SOI: 1.1/TAS DOI: 10.15863/TAS
International Scientific Journal
Theoretical & Applied Science

p-ISSN: 2308-4944 (print) **e-ISSN:** 2409-0085 (online)

Year: 2020 **Issue:** 08 **Volume:** 88

Published: 28.08.2020 **http://T-Science.org**

QR – Issue QR – Article

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THE DEPENDENCIES OF TENSION STRAIN FROM STRESS OF THE FLAT STEEL SPECIMEN

***Abstract**: The deformed state of the steel flat specimen after implementation of the tensile test is presented in the article. The dependencies of tension strain from stress were built. The conclusions on changing the some stress parameters of the flat specimen in the range from elastic strain to partial fracture of material were drawn.*

***Key words**: the specimen, strain, stress, tension, the dependencies, the tensor.*
***Language**: English*
Citation: Chemezov, D., Pavlukhina, I., Bakhmeteva, M., & Petrenko, A. (2020). The dependencies of tension strain from stress of the flat steel specimen. *ISJ Theoretical & Applied Science, 08 (88)*, 101-104.
Soi: http://s-o-i.org/1.1/TAS-08-88-22 ***Doi***: crossref https://dx.doi.org/10.15863/TAS.2020.08.88.22
***Scopus ASCC**: 2211.*

Introduction

The mechanical properties of most metals and alloys are determined on the basis of the performed tests and the experimental values are written in the reference materials. The tensile tests are performed until fracture of the special specimen made of plastic material. The tensile test procedure of the round and flat specimens is provided in the official documents [1-5]. The influence of strain intensity of the specimens on resulting internal stress in material under the action of the external variable load was considered by the authors in the works [6-9]. In particular, the rational strain rates of the metal specimens, the methods for eliminating errors of the calculation of the stress-strain state of material were determined. The analytical dependencies of equivalent elastic strain, maximum shear elastic strain, equivalent stress and the temperature of material from the elongation of the round specimen and the applied load were obtained in the work [10]. Let us consider the tension process from elastic strains to material fracture on the example of changing the calculated values of the elastic volume ratio, the von Mises stress, the elastic strain energy density, the first invariant of the elastic strain tensor, the second invariant of the deviatoric elastic strain tensor, the

Tresca stress, volumetric strain, and the Lode angle for the flat specimen.

Materials and methods

The computer calculation of the tension process of the flat specimen was performed using the *Comsol Multiphysics* (*the Structural Mechanics Module*) software.

The two-dimensional model of the standard flat specimen had the properties of structural steel. Material tension was carried out when applying the variable load along the axis of the flat specimen. The condition of the calculation was given by the equation (1):

$$0 = \nabla \cdot FS + F_v \quad (1)$$

where $\nabla \cdot FS$ is divergence of the 1st Piola-Kirchhoff stress; F is the deformation gradient; S is the 2nd Piola-Kirchhoff stress; F_v is the body load.

The calculation was performed taking into account the stress state of material, at which there is zero stress in the normal direction, to the application axis of the tension force and to the direction of crack growth. The study method was accepted as stationary. The conditions for performing the tensile test were normal.

Results and discussion

The deformed state of the flat specimen model after the tensile test is presented in the Fig. 1. The initial state of the flat specimen model is shown by the black contour. The deformed state of the flat specimen model is shown by the color surface. The blue color on the model indicates minimum strain of the specimen, and the red color indicates maximum strain.

Figure 1 – The deformed state of the flat specimen model.

The flat specimen is elongated by 4.7% of the initial length at the moment of fracture. Fracture occurs at the distance between the shoulders of the flat specimen near the grip section. Similar strain of the specimen material, but of lower intensity, is observed in the opposite grip section. The more detailed description of intensity of the stress-strain state of the flat specimen during tension is presented in the Fig. 2.

The Poisson's ratio is 0.3 for steels. This indicates that material is subjected to plastic strain (tension, compression, torsion, etc.). The elastic volume ratio is the ratio of the deformed elastic volume of material to the undeformed volume. The displacement of the flat specimen during tension for the short distance is accompanied by increasing the deformed elastic volume of material by 1.8%. The ratio value decreases with increasing intensity of material strain. Elastic strains are equal to zero at the moment of cracks formation and subsequent partial fraction of material.

The uniaxial stress state of material was considered along the entire length of the deformed flat specimen. The von Mises stress increases before the specimen fracture zone and decreases after the fracture zone. Similar changes are observed when analyzing the elastic strain energy density of material of the flat specimen. In the zone of partial fracture of the flat specimen, the volume of material (located near the centerline) was determined, which is 17% less deformed than the other volumes.

The first invariant of the elastic strain tensor is responsible for relative changing the material volume of the flat specimen in the elasticity condition. The negative values of the force acting on the surface of the flat specimen indicate strain of tension. Changing the first invariant of the elastic strain tensor of the specimen material from pressure occurs by the linear function. Material undergoes tension strain at the positive values of the first invariant of the elastic strain tensor, and vice versa. Compression strain is observed at the certain length of the grip section of the flat specimen (from the side of the fracture zone).

Intensity of elastic strains of changing the shape of the flat specimen is determined by the second invariant of the deviatoric elastic strain tensor. The certain value of the Tresca stress characterizes transition to the plastic state at maximum shear stress. The values of these two parameters increase and decrease again by 75-80% at achievement of the maximum values. The nature of changing the parameters when increasing and decreasing the values is almost the same.

