagonal, square and hexagonal ring type deforming elements.

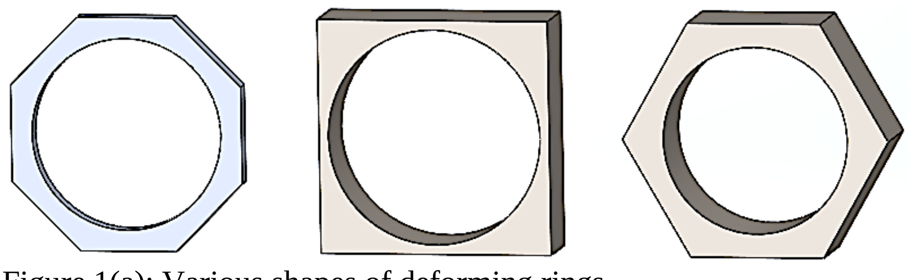


Figure 1(a): Various shapes of deforming rings

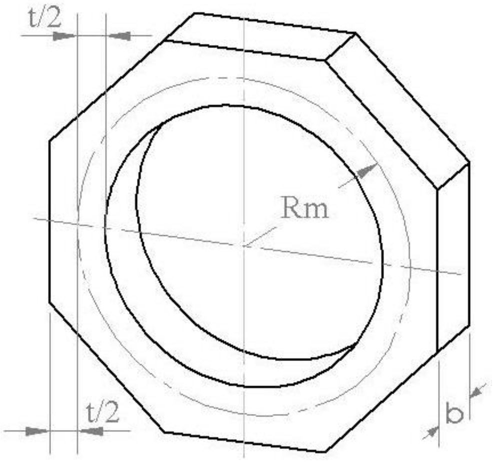


Figure 1(b): Dimensions of a deforming ring

Research studies conducted on octagonal deforming rings with varying dimensions have witnessed that an increase in height and a decrease in the thickness of the deforming ring increases ring's sensitivity but decreases ring's stiffness. Although ring-width has no measurable effect on stiffness, its increase decreases the ring's sensitivity. The ring's sensitivity has been found unaffected with any change in edge-radius $r_e$of the ring whereas ring's stiffness has been found decreasing with any increase in edge-radius $r_e$of the ring (Soliman, 2015).

When loaded, not all the rings deform in the way assumed in the theory for thin ring. This happens because of the shape and size of the deforming rings. The ratio Rm/t is used to differentiate between thin (R_m/t > 10) and thick (R_m/t < 5) deforming rings. Based on experimental data and shape of deforming rings, modifications over equations of ring theory have been suggested by many researchers (Kroencke et al., 1989, Kumar et al., 2013 & Kumar et al., 2015).

Locations of strain gauges on the deforming ring should be selected so as to obtain minimum cross-sensitivity under the deformation. Also, the orientation and location of deforming rings in cutting-dynamometer assembly should be made to achieve maximum response from the Wheatstone bridge circuit (Yaldız et al., 2007).

4. METHODOLOGY

For the current study, finite element models of deforming rings of varying shapes, sizes and materials were made on SOLIDWORKS from the data available in the literature. SOLIDWORKS was employed to model the deformation by constraining the deforming rings so as to meet the actual condition of loading during cutting. Model simulation results related to strain, maximum stress and equivalent (von-Mises) stress were obtained for each geometrical model. Comparison between simulation values and the values obtained from theoretical relations for the parameter were then made.

