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Modeling Lamellar Cracks

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In this work, studies of models simulating lamellar cracks were conducted. These cracks are formed in rolled sheets with non-metallic inclusions. Studies of lamellar cracks began in the 1960s, but there is still no satisfactory theory explaining their formation.

In this work, the application of modeling of samples with non-metallic inclusions for the study of lamellar cracking has been presented. Studies were conducted using two research methods: the photoelastic method and the finite element method.

The possibility of crack formation was analyzed in models generated from images obtained from metallographic specimens.

Keywords: Non–metallic inclusions, photoelastic tests, finite element method, lamellar cracking

1. Method of modeling lamellar cracks

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. Fig. 1 presents a view of lamellar cracks in a sample after a tensile test was conducted. The characteristic forms of fracture of a lamellar crack are visible: "terraces" parallel to the sheet surface and "jogs" aligned at angles.

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)

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

- for loading method II (coplanar shearing)

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

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 $KI = KII = 0$.

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).

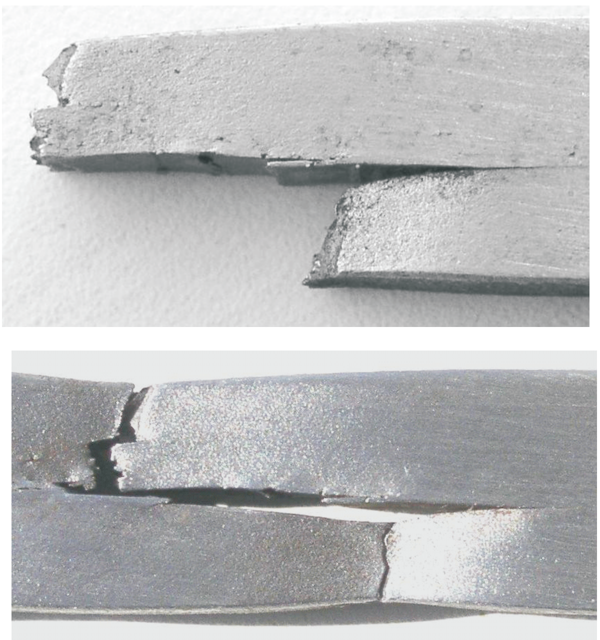

Figure 1 View of lamellar cracks after tearing of the sample

Non–metallic inclusions have significantly lower strength and elasticity (Young's modulus) than ferritic–pearlitic steel, in this case. Such inclusions may have the nature of voids and can become crack nuclei.

Samples were made with a fissure in the center of the sample and with fissures in a system similar to the actual arrangement of inclusions obtained on the basis of a metallographic specimen. Studies were conducted using two research methods: the photoelastic method and the finite element method.

The studied samples were placed in a polariscope and subjected to uniform tension or bending. The images of obtained isochromatic lines are shown on the figures. The results of these studies were compared with numerical calculations.

2. Models simulating lamellar cracks

Figure 2 shows an exemplary metallographic specimen of pearlitic–ferritic steel sheet with non–metallic inclusions in the form of manganese sulfides MnS and aluminates Al_2O_3. This is a typical image of a sheet in which lamellar cracks may form. Narrow sulfide bands can be seen in the middle of the photograph.

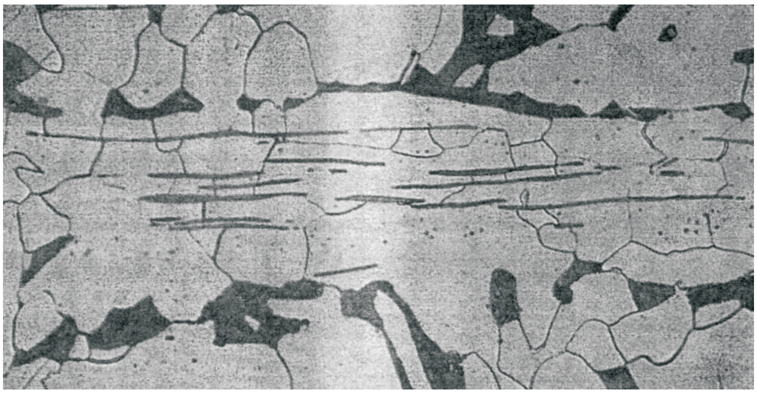

Figure 2 View of metallographic specimen of a sheet with inclusions

Based on typical metallographic specimens of steel sheets, two types of distributions of artificial fissures were accepted for study. These distributions are shown in Fig. 3. A central fissure and a symmetrical system of four inclusions (voids) were selected for study.

3. Photoelastic studies

Models were made from typical epoxide resin (EP 52). Their properties and the method of their determination were given in work [4].

The placement of artificial fissures in the model was similar to the arrangement of actual inclusions observed in views of metallographic specimens of sheets obtained from scrapped overhead crane girders.

