TENSILE TEST SPECIMEN FOR DIFFERENT TEST SPECIMEN GEOMETRIES

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Abstract: *This study was aimed to analyze and compare the strength of tensile test specimens with geometrical alterations. In this study, the Type I standard test specimen created according to the ASTM D638-14 standard was used. Then, geometric alterations were made on this standard test specimen. All specimens were created by Autodesk Inventor modelling software and analyzed and simulated with "Static Structural Method in CAE (Computer Aided Engineering) software" by defining Polylactic Acid (PLA) material. Results of geometrical alterations, five different kinds of test specimen were developed. Alterations were S-1, slotting in the middle of the test specimen; S-2, drilling two holes of same diameters to the test specimen at equal intervals; S-3, adding radii to the corners of the test specimen; S-4, enhancing the thickness of the test specimen and S-5, adding two cam slots to the test specimen at equal intervals, respectively. As a result of each theoretical specimen's data from simulations, the tensile strengths of the specimens were compared and their maximum deformations.*

Key words: *ASTM D638-14, Maximum deformation, Polylactic Acid (PLA), Tensile test simulation, Tensile test specimen.*

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1. Introduction

The purpose of applying tensile testing to materials is to determine the properties of materials commonly used in many different areas. The mechanical properties of the material are obtained as a result of the tensile test. For instance, the properties of the material such as yield strength, tensile strength and rupture strength are obtained. All these results are in a structure defined by national and international standards. With the developing technology, simulations of the tensile test are performed with Computer-Aided Design (CAD) and analysis programs.

In recent years, it was observed that three-dimensional (3D) printing materials were used in many sectoral applications such as prototype manufacturing, industry and automotive. As 3D printing materials have low cost, fast and easy manufacturing features, their use in this field is becoming more and more common. Due to the superior advantages of three-dimensional printing materials, the ability to easily penetrate new application areas and existing application areas play an important role in the future of 3D printing materials.

2. Literature Review

Various alterations have been made geometrically, structurally and productively in standard tensile specimens produced from various materials used in the additive manufacturing (AM), and as a result of these alterations, many national and international studies have been conducted to examine the tensile strength and maximum deformation of the specimens.

The impact of the infill pattern on structural strength was demonstrated for 3D printed tensile tests specimen using PLA material via AM. Various tensile test specimens in linear, hexagonal and diamond types of infill patterns with a 50 percent infill rate were manufactured and compared the tensile strengths and maximum deformations of these specimens by analysing them. It was classified the structural strength of patterns from high to low as Hexagonal > Linear > Diamond (Sucuoglu et al., 2018).

ASTM D638 Type IV specimens were manufactured with the AM using PLA and performed experimental and theoretical tensile tests and then compared the results, respectively. As a result of the tests, minimum equivalent stress and maximum equivalent stress were respectively observed as 1317.03 N and 1428.67 N. Also, the maximum deformation was observed at 1428.67 N (Kumar & Narayan, 2018).

The effect of structure orientation, layer thickness and feed rate on the strength of specimens were investigated with a low-cost three-dimensional printer manufactured with PLA. As a result of these examinations, it was observed that the ductility decreased as the layer thickness and feed rate increased. Also, it was proved that as the layer thickness increases, the mechanical properties increase and as the feed rate for the vertical direction increases, the mechanical properties decrease (Chacon et al., 2017).

A new binder layer on pure PLA and carbon fiber spliced PLA specimens were designed and manufactured tensile test specimens and bending test specimens. Tensile and bending tests were carried out on these specimens. As a result of these tests, the mechanical properties and mass analysis of the specimens were investigated experimentally. With the experimental analysis, it was concluded that the mass of the laminated specimen was lighter than the carbon fiber (CF)/PLA, the tensile and mechanical properties were higher than that of the pure PLA specimen (Li et al., 2018).

Twenty specimens in total were manufactured with AM using PLA material. Four different filling patterns were used to evaluate the properties of these manufactured specimens. The open-source 3D printer was used to print five PLA specimens for each different infill pattern. To determine the tensile and bending strength, tensile and 3-point bending tests were performed on the printed specimens. The results obtained showed that the linear pattern has the highest tensile and bending strength. As the average tensile strength of Rectilinear was obtained 19.1 MPa and the average module flexibility of 10.51 GPa (Khan et al., 2018).

