The Tensile and Compressive Stress Analysis with Finite Element Method on Sigma Profiles Containing Angled Hole

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Abstract

This study presents stress and strain distribution on sigma profile beams that contain angled hole. The effects of hole angle (*55º, 60º, 65º, 70º, 75º, 80º, 85º* and *90º* as perpendicular to cross sectional plane) on the tensile and compressive stresses are investigated and analysed. Three different profile size (*20x20, 25x25 and 30x30 mm*), different loads and lengths are used. Finite Element Analysis (*FEA*) solutions are compared with analytical results and accuracy of *FEA* is tested. In this study, *ANSYS* program is used for *FEA*. Statistical analysis is performed and it is concluded that *FEA* can be used as a reliable method to determine the stress and strain values on sigma profiles containing angled holes.

Key words: Sigma profiles with angled hole, tensile and compressive stress, finite element analysis

1. Introduction

In general, engineering problems are mathematical models which are differential equations with a set of corresponding boundary and initial conditions. In any given engineering problem, there are two sets of parameters that influence the system behaviors. Firstly, we should consider the parameters that provide information regarding the natural behavior of a given system. These parameters include properties such as modulus of elasticity, thermal conductivity, and viscosity. Secondly, there are parameters that produce disturbances in a system. These parameters include external forces, moments, temperature difference across a medium, and pressure difference in fluid flow [1].

In contrast to analytical solutions, numerical solutions approximate exact solutions only at discrete points, called nodes. There are two common types of numerical methods: (1) finite difference methods and (2) finite element methods [1]. Although Finite Element Analysis (*FEA*) has been extensively used with success, this kind of analysis requires the generation of a large set of data in order to obtain accurate results and consumes large investment in engineering time and computer resources [2]. *FEA* gives accurate solutions through the using of engineering analysis and depends on *FEA* in the applications of mechanical engineering by using developed computer program [3].

FEA is a computer aided numerical method based on the discretization of the domain, structure or continuum. Discretization divides the medium of interest into a number of small subregions and nodes into number of elements. After that, the solutions are

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obtained [4]. *ANSYS* is a general-purpose finite element computer program. *ANSYS* is capable of performing static, dynamic, heat transfer, fluid flow, and electromagnetism analyses and has been a leading *FEA* program for well over 20 years [1].

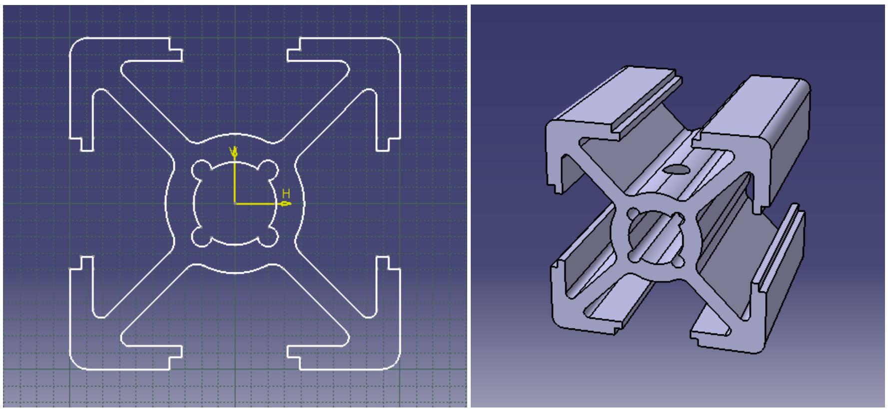
The large displacement behavior of tapered cantilever beams subjected to end forces is studied by the finite element method. A finite element formulation derived and used. The numerical results show that the finite element formulation give the accurate results. The effect of the material inhomogenity, taper ratio, and taper type on the large displacement are also pointed out [5]. Functionally graded cantilever beam is subjected to bending, shear force and pressure, respectively. Plane stress case is assumed and airy stress function is used. Elastic solutions for the beam are obtained. Effect of nonhomogeneous materials with different modulus on the elastic field in a cantilever beam is highlighted [6]. It is also available research about a proposed standard set of problems to test finite element accuracy, and finally it can be seen that the tests are able to display most of the parameters which affect finite element accuracy [7].