5. GEOMETRIC MODELS

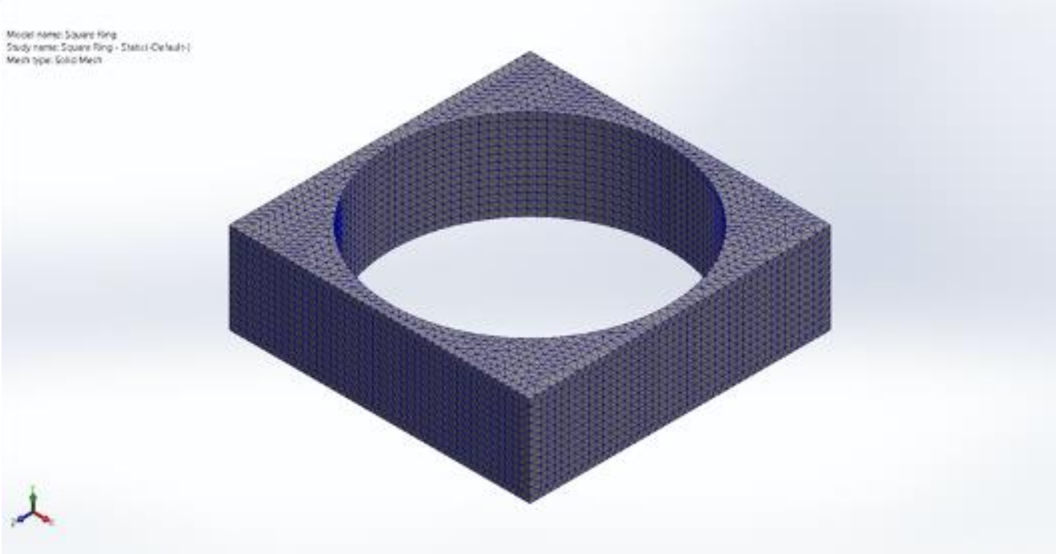
In analyzing suitability of materials for the cutting dynamometers, study of deformation of 3-dimensional geometrical models were constructed to model the deformation of differently shaped deforming rings with the bottom surface rigidly fixed to the dynamometer housing using SOLIDWORKS software package. The design parameters for the rings like ring-shape, width, height, thickness and edge-radius were defined on the geometrical models precisely.

Five different geometrical models were constructed to represent deforming rings with octagonal, hexagonal and square shapes. Refer Table 1 for geometrical models considered under sthid study with their specifications. All the rings had circular holes at the centre (Soliman, 2015, Kumar et al., 2015 & Kumar et al., 2013) except the one deforming octagonal ring which was constructed with a central elliptical hole with a major axis oriented horizontally (Uddin et al., 2016).

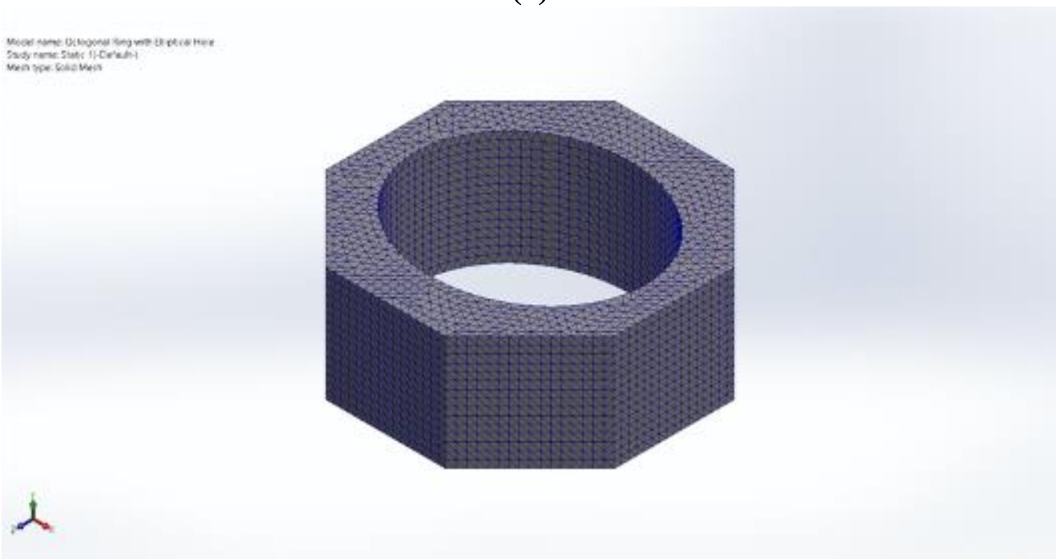
(a)

(b)

(c)



(d)



(e)

Figure 2 (a - e): The deforming ring models that were used under this study. Refer Table 1 for specifications.

