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ASSESSMENT OF THE CRITICAL VALUES OF STRESS AND STRAIN OF MATERIAL ON THE BASIS OF ANALYSIS OF UNIAXIAL TENSILE TEST DATA

In the article, a method of determining the critical level of deformation of ferritic steel S355JR on the basis of measurements of grain elongation is proposed. Tests were carried out on steel in two microstructure states: ferrite-pearlite and bainite. Parameter values for the Ramberg–Osgood law and true stress–strain dependencies were set. The results obtained were compared with the results obtained according to other methods.

INTRODUCTION

The creating of the true stress–strain dependencies and knowledge of the critical level of stress and strain values of a material are needed during numerical analysis of the process of element destruction. Determination of the true dependencies of the stress–strain is carried out on the basis of processing data obtained during uniaxial tensile testing [1] up to the end of the balanced elongation of the specimen, and it is not difficult to make a diagram. The situation is complicated by the formation of the necking, because the strain is localized in a small section of the specimen. The main problem during the construction of the true diagram is to establish the current measurement base and the current diameter during the specimen loading. A description of the experimental data by power dependence and the determination of the parameters of the Ramberg–Osgood law is presented in the paper [3] and described in the thesis [4]. The authors of these papers proposed to approximate the dependence obtained for the data from the range of balanced elongation of the specimen to a further range of strains.

In this article, the results of tests carried out on uniaxial tensioned specimens in order to determine the critical levels of stress and strain are described. The assessment of the strain level was performed on the basis of changes in the grain sizes of ferrite.

EXPERIMENTAL TESTS

The tests were performed on standard S355JR steel [2] specimens subjected to laboratory heat treatment (HT). The first variant, HT1, depended on normalization, allowing the specimen to gain a typical ferrite-pearlitic microstructure (Fig. 1a). Processing in this case depended on soaking the material for a period of 20 minutes at 950°C and then cooling the furnace. As a result of the second variant (HT2), material with a bainite microstructure (Fig. 1b) was obtained. The processing depended on hardening of the material by annealing it at 950°C for 20 minutes and then cooling it in oil. Chemical composition of the tested steel is given in table 1. The standard characteristics of the material obtained during the tensile test are shown in the table 2 and graphs are shown in the figure 2.

C	Si	Mn	Cr	Ni	S	P
0.2	0.2- 0.5	1.5	max. 0.003	max. 0.003	max. 0.004	max. 0.004

Table. 1. *Chemical composition of S355JR steel*

Heat treatment	Re [MPa]	Rm [MPa]	A [%]	Z [%]
Normalization (HT1)	402.17	545.29	30	75.3
Hardening (HT2)	617.23	929.53	12	59.3

Table 2. *Tensile characteristics of the S355JR steel*

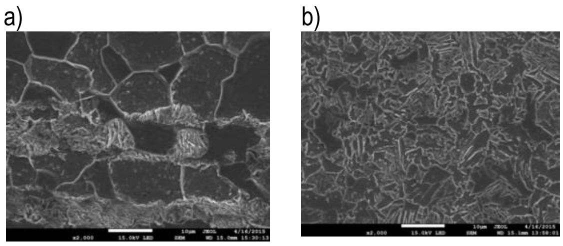


Fig. 1*. Microstructure of the S355JR steel after heat treatment:* a) ferritic-pearlitic, b) bainitic

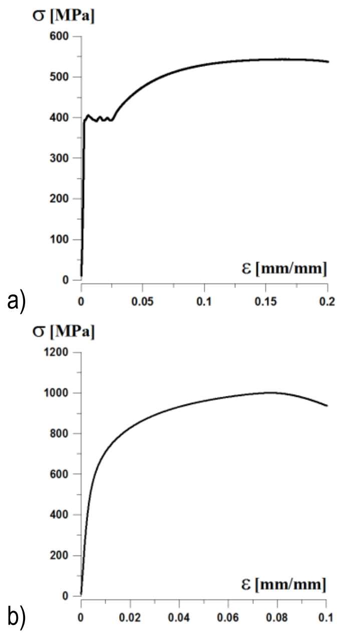


Fig. 2. *Stress-strain curves of the S355JR steel after heat treatment: a) HT1, b) HT2*

In order to estimate the amount of strain of the specimens that were subjected to the uniaxial tension test, cuts were made along the specimens and microsections were made. Hardness measurements were carried out on the microsections in the direction of the axis by the Vickers method, with loading 1N. Next, photographs of the microstructure were taken around the appropriate measurement imprints by scanning microscope (Fig. 3). Hardness in the expanded portion of the specimen increased significantly towards the location of the specimen fracture. In the specimen subjected to HT1, the hardness increases from 160 to 260 HV1, an increase equal to 100 HV1. In the specimen subjected to HT2, the hardness increases from 250 to 370 HV1, an increase equal to 120 HV1. Such significant changes in hardness indicate a significant increase in the strength of the material.

