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Study of the Formation of Lamellar Cracks

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In rolled sheets, non–metallic inclusions are distributed along the thickness of the sheet as narrow lines running parallel to the rolling direction. Such inclusions are the nuclei of lamellar cracks.
This work presents the application of the numerical method for study of lamellar cracking. Numerical models of samples with long artificial fissures set in the area of the sheet axis were studied along with other encountered inclusion distributions.
Changes in the stress state in the area of the inclusion were observed as the load increased. Stress concentration leads to the formation of lamellar cracks – the joining of voids in the direction parallel to the exterior surface of the sheet (so–called "terraces" are formed) and at angles (so-called "jogs" are formed).
The results of experimental tests were compared with the results of numerical calculations using the finite element method.

Keywords: Lamellar cracks, experimental tests, numerical method, finite element method.

1. Introduction

The numerical method is one of the known conventional methods of modeling experimental tests of the mechanics of a solid body.

The experimental tests obtained with a scanning electron microscope has proved to be highly convenient for studying stress distribution, especially for coplanar systems. There are also techniques for studying spatial systems. This method is practically the only one allowing for stress visualization: points of stress concentration can be observed particularly well. This method is also aesthetically pleasing, because the obtained images are a set of colored lines.

Determination of the stress field using the obtained with a scanning electron microscope method is laborious, because it requires measurement at every point of the field in which stress values are intended to be calculated. For this reason, many researchers do not use this method; some scientists also consider it to be outdated. However, the application of this method gives another perspective of the phenomena occurring in the sample and makes it possible to "view" stresses. As is generally the case, several independent research methods need to be used and the results obtained through different methods need to be compared. Above all, the results must be compared with reality – that is, with an experiment.

This work presents the application of the numerical method to the study of lamellar cracking.

In the case of adhesion between the base material and non–metallic inclusions, changes of the stress state are observed along the direction of tension between inclusions as well as in the vicinity of inclusions. Changes in stress distribution occur here, which may cause an increase in shear stress along the lines connecting the vertices of inclusions. According to hypotheses concerning strain analysis in an elastic–plastic state, this can have an effect on the formation of cracks. Non–metallic inclusions have a significantly lower strength and elasticity (Young's modulus) than (in this case) ferritic–pearlitic steel. Such inclusions may have the nature of voids and can become crack nuclei. Fig. 1 shows a typical ferritic–pearlitic steel structure with banding encountered after single–direction rolling. Non–metallic inclusions of manganese sulfides can be seen in the cross–section.

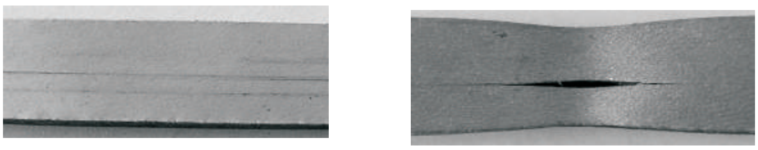

Figure 1 Metallographic specimen of a sheet with visible inclusions

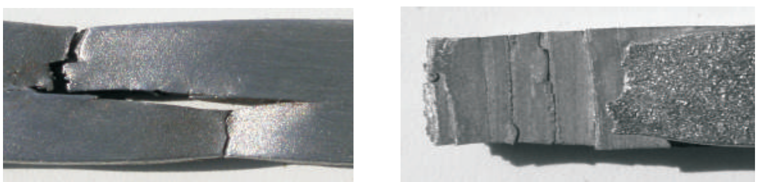

Figure 2 View of the sample just before tearing and after tearing of the samples

During static tensile testing of such samples, an increase in the thickness of the fissure with non–metallic inclusions and the appearance of two characteristic "necks" can be observed.

Non–metallic inclusions are the nuclei of the formation of lamellar cracks.

In crack mechanics, the basic case is a fissure running perpendicular to the direction of tension. In actual materials, however, fissures and cracks running parallel to the loading direction also exist.

A fissure running parallel to the direction of tension creates neither stress concentration nor high values for the stress intensity coefficient.