Volumetric strain is the ratio of the material volume reduction to the initial volume when all-round compression. The values of volumetric strain are equivalent to the values of the elastic volume ratio. The Lode angle defines the "type" of the stress state of material and is expressed by principal stresses or strains. The Lode angle is the smallest angle between the line of pure shear and the projection of the stress tensor on the deviatoric plane. The values range of the

Lode angle from 0 to 0.65 rad corresponds to tension of the flat specimen. The volume of the specimen material is more subjected to compression at the small values of the Lode angle (up to 0.3 rad).

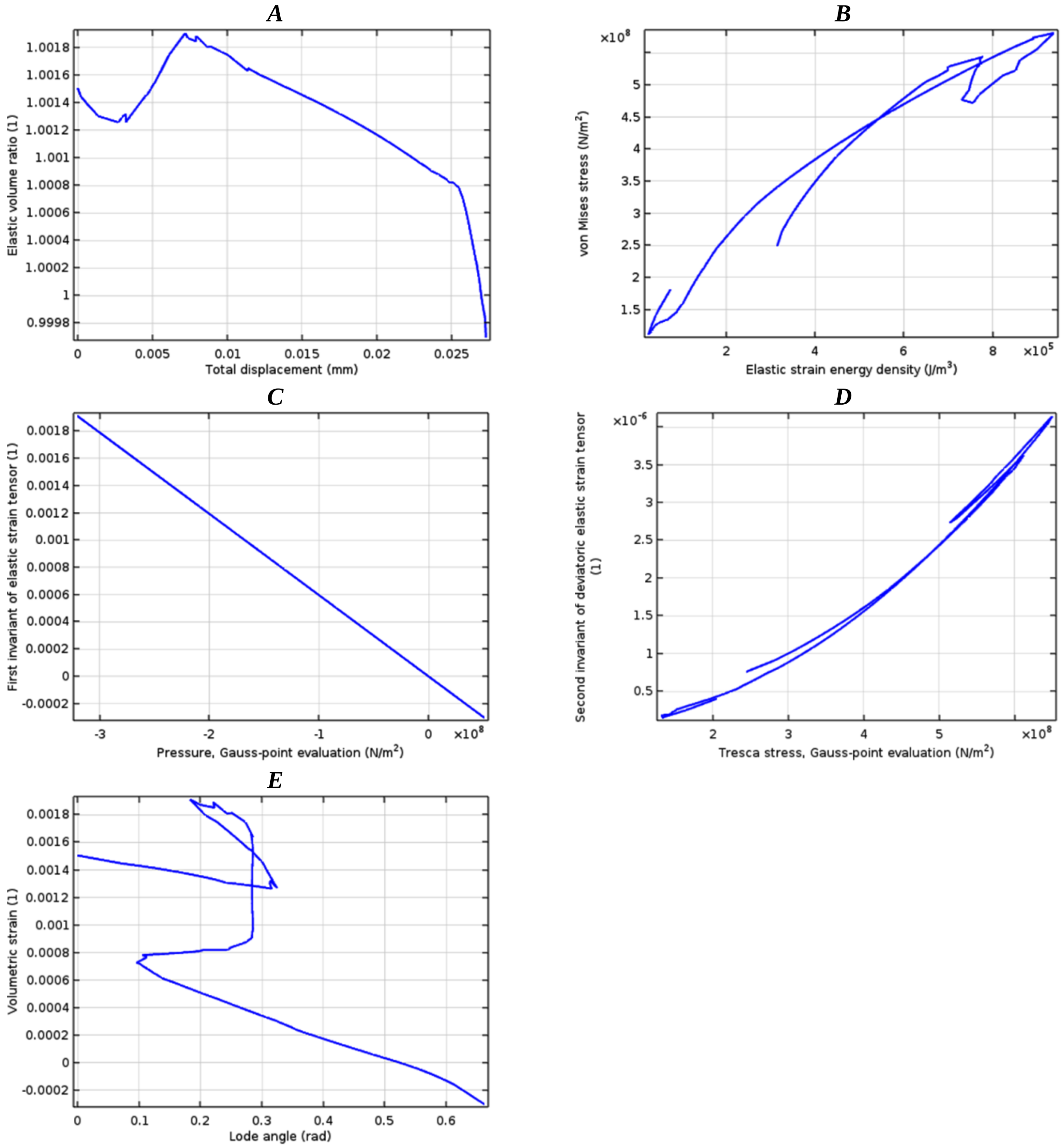

Figure 2 – The calculation results of the stress-strain state of the flat specimen during tension: *A* – the dependencies of the elastic volume ratio from the total displacement; *B* – the dependencies of the von Mises stress from the elastic strain energy density; *C* – the dependencies of the first invariant of the elastic strain tensor from pressure; *D* – the dependencies of the second invariant of the deviatoric elastic strain tensor from the Tresca stress; *E* – the dependencies of volumetric strain from the Lode angle.

Conclusion

Tension of the flat specimen leads to elastic and plastic strains of material. Elastic strains in the volume of material do not exceed 2%. Elastic strains occur more intensively, where the load was applied to the flat specimen. Relative changing the volume of material decreases when decreasing pressure on the specimen. Strains from stresses increases proportionally when tension of the flat specimen. The specimen is subjected to tension strain, since the values of the Lode angle are only positive.

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