Tensile test specimens were produced with five different layer orientation with the AM using Acrylonitrile Butadiene Styrene (ABS) material. Also, tensile strength, modulus of rupture, and impact resistance of specimens were found. Orientations were made as 0/45/90 degrees, respectively. It is proved that the layers are left along the length of the specimens in the 0° direction, showing superior strength and impact resistance compared to all other orientations. It was claimed that anisotropic properties were probably due to poor interlayer bonds and interlayer porosity (Es-said et al., 2000).

It was aimed to focus on the mechanical properties of specimens manufactured with the AM using PLA material under different thermal conditions. It was claimed that anisotropic properties were probably due to poor interlayer bonds and interlayer porosity. Specimens were tested under static load in the range of 20 degrees to 60 degrees, considering the different filling directions. In line with the experimental results, it made it possible to understand the effect of control factors on the mechanical properties of specimens produced using the AM. It was observed that the hardness in PLA layers decreased from 30 to 16 per cent by increasing the temperature from 40 degrees to 50 degrees before and after extrusion with the 3D printer. Also, the results of the tensile tests carried out on the specimens at different temperatures were reported and discussed (Grasso et al., 2018).

Specimens were manufactured using PLA material with AM based on ASTM standards and performed a series of monotonic tensile tests on these specimens. Experiments have tested a total of 13 "dog bone" specimens in which the fill percentage, fill geometry, load orientation and stretching rate of the material have changed. The tensile test and found that the specific final tensile strength (MPa/g) was decreased as the fill percentage decreased, and the hexagonal pattern fill geometry was stronger and stiffer than linear fill (Daniel & Chris 2018).

To optimize the material properties in the simulation to match the equivalent strain size experiments, work was carried out. It was conducted to examine the experimental Young’s Modulus of manufactured tensile test specimens.

Heterogeneous structure and size greatly were influenced by the strength of the specimens. The tensile mechanical properties for printed PLA material were significantly changed after being produced. In this study, the young modulus of PLA material was shown to increase by 77 per cent compared to the properties of the previously produced tensile test specimen (6200 MPa to 3500 MPa, respectively). Furthermore, the Poisson’s ratio of the tensile test specimen was decreased by 44% after printed when compared to pure PLA properties (0.2 to 0.36, respectively) (Cardenas & Caldin, 2015).

Observation of the relationship between two printing parameters, infill pattern and infill density were aimed to on the tensile test specimens. Three infill densities, 25%, 50%, and 75%, and three infill patterns, grid, tri-hexagon, and concentric, were chosen. The obtained results have appeared that increasing the infill density enhances the tensile properties for the three infill patterns. The concentric filling pattern showed the highest tensile properties compared to the other two, while the grid and tri-hexagonal pattern were examined to be of similar levels (Rismalia et al., 2019).

3. Material and Method

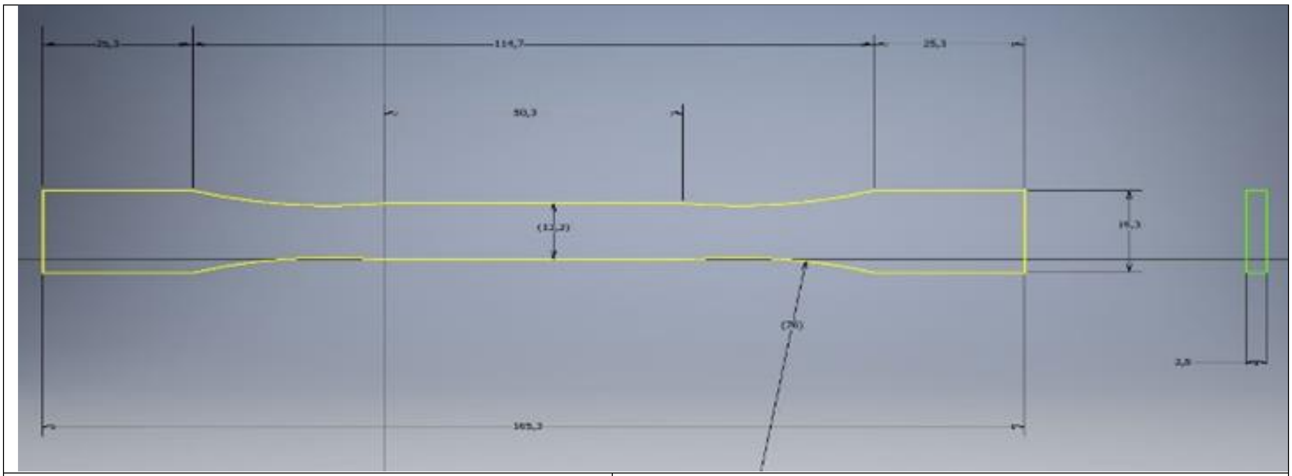
Standard and new tensile test specimen geometries were obtained by making the various alterations with CAD software. The strength properties of these geometries were analysed by Static Structural Method in CAE software.