In a sample subjected to uniform tension with a fissure aligned at an angle of β to the direction of tension, the values of stress intensity coefficients are equal to [3]:

- for loading method I (tearing of the fissure vertex)

$$K_I = \sigma_{ext} \cdot \sqrt{\pi \cdot a} \cdot \sin^2 \beta \tag{1}$$

- for loading method II (coplanar shearing)

$$K_{II} = \sigma_{ext} \cdot \sqrt{\pi \cdot a} \cdot \sin \beta \cdot \cos \beta \tag{2}$$

where:

σ_{ext} – external tension stress value

a – half of the fissure length.

For a fissure parallel to the direction of tension, $\beta = 0$, and so $K_I = K_{II} = 0$.

These relationships are obvious for fissures and cracks with thicknesses approaching zero, but in cases where crack nuclei are caused by non–metallic inclusions, which have the nature of fissures of a specific thickness and shape after sheet rolling, then a mixed mode of cracking can occur at the ends of such fissures (caused by non–metallic inclusions).

2. Numerical determination of stress distribution

The distribution of stresses and displacements has been calculated using the finite element method (FEM) [2, 7]. Based on the images of numerical models, analogous numerical models were made and calculations were performed using the finite element method. Calculations were made using two-dimensional models in a coplanar stress state.

Finite element calculations were performed in order to verify the experimentally observed the metallographic distribution the strain state. The geometry and materials of models were chosen to correspond to the actual specimens used in the experiments. The numerical calculations were carried out using the finite element program ANSYS and by applying the substructure technique. A finite element mesh of the model (used for numerical simulation) are presented in Fig. 3.

This method, like every research method, should be used along with other methods, e.g. experimental and numerical. It is particularly effective to compare test results with results obtained using the finite element method; this is because, using this method, a numerical image of isochromatic lines can be made, enabling direct comparison of images.

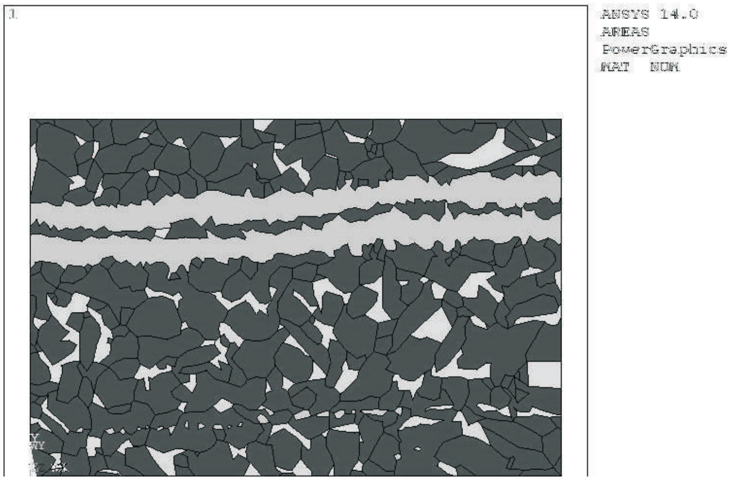

Figure 3 Finite element mesh of the model

In case of determining critical load causing cracking of material with finite element method (*element birth and death*) will be applied. This method consists in it, that when in the top of the crack rate of intensity factor is achieving the critical value i.e. what $K_I = K_{IC}$ hop then is betting, that elements in tip of crack are disappearing, the crack is expanding, the cycle of calculations is staying repeated and then again a coefficient of intensity factor which the value is reaching critical value i.e.