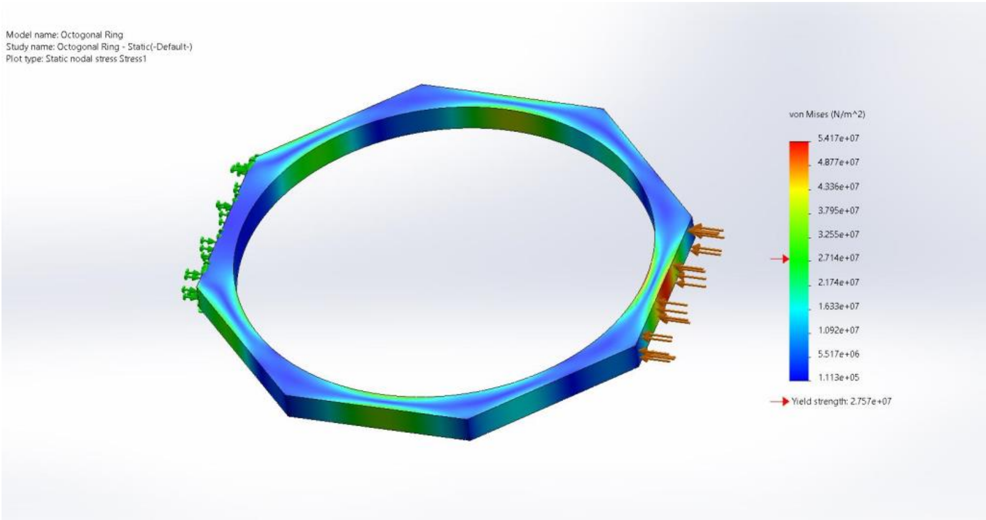
Table 1: Specifications of Geometrical Models

S. No.	Ring-shape	Design Parameters (mm)				Material	Ultimate tensile strength (MPa)	Force	Reference
		R_m	b	t	r_e				
1	Octagonal	46	6	4	0	Aluminum 1060	E = 68.947 GPa σ_e = 27.579 MPa σ_u = 68.948 MPa ν = 0.33	100N	Soliman, 2015
2	Octagonal	36	6	8	2	Aluminum 1060		100N	Soliman, 2015
3	Hexagonal	91	35	10	0	EN 24 steel	E = 210 GPa ν = 0.3	20kN	Kumar et al., 2015

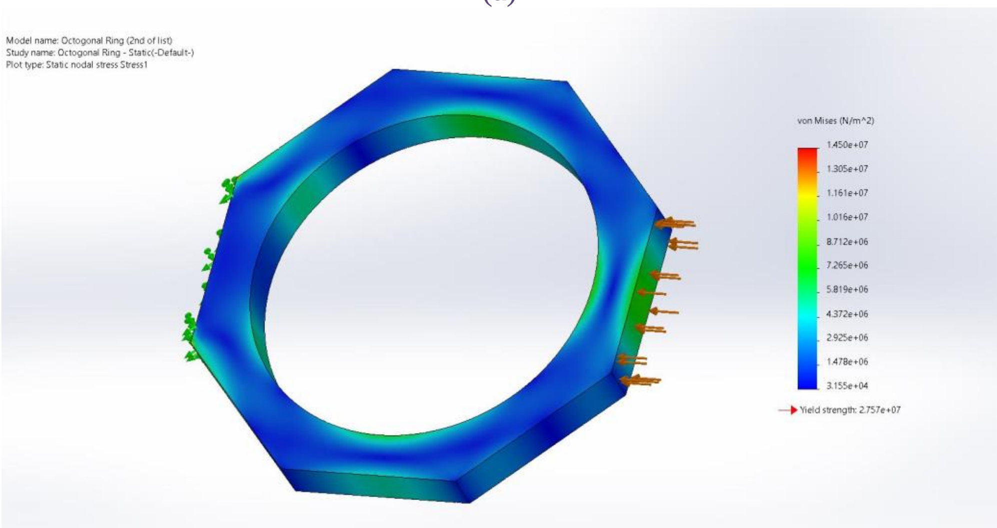
4	Square	48	30	4	0	EN24 steel	E = 210 GPa ν = 0.3	1kN	Kumar et al., 2013
5	Octagonal with elliptic hole	R_{major} = 34 R_{minor} = 30	30	7.68	0	AISI 4340	E = 205 GPa ν = 0.3	5kN	Uddin et al., 2016

6. ANALYSIS

3-dimensional geometrical models for the rings under current study were constructed and constrained to match the actual conditions of rings in the dynamometer assembly and the loading using SOLIDWORKS software package. Analytical calculations have been made for stress and strain developed in the rings considered in this research using the formulae available in literature.