This study has a new perspective to determination of tensile and compressive stresses of the sigma profile. Two different methods that are analytical results and Finite Element Analysis (*FEA*) are used. Both of results are compared with each other. Results generated by using *ANSYS* are verified with the analytical results.

2. Materials and Method

2.1 Determination of material properties

The sketching and creating the solid model of the sigma profile are seen in Fig. 1. Three dimensional (*3D*) modeling is carried out in *Catia*.



a) ***b)***

Figure 1. a) Sketching of the sigma profile **b)** Solid model of the sigma profile

Table 1 shows mechanical properties and variables of sigma profile:

Table 1. Mechanical properties and analysis variables for sigma profile

DIN	**Edin, *MPa***	**Length, *mm***	**Load, *N***	**Angle of the hole, *degree***	**Profile size, *mm***
DIN EN AW 1200	70000	200 400 600 800 1000	5000 10000 15000 20000 25000	55 60 65 70 75 80 85 90	20x20 25x35 30x30

Stress and strain analysis of sigma profiles under tensional and compressive loading are performed in *ANSYS*. Effects of the angled hole on the stress-strain variation are investigated. Tensional and compressive loads are applied between *5000 N* to *25000 N*. Poisson ratio of steel beam is *0.3* and three different profile size are chosen as *20x20*, *25x25* and *30x30 mm*. Stress-strain solutions can be obtained with Eq. 1-4 [8].

Where *A* is cross-sectional area and *F* is load, if the resulting axial stress $\sigma = F/A$ does not exceed the proportional limit of the material, Hooke's Law can be applied;

$$\sigma = E\varepsilon \qquad (1)$$

From which it follows that

$$\varepsilon = \frac{\sigma}{E} = \frac{F}{AE} \qquad (2)$$

Strain ε is defined as $\varepsilon = \delta/L$,

$$\delta = \varepsilon L \qquad (3)$$

δ is deformation or displacement, *E:* Modulus of Elasticity or Modulus of Young, L is initial profile length,

Equating and solving for the deformation:

$$\delta = \frac{FL}{AE} \qquad (4)$$

When F is greater then zero, elongation occurs. When F is smaller than zero, contraction occurs.

2.2 Finite Element Analysis (FEA)

Three dimensional model (3D) of sigma profile is performed in *Catia*. After that, model is exported by *ANSYS* and profile is subdivided into nodes and elements. Collection of elements is called mesh and it is necessary to make mesh optimization to get more accuracy results. Mesh optimization is carried out until the *FEA* results and analytical solutions are close to each other. After the determination of mesh model, boundary conditions, initial conditions, and load are applied on the sigma profile containing angled hole. One side of the beam is fixed and the load is applied on the free surface. Then *FEA* analysis is performed and results are compared with the analytical solutions. It is aimed to determine the maximum normal stress around the hole according to the variables (Fig. 2).