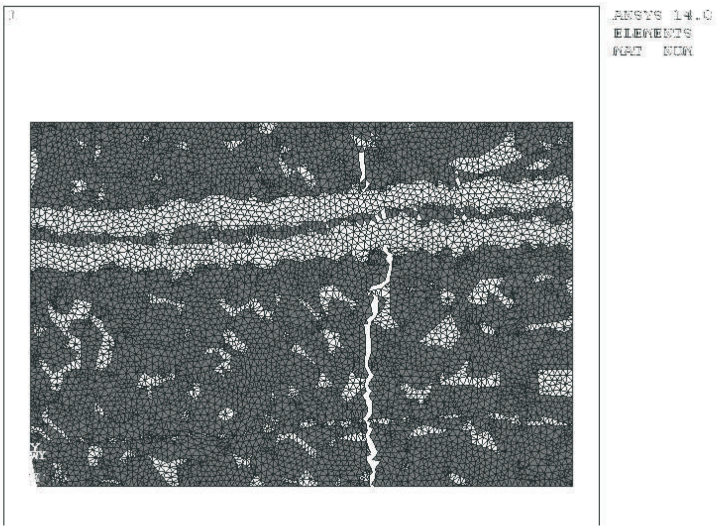

Figure 4 Finite element mesh of the model

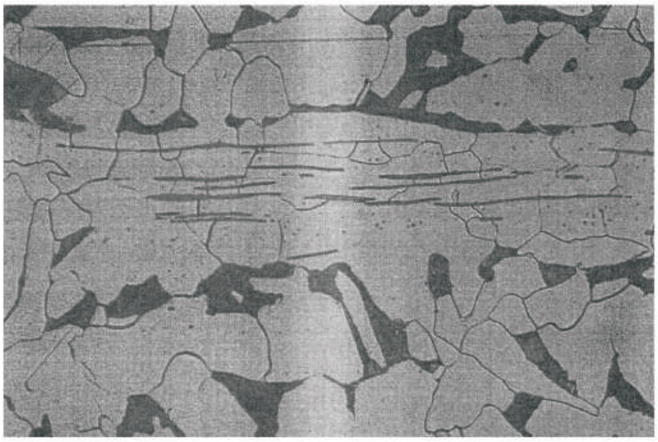

Figure 5 Metallographic specimen photographs obtained with a scanning electron microscope