(a)



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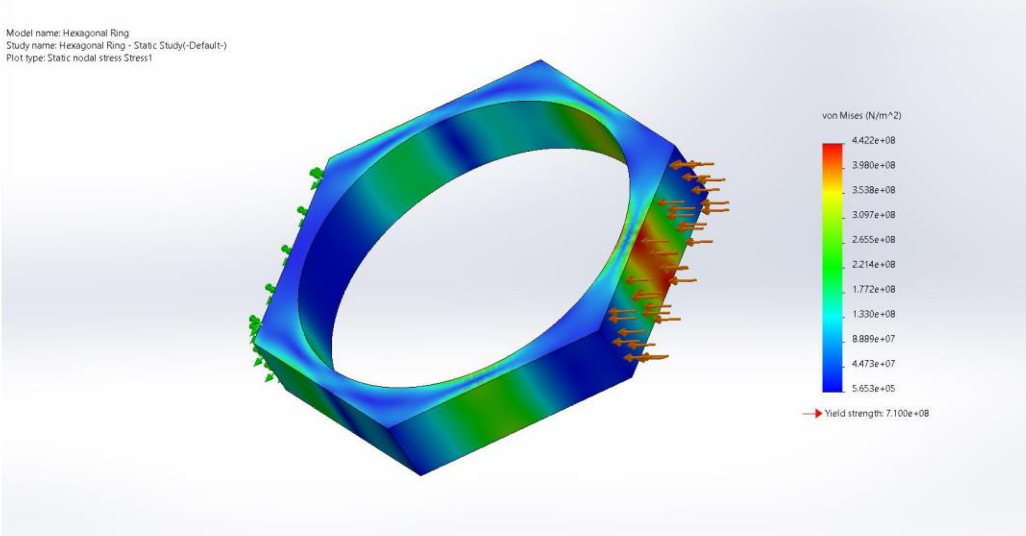

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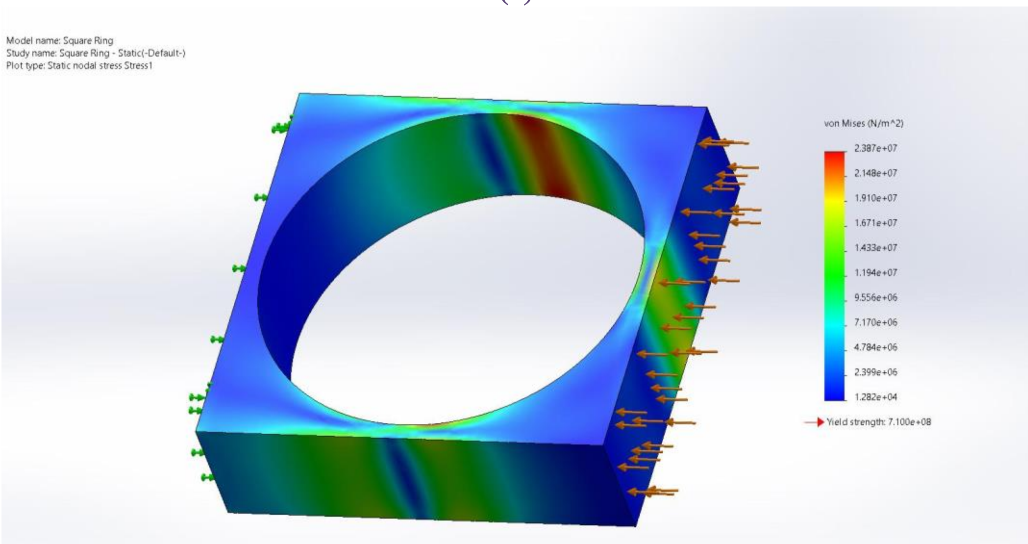