3.1 Polylactic Acid (PLA)

Polylactic acid (PLA) is a thermoplastic polyester which can be produced from renewable resources. It is considered a substitute for iron alloy material in prototype manufacturing as its cost is highly low and possesses superior process-ability. PLA is likely to reduce the impact on the environment due to the production and use of petrochemical polymers (Fehri et al., 2010).

PLA has a larger strength and lower ductility than the traditional Acrylonitrile Butadiene Styrene (ABS) material. PLA is a sustainable thermoplastic alternative addressing the problem of added waste from end-users manufacturing components at home and has similar characteristics as ABS. PLA parts manufactured with AM have also been of high interest to the medical field, due to its biocompatibility in applications such as tissue engineering and custom-made patient-specific implants (Jonathan et al. 2016).

PLA has a lower effect of warping due to its lower coefficient of thermal expansion increasing the adhesion of part to the printed surface and reduces cracking of the part while printing (Todd & Megan, 2014). Table 1 shows the material properties of PLA material with the specimen design according to ASTM D638-14 standard procedure.

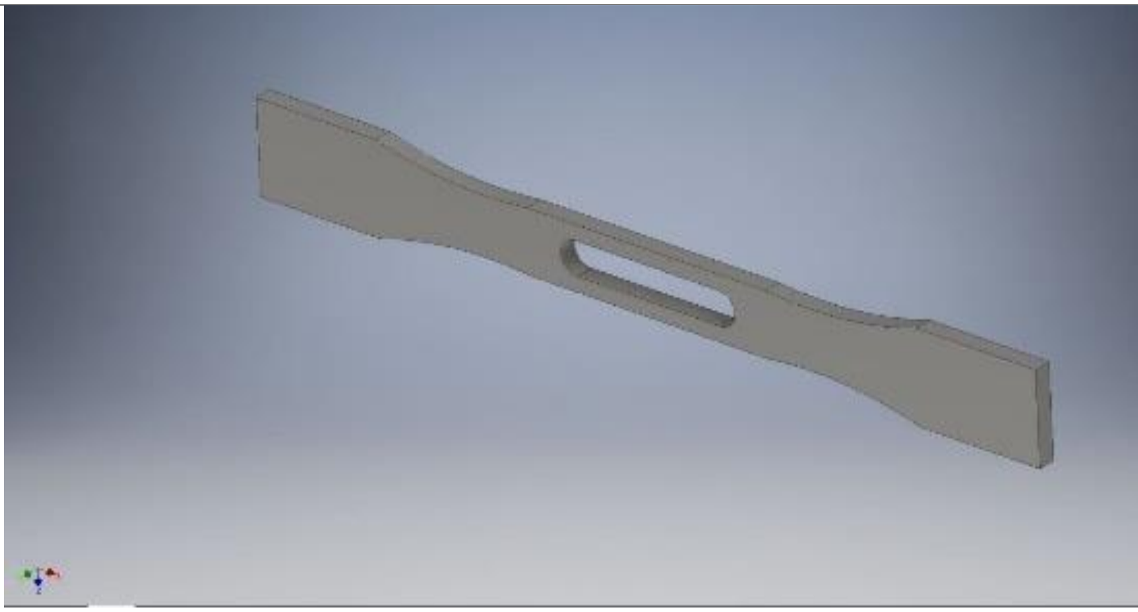


Characteristic	Amount (unit)
Solid density	1.25 (g/cm^3)
Tensile strength	59 (MPa)
Ultimate tensile strength	73 (MPa)
Young modulus	1.28 (GPa)
Poisson ration	-