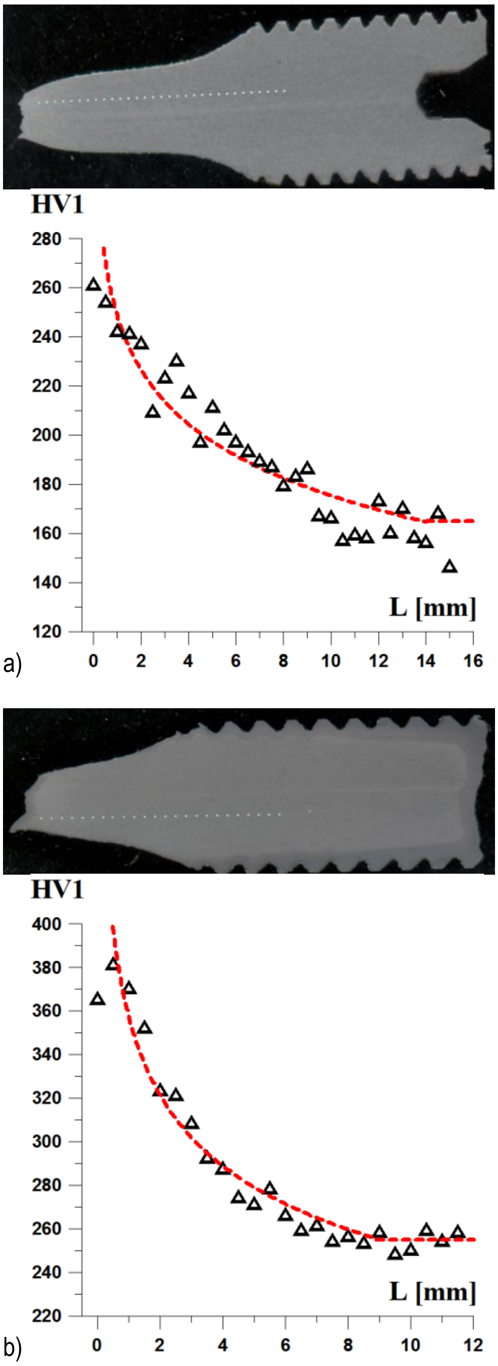


Fig. 3. The hardness distribution in specimens of the S355JR steel: a) after HT1, b) after HT2

In order to determine the level of strain of the steel in the specimens near the measuring points by scanning electron microscopy, pictures of the microstructure were taken. Selected pictures of undeformed material, the material in the equally elongated portion of the specimen, and the material in the neck are shown in figure 4 (specimen after HT1) and in figure 5 (specimen after HT2).

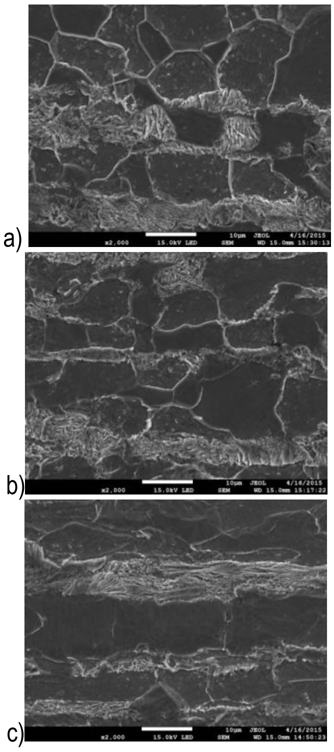


Fig. 4. Microstructure of the S355JR steel after HT1: a) undeformed material, b) material in the equally elongated portion of the specimen, c) material in the neck