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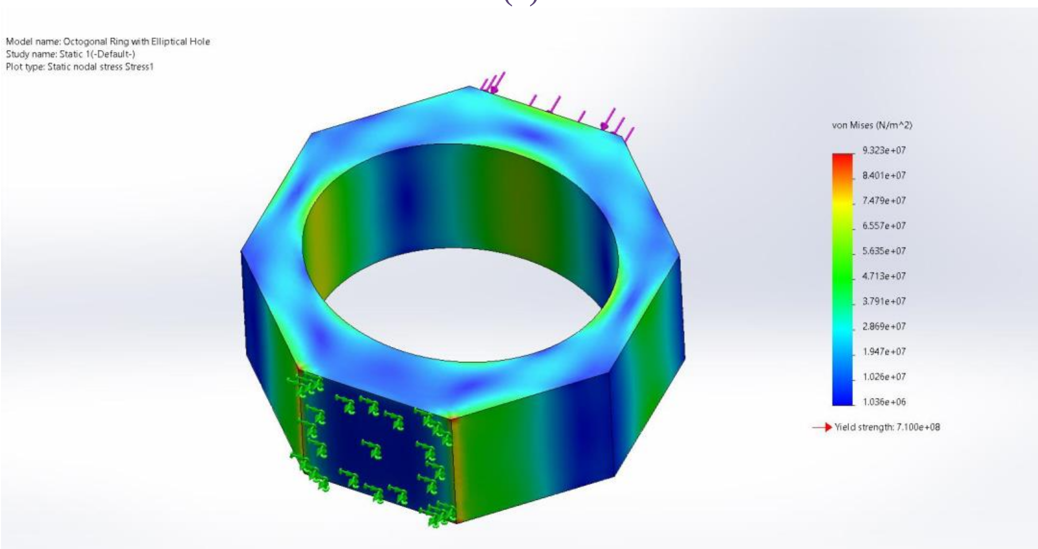
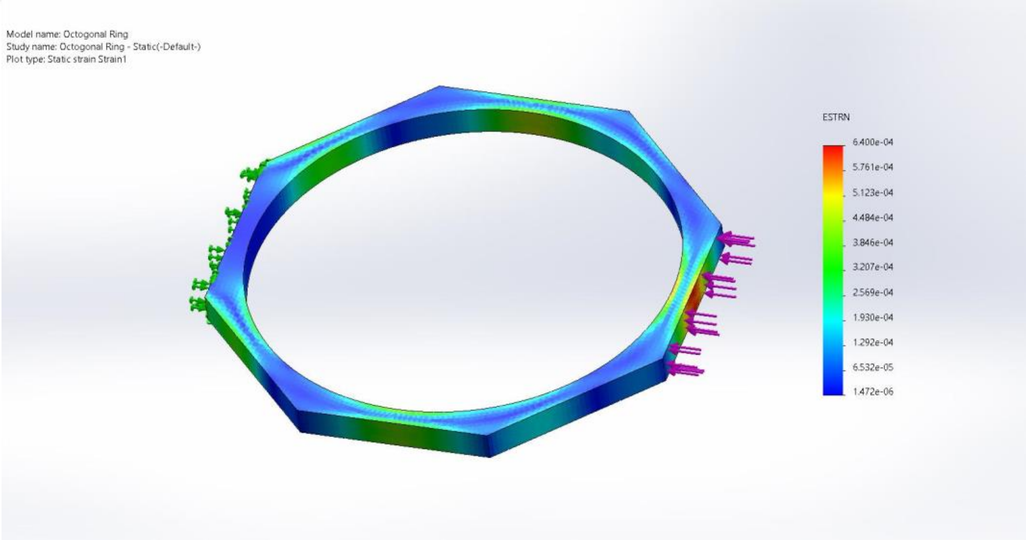


(e)

Figure 3 (a - e): The resulting stresses on applying SOLIDWORKS finite element analysis on deforming ring models under this study.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Study name: Octogonal Ring - Static(-Default-)
Plot type: Static strain Strain1
ESTRN
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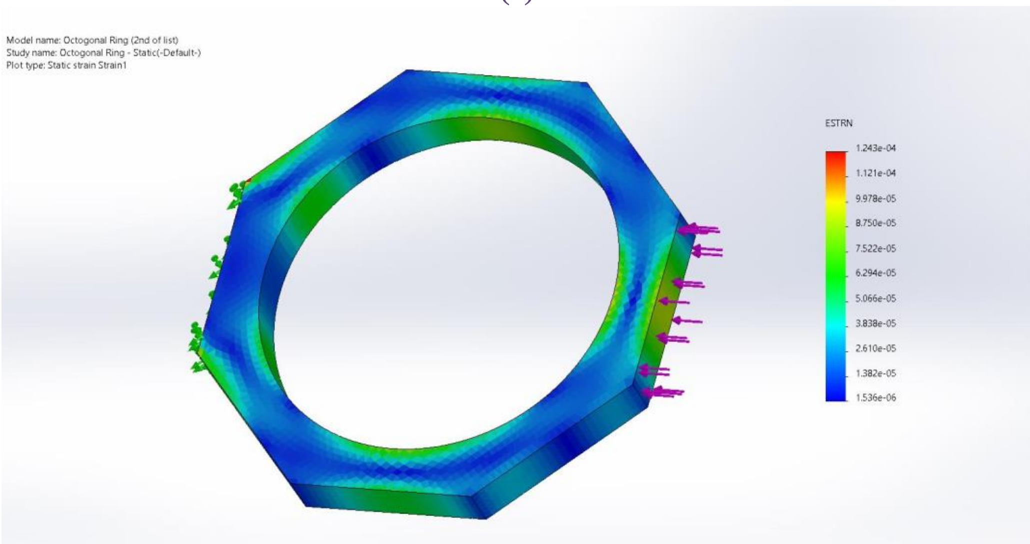
5.761e-04
5.123e-04
4.484e-04
3.846e-04
3.207e-04
2.569e-04
1.930e-04
1.292e-04
6.532e-05
1.472e-06