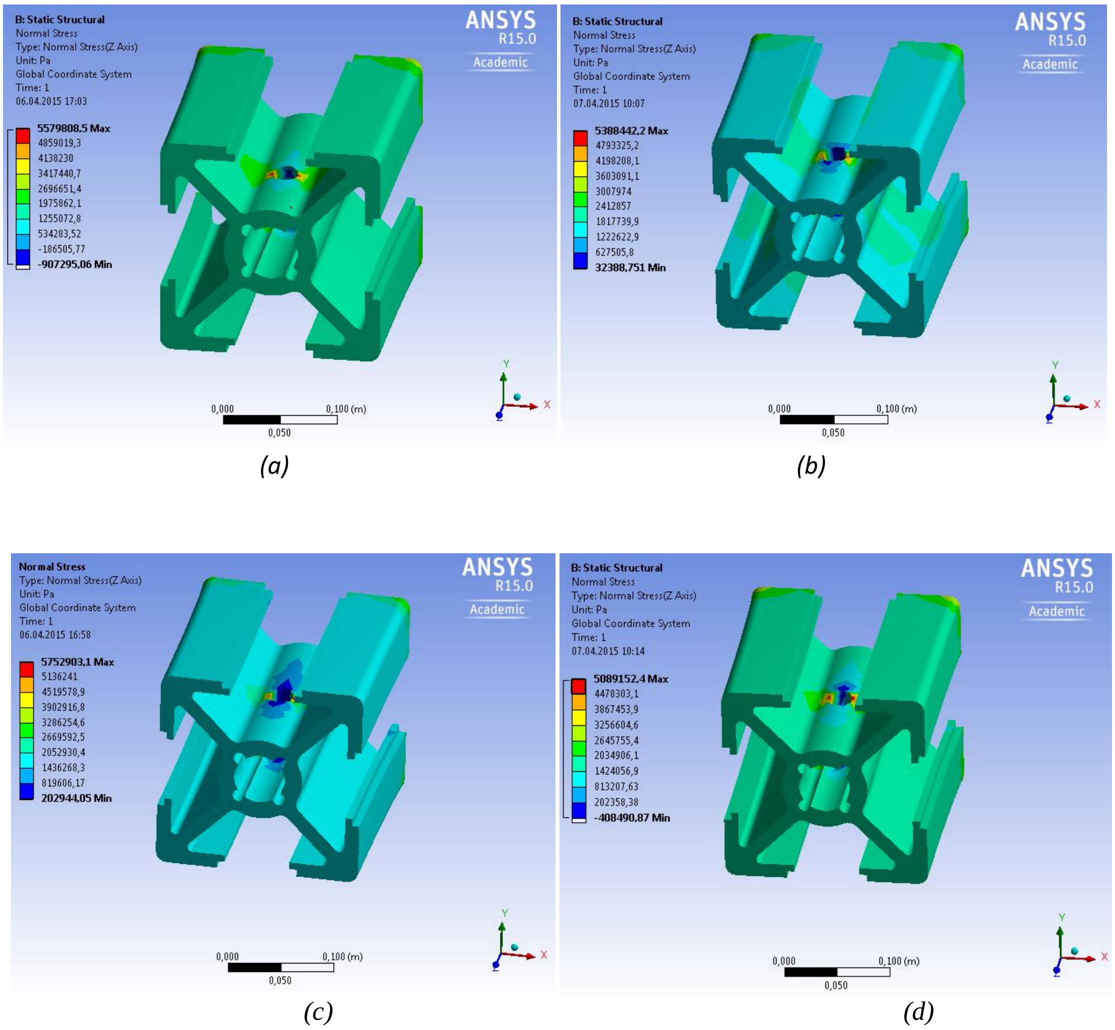


Figure 2. Equivalent normal stresses for *25000 N* and *20x20x200* profil size **a)** *60°* angled hole **b)** *70°* angled hole **c)** *80°* angled hole **d)** *90°* angled hole

3. Results and Discussion

Analysis results are classified according to the profile size, length of the profile *(L)*, magnitude of the axial load *(F)* and angle of the hole. Relationship between stress and strain rates according to the different lengths and loads is seen in the Fig 3. The graph is created for sigma profile containing *60°* angled hole for five different loads (*5000, 10000, 15000, 20000, and 25000 N*). The stresses remains same while length is changing, but the strain rates increases with increasing length.