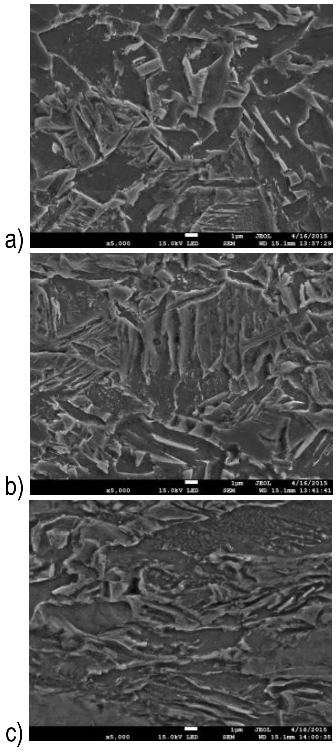
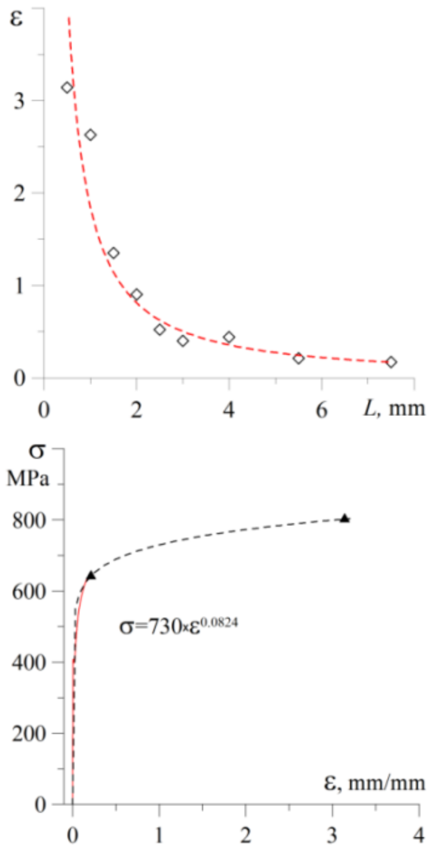


Fig. 5. Microstructure of the S355JR steel after HT2: a) undeformed material, b) material in the equally elongated portion of the specimen, c) material in the neck section

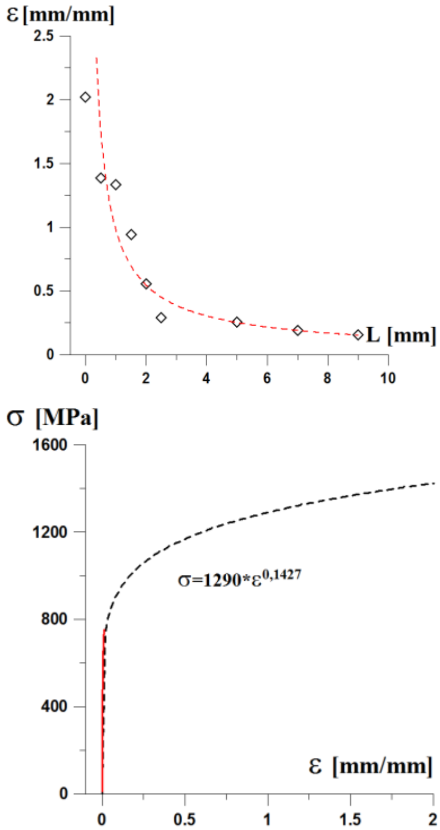
In the quality base of the measurement unit, grain sizes of the ferrite steel in undeformed condition were selected. The true strain was calculated based on the measurements of the ferrite grains in different parts of the specimen. The measurements were made on the pictures with a magnification of 1000x. The mean value of strain at any point was determined based on the measurements of 100–300 grains. In the specimen made of S355JR steel with ferritic-pearlitic(f-p) microstructure, at a distance of 6 mm from the edge of the specimen fracture, which corresponds to the equally expanded portion of the specimen, the value of strain is equal to 0.21 (Fig. 6a). In the neck, near to the fracture edge, the level of strain increases rapidly, and directly at the fracture edge it is equal to 3.14. Values of the loading force of the specimen at the moment of uniform tension and at the critical moment are known, which allows the appropriate values of the true tension to be determined. The plot of true stress-strain for the S355JR steel with f-p microstructure is shown in figure 6b (dashed line). In the initial stage, until the level of strain is equal to 0.21, the approximated dependence agrees well with the graph obtained from the data recorded during an attempt of uniaxial tension (solid line).



a) b)

Fig. 6. (a) The distribution of true strain, ▯11t, along tensile specimen, b) true stress-strain plot for the S355JR for ferritic- pearlitic microstructure