(a)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Study name: Octogonal Ring - Static(-Default-)
Plot type: Static strain Strain1
ESTRN
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8.750e-05
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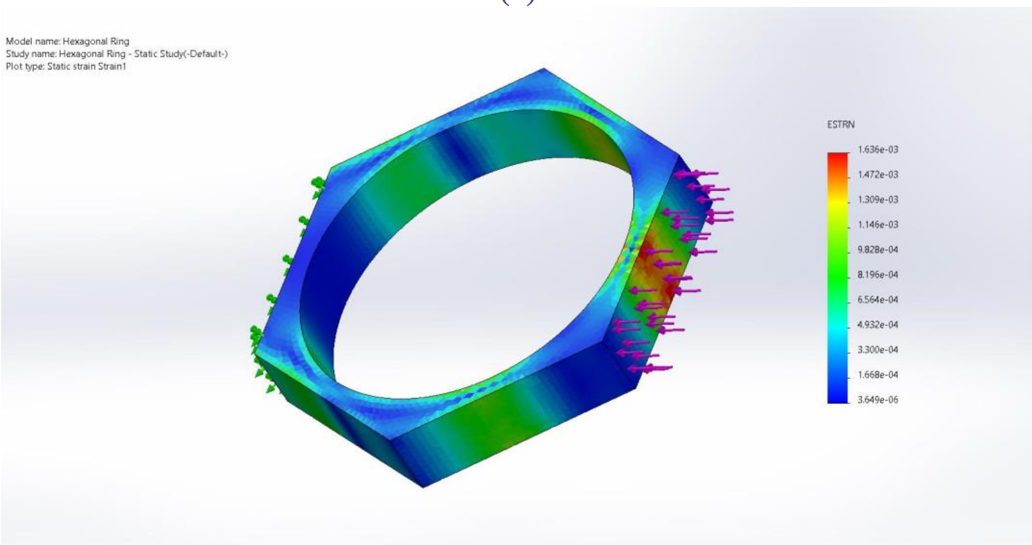
(b)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ESTRN
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1.146e-03
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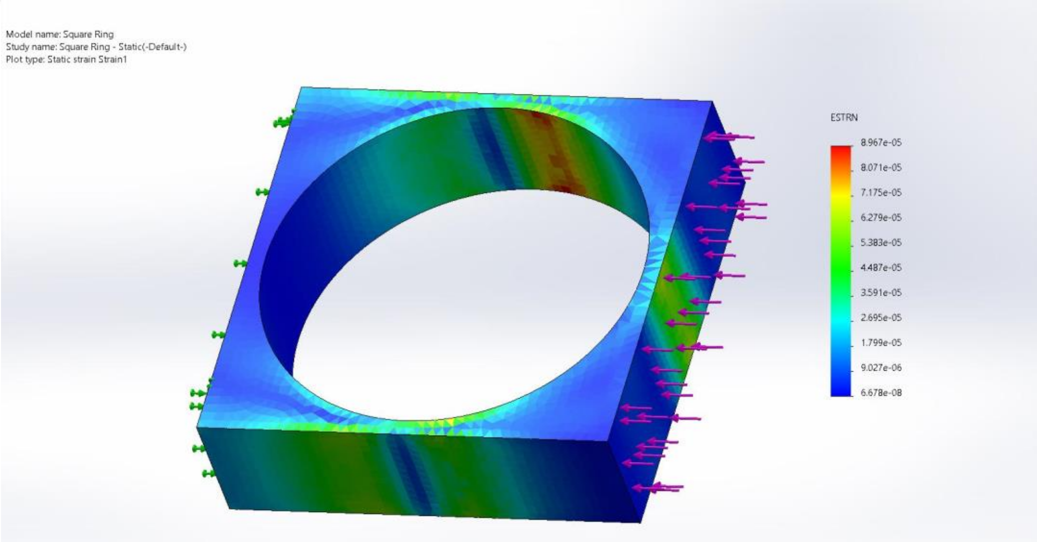
3.300e-04
1.668e-04
3.649e-06