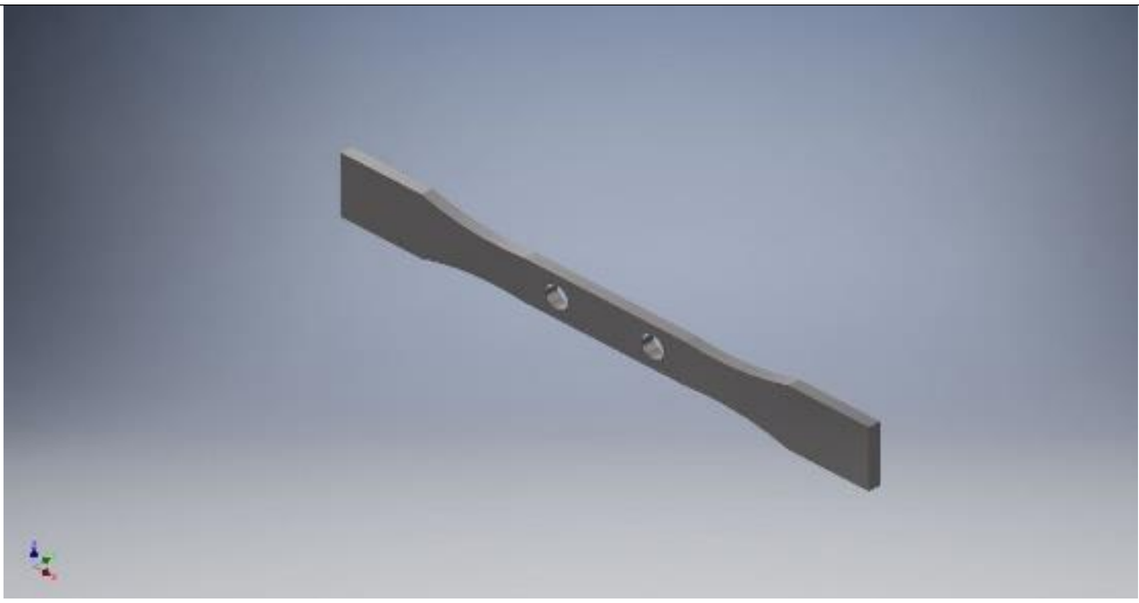
Tab. 1. Physical and mechanical properties of PLA material with the specimen design according to ASTM D638-14 standard procedure (Farah et al., 2016).