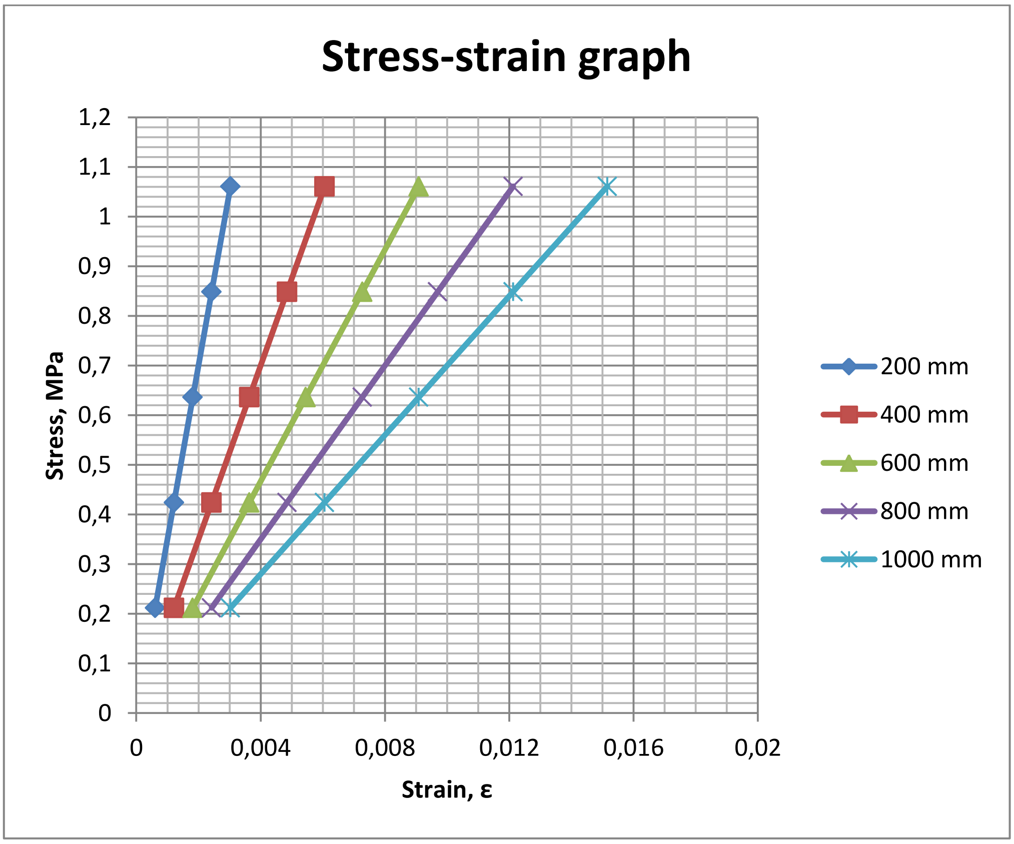


Figure 3. Stress-Strain graph for *25x25* sigma profile for *60°* angled hole

Variation in stress for *20x20* sigma profile and *200 mm* length can be seen in Fig. 4. The hole angle and different loads are chosen as parameters. The stress rates are higher for *25000 N* than the other loads as it is expected. Stress rates tend to decrease at *65°* angled hole for *10000,15000, 20000 and 25000 N*. Maximum stress comes up at *85°* angled hole for *5000 N*. The smaller angles provides lower stress rates due to the fact that the cross sectional area of the hole grows up.

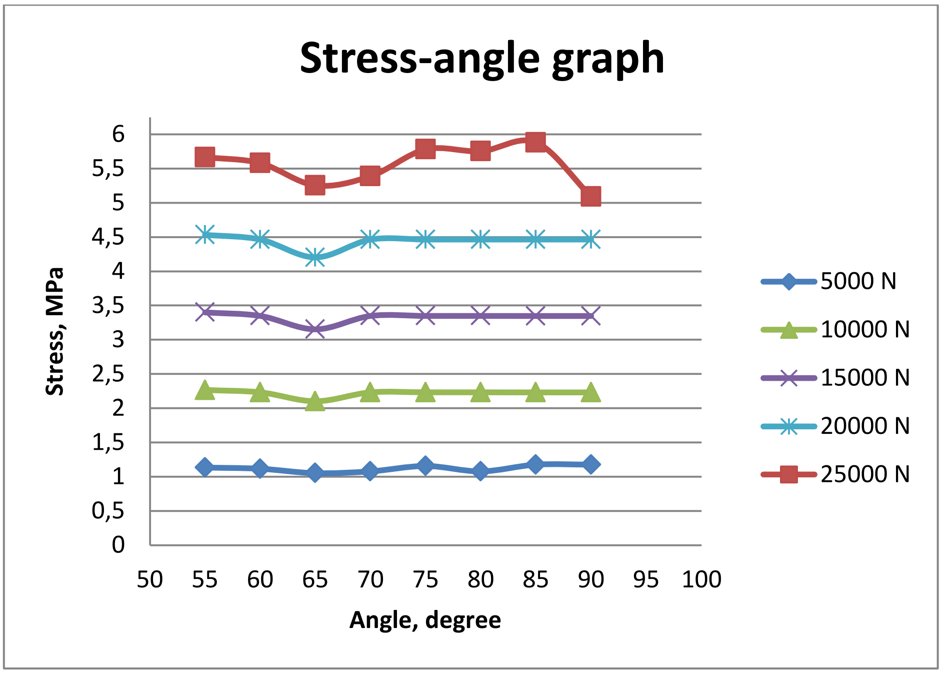


Figure 4. Stress variation according to the angle of the hole for *20x20* sigma profile, *200 mm* length