(c)



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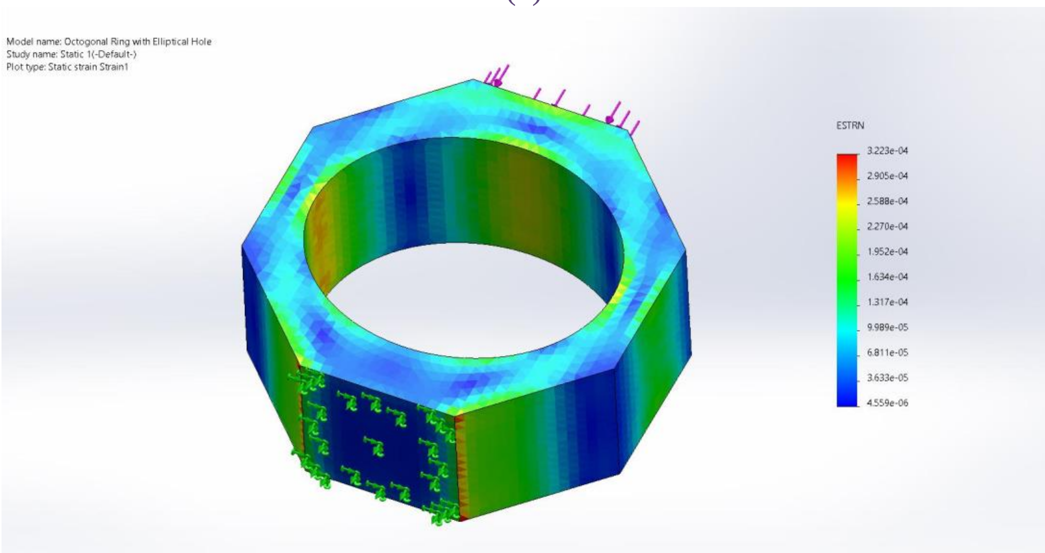

(e)

Figure 4 (a - e): The resulting strain on applying SOLIDWORKS finite element analysis on deforming ring models under this study.

Finite element analysis (FEA) is then performed on constructed and constrained geometrical mesh models with their materials applied suitably. Figure 3 shows the resulting stresses whereas Figure 4 shows the resulting strain when applying FEA on the geometrical models considered. The results of analytical and FEA are then collected and tabulated in Table 2 for both stress and strain developed in the deforming rings.

Table 2: Analytical and FEA Results of Models

S. No.	Ring-shape	Material	Force	Stress(MPa)		Strain (µm/m)	
				Analytical	FEA	Analytical	FEA
1	Octagonal	Aluminum 1060	100N	19.5	54.17	282.2	640

2	Octagonal	Aluminum 1060	100N	6.96	14.5	100.9	124.3
3	Hexagonal	EN 24 steel	20kN	364	442.2	1730	1636
4	Square	EN24 steel	1kN	27.3	23.87	1300	89.67
5	Octagonal with elliptic hole	AISI 4340	5kN	98.9	93.23	485	322.3

The Table 2 shows the values for stress and strain produced in the material of deforming rings considered under the study from analytical and SOLIDWORKS's FEA as well. The outcome from the analytical method and FEA are very similar.

7. RESULT

The variation in the values from two methods is simply due to the fact that the analytical method is based on simple ring theory. The results of stresses and strains from SOLIDWORKS's FEA under this study are very close to the corresponding analytical values obtained from the literature. The deviation in FEA obtained values for stress and strain for an octagonal model with design parameters - R_m, b, t values of 46 mm, 6 mm, 4 mm respectively are large compared to the analytical ones available in the literature. For other geometrical models of deforming rings, this deviation very small showing the FEA results in good agreement with the corresponding analytical findings. Greater the difference between the relative values of stress and strain from analytical and FEA approaches, the larger the deforming ring's deviation from simple ring theory.

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