3.2 Geometrically Modified Specimens

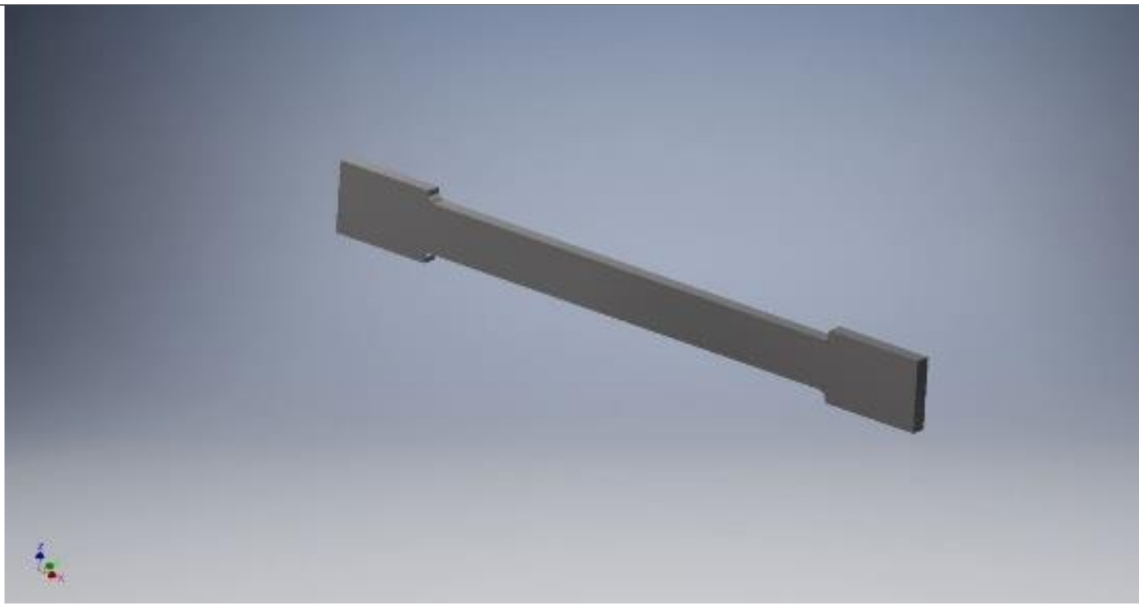
The alterations are modelled in 3D on CAD software. The dimensions of the geometries created for better comparison are given at similar values. Also, all specimen's thickness is 3.5 mm. Alterations were, (S-1) putting slot to the middle of the test specimen, (S-2) drilling two holes of same diameters to the test specimen at equal intervals, (S-3) adding radii to the corners of the test specimen, (S-4) enhancing the thickness of the test specimen and (S-5) adding two cam slot to the test specimen at equal intervals, respectively (Fig.1).



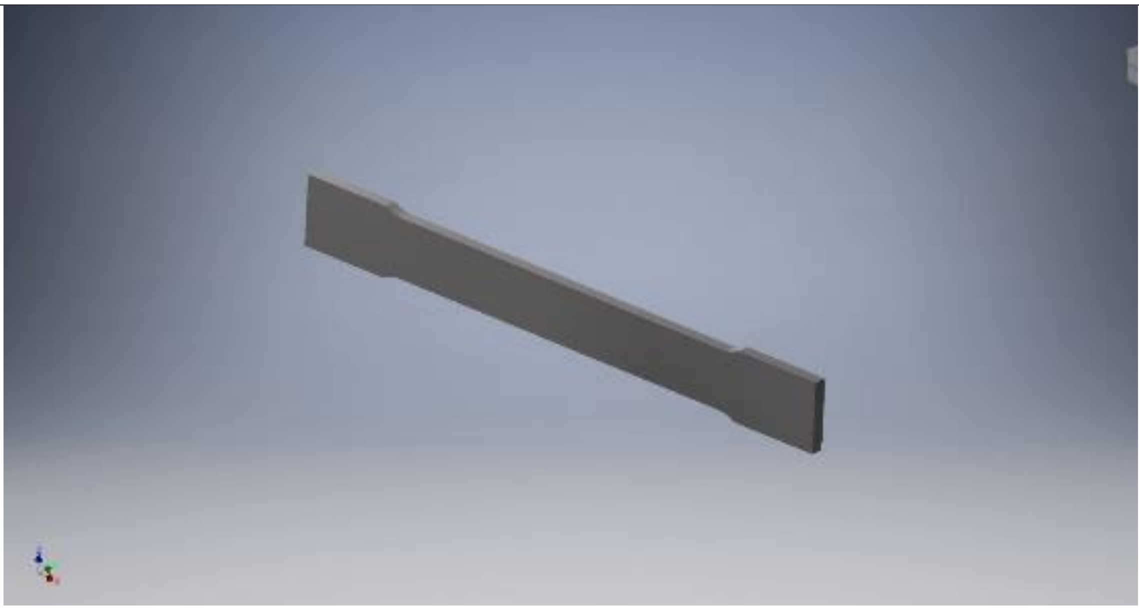
(a)



(b)



(c)



(d)