In the case of the specimen of S355JR steel with bainite microstructure, in the equally expanded portion of the specimen, the strain value is equal to 0.12 (Fig. 7a). In the neck, the level of strain increases as the fracture edge is approached and is equal to 2.02 directly at the fracture edge. The values of the actual stress were calculated using the same algorithm as in the case of the specimen with f-p microstrukture. The graph of true stress–strains for the S355JR steel with bainitic microstructure is shown in the figure 7b (dashed line).



a) b)

Fig. 7. (a) The distribution of true strain, ▯11t, along tensile specimen, b) true stress-strain plot for the S355JR for bainite microstructure

The parameters for the description of dependencies ▯11t=f(▯11t) according to the Ramberg–Osgood law were determined on the basis of the assessed levels of strain and stress. The values of power exponent n determined on the basis of grain measurement and according to other methods are summarized in table 3. The Ramberg-Osgood exponent, n, should be calculated by some methods. One of them based on logarithmic of Ramberg-Osgood law and follow introduced into equation the values of▯▯ and ▯ which correspond the Re and Rm. Next the Ramberg-Osgood parameters are calculated with system of two line equations. Another method is proposed in procedure used in laboratory program “Fracture” and was described in works [3-5].

The values of the power exponent n determined according to the proposed approach are slightly higher than those obtained according to the proposed method in the thesis [3–5]. Higher values of the power exponent n lead to lower strengthening of the material and accordingly to lower positions of the curves of $\sigma_{11t} = f(\varepsilon_{11t})$ (Fig. 9)

S355JR steel	Calculation based on the points of R_e and R_m	Calculation according to the procedure [3]	Calculation based on the grain measurement
Ferritic-pearlitic	8.25	9.51	12.14
Bainitic	5.67	5.92	7.01

Table 3. The values of Ramberg-Osgood power exponent

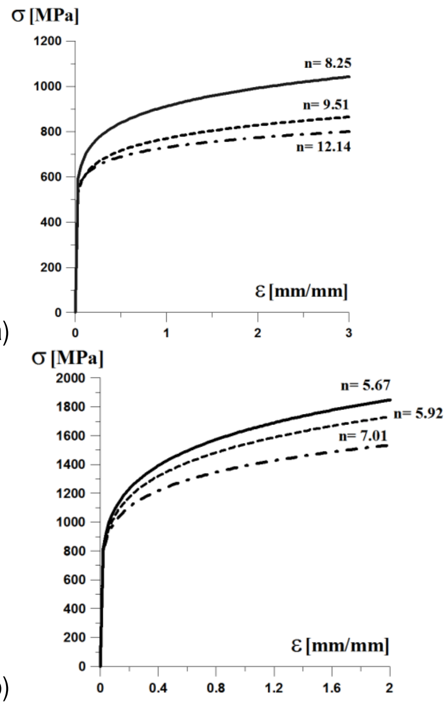


Fig. 9. *Comparison of the plots □11t =f(□11t) for n determined by various methods: a) S355JR for ferritic-pearlitic microstructure, b) S355JR for bainite microstructure*

SUMMARY

For the S355JR steel with ferritic-pearlitic microstructure a critical strain value was accepted equal to 3.14. This is the strain designated for grains in close proximity to the fracture edge of the specimen. In the ferritic-pearlitic microstructure of S355JR steel at this level of strain it was possible to observe a number of discontinuities in the form of micro-cracks and voids arranged in series that were formed along grain boundaries or along the non-metallic inclusions (Fig. 8a).

For the S355JR steel with bainitic microstructure, the critical strain value was set at 2.02. In the material located in close proximity to the fracture edge, the discontinuities and micro-cracks appear between the phases of bainite and ferrite or at the non-metallic inclusions (Fig. 8b).

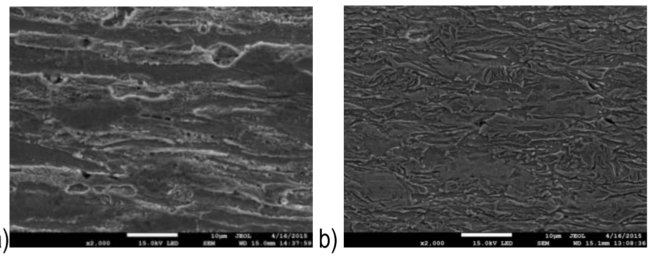
a)  b)

Fig. 8. *Discontinuities located in close proximity to the fracture edge: a) for ferritic-pearlitic microstructure, b) for bainitic microstructure*

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