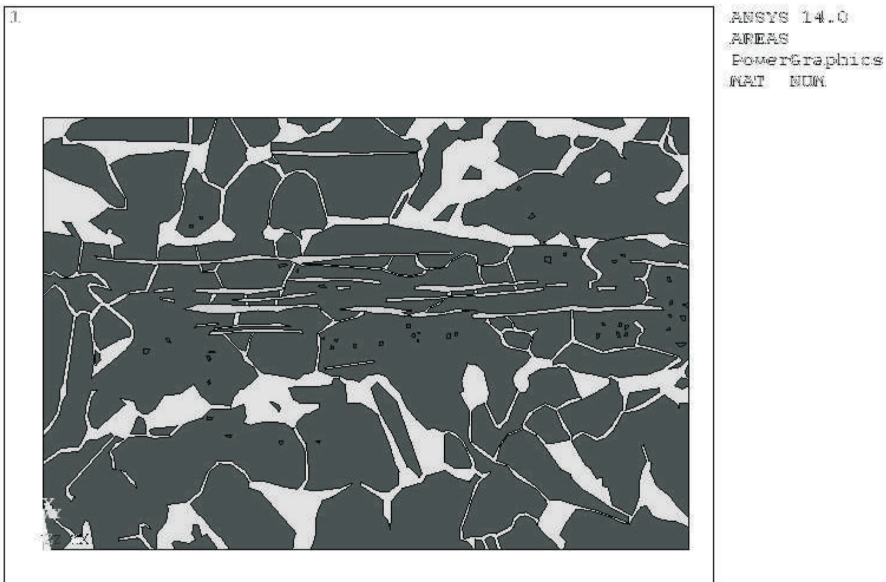

Figure 6 Finite element mesh of the model

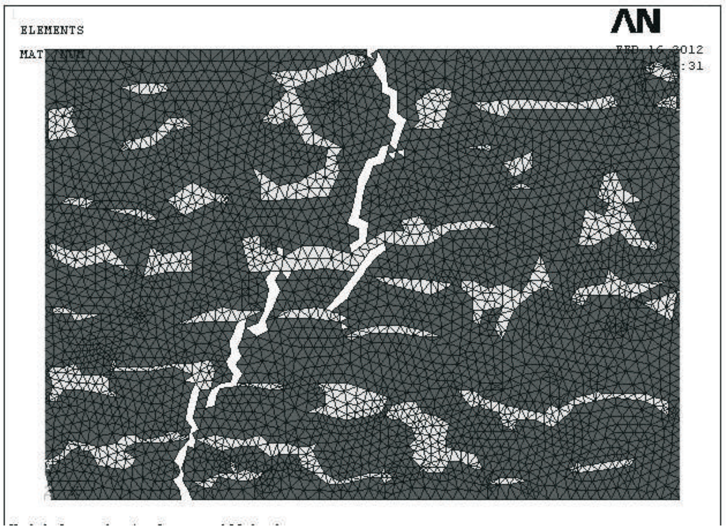

Figure 7 Distribution of reduced stresses according to Huber's hypothesis in the model studied using the metallographic method obtained by means of the finite element method

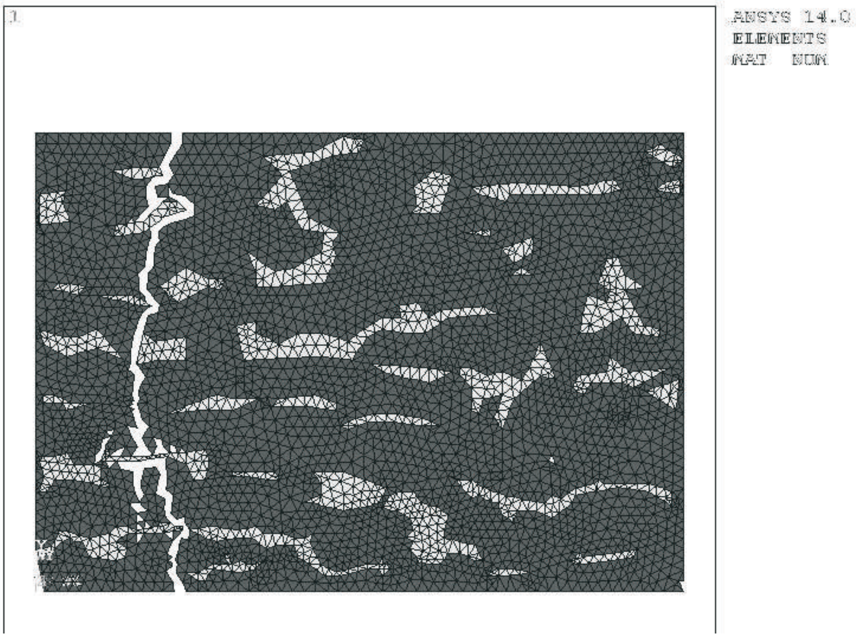

Figure 8 Distribution of reduced stresses according to the maximum shear stress hypothesis in the model studied using the numerical method obtained by means of the finite element method

3. Results of numerical calculations of the model with fissures simulating lamellar cracks

Comparative calculations using the finite element method were conducted for the same geometrical parameters and the same mechanical properties as the studied models.

Calculations were made for the same loads as in metallographic studies, the same material data (that is, material properties), and the same load characteristics.

Comparative calculations using the finite element method were conducted for the same geometrical parameters and the same mechanical properties as for the studied models.

Stress and strain calculations were conducted for the sample dimensions, material data (that is, material properties), and load characteristics accepted for calculations; the destructive load was determined on the basis of tests.

4. Conclusions

The numerical c method, as a modeling method for research, is very well suited to analysis of the formation and propagation of lamellar cracks.

This method makes it possible to determine the stress state not only at a specific point, but also to show the entire stress field. It makes it possible to quickly determine points of stress concentration, and thus potential places for formation and propagation of cracks.

The application of the numerical method is relatively fast and inexpensive. It is also easy to model inclusions, voids, and possible strengthening of the material (e.g. reinforcement).

This method, like every research method, should be used along with other methods, e.g. experimental and numerical.

The numerical method is very well good to validation of the distribution of reduced stresses according to the Huber's hypothesis and maximum shear stress hypothesis.

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