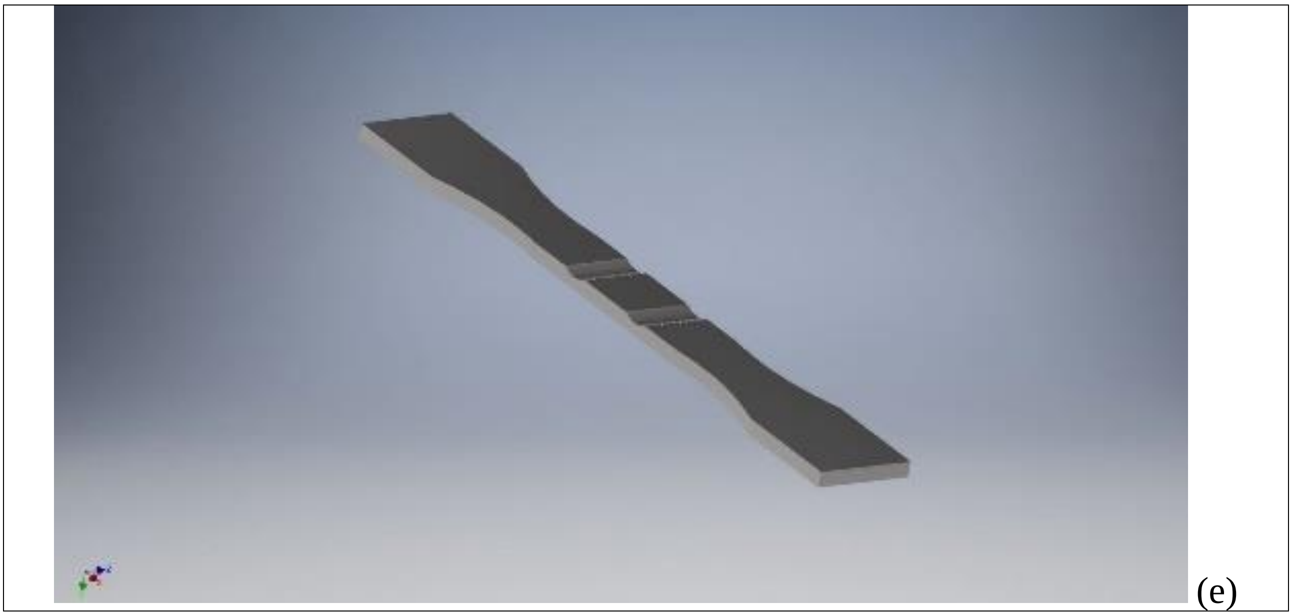
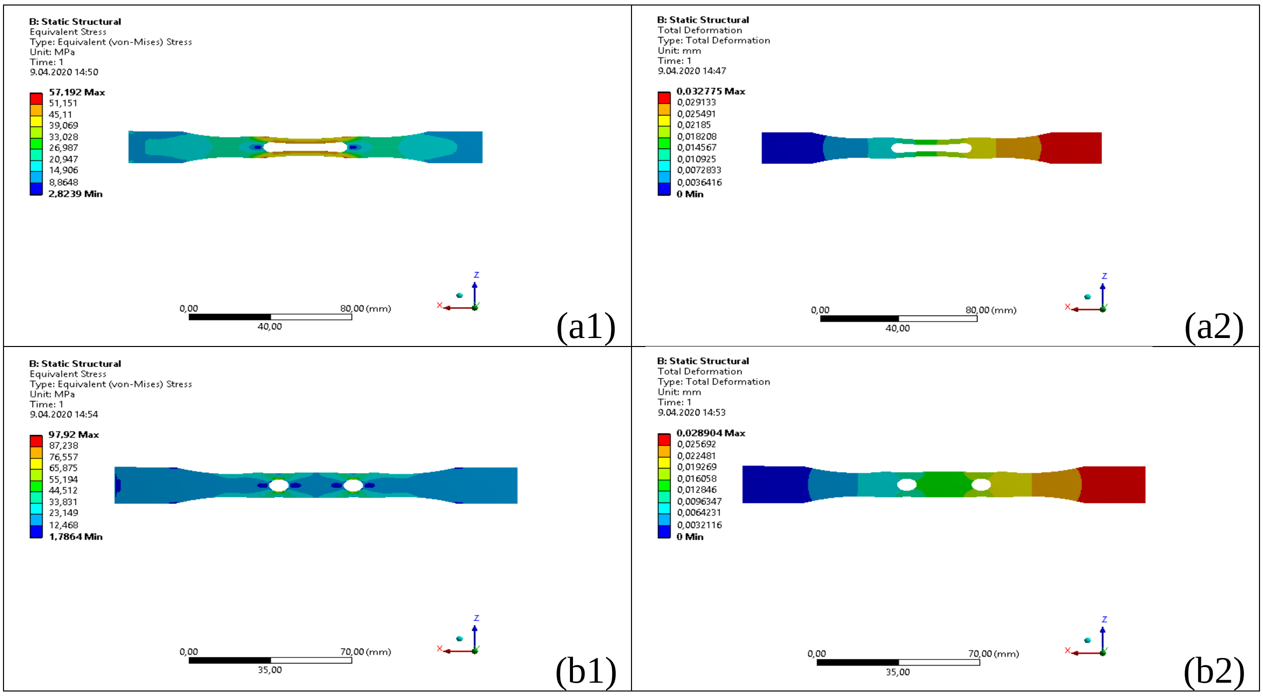