In Fig. 5, strain variation is seen for different profile size as *20x20*, *25x25* and *30x30*. The graph is created for *1000 mm* length, *10000 N* load and it is aimed to observe the effect of the hole on strain distribution. When the profile is greater size, stress decreases due to the increasing of cross sectional area. It can be said that *30x30* profile has smaller strain rates in comparison to *25x25* and *20x20* under the same tensional loading conditions. Strain rates increase with the increasing of the hole angle for all of the profile size. While maximum strain occurs in the *90°* angled hole for *20x20* profile, minimum strain comes up with the *50°* angled hole for *30x30* profile.

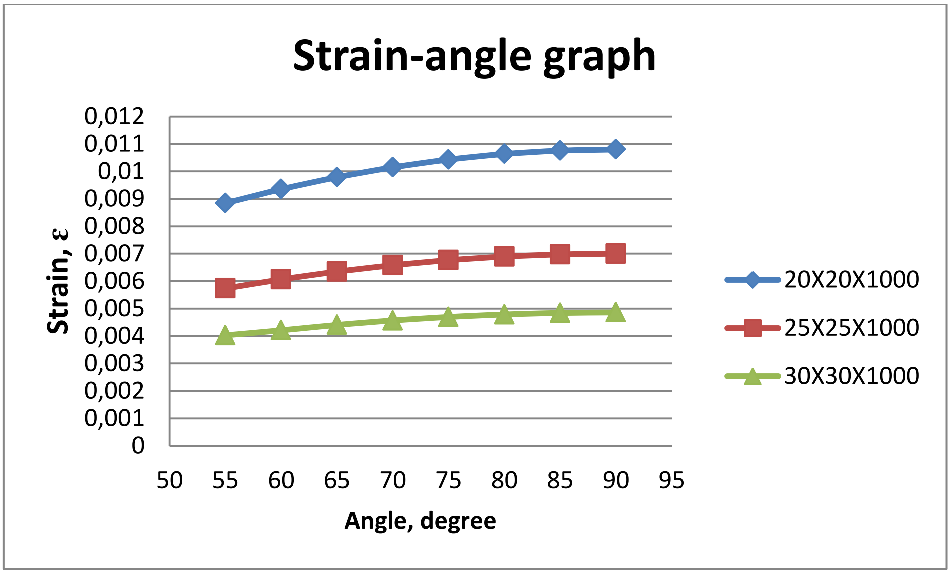


Figure 5. Strain variation according to the angle of the hole for *20x20*, *25x25* and *30x30* sigma profile, *1000 mm* length and *10000 N* loading

Table 2 concludes that the the statistical analysis of *FEA* results of displacements under tensional loading. Absolute Fraction of Variance (R^2) is very close to 1 and Root Mean Square Error (*RMSE*) is close to 0 as it is expected. Mean Error Percentage (*MEP %*) is very low and statistical analysis results verify the accuracy of *FEA*.

Table 2. Statistical analysis of *FEA* results of displacements under tensional loading

	Absolute Fraction of Variance (R^2)	**Root Mean Square Error (*RMSE*)**	**Mean Error Percentage (*MEP %*)**
Displacement $(\Delta L)_{FEA}$	0.999999976	0.008021644	0.009997253

Conclusions

In this study, it is aimed how stress and strain distribution on sigma profile change with the angled hole. Two different methods are used for calculation of the stress-strain rates. These methods are analytical method and numerical method that is Finite Element Analysis (*FEA*). *ANSYS* software is used for *FEA*. After gaining the results form *ANSYS*, a comparison of analytical and numerical method is carried out. Statistical analysis shows the accuracy of *FEA*. It is possible to obtain a great number of graphs with the *FEA* solutions and get better stress-strain conditions for sigma profile under tensile and compressive loading.

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