Fig. 1. Putting slot to the middle of the test specimen (S-1) (a), drilling two holes of same diameters to the test specimen at equal intervals (S-2) (b), adding radii to the corners of the test specimen (S-3) (c), enhancing the thickness of the test specimen (S-4) (d), adding two cam slot to the test specimen at equal intervals (S-5) (e) in 3D.

4. Results and Discussion

The calculated strengths and deformations of tensile test specimens were examined and compared. The analysis results obtained are as follows (Fig.2).



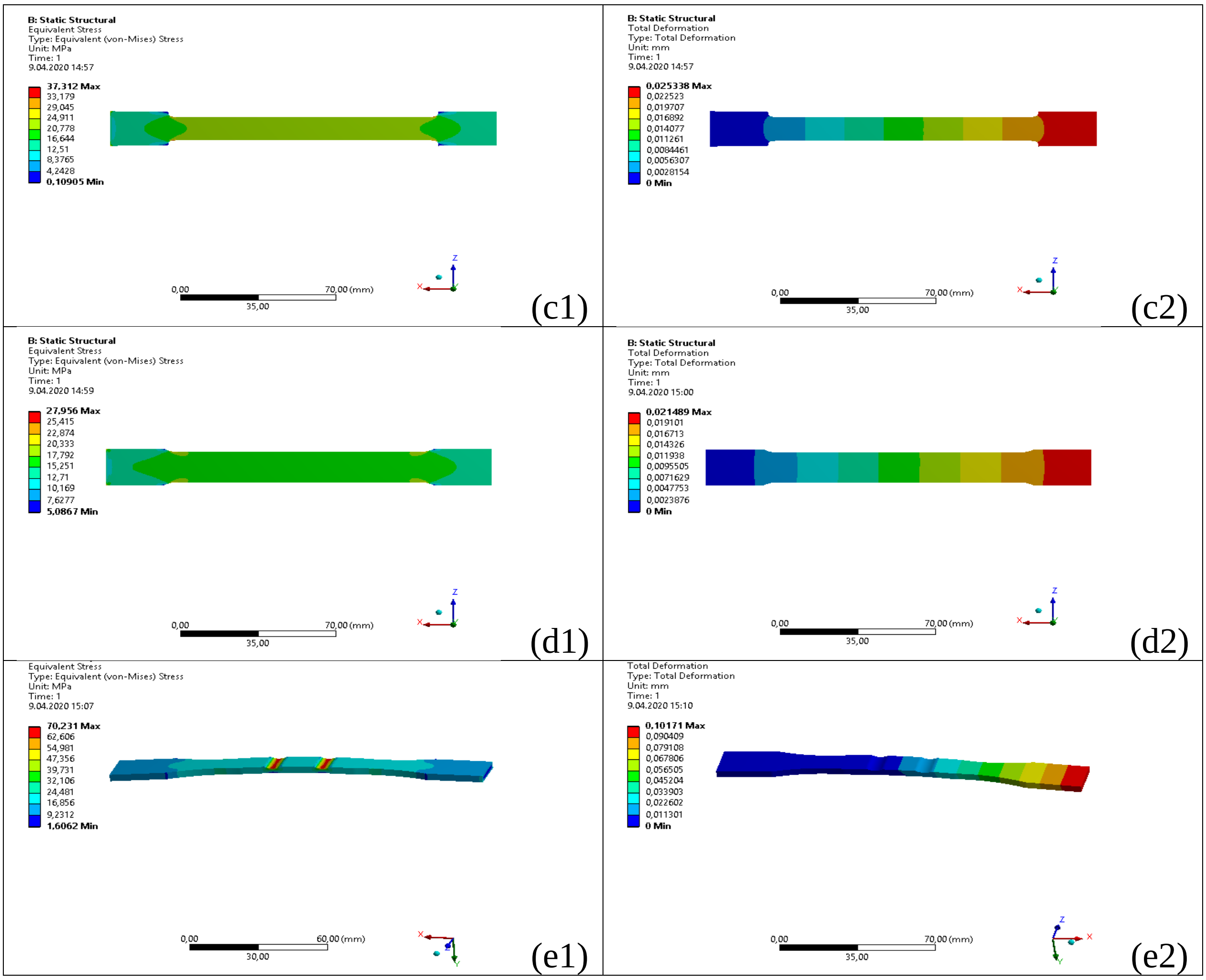


Fig. 2. Equivalent Stress distribution of (S-1) (a1), (S-2) (b1), (S-3) (c1), (S-4) (d1), (S-5) (e1); total deformation of (S-1) (a2), (S-2) (b2), (S-3) (c2), (S-4) (d2), (S-5) (e2).

The analysis results for S, S-1, S-2, S-3, S-4 and S-5 specimens are given in Tab. 2 for comparison.

Specimen	S	S - 1	S - 2	S - 3	S - 4	S - 5
Equivalent (von Mises) Stress σ MPa (N/mm^2)	27.943	57.192	97.92	37.312	27.956	70.231
Total Deformation (mm)	0.02486	0.03278	0.02890	0.02534	0.02149	0.10171

Tab. 2. Comparison of Specimens with different processes.

Tab. 2 shows that the equivalent stress and normal stress results were found to be compatible with each other. The equivalent stress and strain of the S-2 specimen were found to increase three and a half times compared to the S specimen. On the other hand, alterations on geometry increased the equivalent stress of the specimens in general. The greatest stress value was seen in the S-2 specimen with 97 MPa and then in the S-5 specimen with 70 MPa.

Subsequently, high stress was observed in S-1 with 58 MPa and S-3 with 37 MPa, and also the lowest stresses were observed S-4 with 27 MPa and S specimens with 27 MPa.

In general, alterations on geometry has increased the total maximum deformation of the specimens. The greatest deformation was seen in the S-5 specimen with 0.1 mm and then in the S-1 specimen with 0.032 mm. Subsequently, high deformation was observed in S-2 with 0.028 mm and S-3 with 0.025 mm, and also the lowest deformation was observed S-4 with 0.021 mm and S specimens with 0.024 mm.

5. Conclusion

In this study, the effects of geometric alterations on the mechanical properties of the tensile test specimen were obtained. The results showed that the changes made on the specimen were decreased the strength of the specimen. The reason for this depends on the density and geometrical alterations.

Specimens were named as S, standard specimen; S-1, slotting in the middle of the specimen; S-2, drilling two holes of same diameters to the test specimen at an equal interval; S-3, adding radii to the corners of the test specimen; S-4, enhancing the thickness of the test specimen; S-5, putting two cam slots to the test specimen at equal intervals.

The classification of the made geometrical alterations related to equivalent stress was S-2>S-5>S-1>S-3>S-4>S.

The classification of the made geometrical alterations related to total deformation was S-5>S-1>S-2>S-3>S>S-4.

In the future study, it is planned to verify and compare the data obtained from simulations done in the computational environment with the tensile test in experimentally.

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