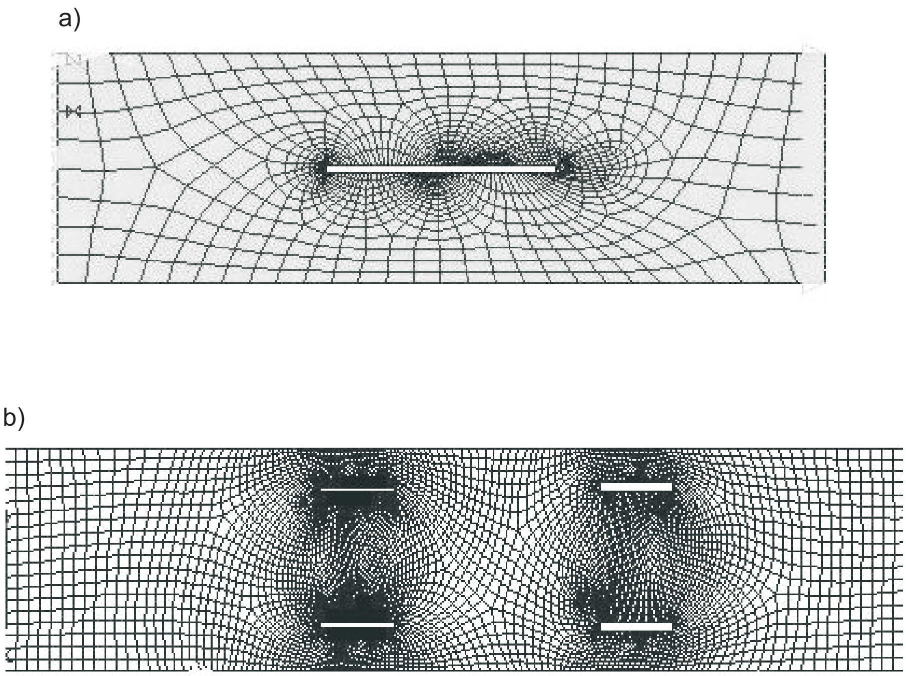

Figure 3 a) Model with one central fissure, b) Model with four fissures

The studied samples were placed in a polariscope and subjected to uniform tension or pure bending; isochromatic images were obtained. Studies were conducted using white light or monochromatic sodium light, with linear and circular polarization. Thus, total or partial isochromatic lines were obtained.

Photoelastic studies were conducted by increasing the load and analyzing the stress state after each such increase (based on isochromatic line distribution) so as to determine the influence of voids on changes in stress fields and their mutual interaction upon the areas surrounding voids or fissures.

Fig. 4 presents an image of a model with a central fissure during an axial tensile test. Monochromatic light was applied: yellow sodium light. Total isochromatic lines are visible (polarizer perpendicular to analyzer) in circularly polarized light. Fig. 5 presents an analogous image of partial isochromatic lines in circularly polarized white light (polarizer paralell to analyzer).

Small concentrations of stress are visible on both ends of the fissure subjected to tension.

The model with four fissures was subjected to a bending load as a beam bent at four points. Images of isochromatic lines in white light for a load of $P = 726$ N are presented in figure 6, and the same sample in sodium light for a load of $P = 1,050$ N can be seen in the next figure. Stress concentrations can be observed only at the ends of compressed fissures.

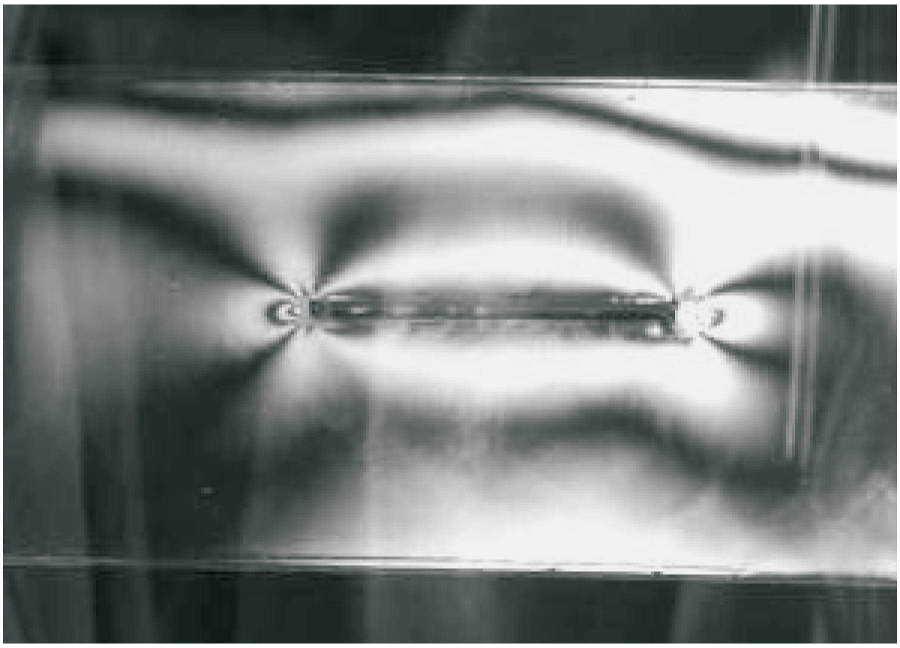

Figure 4 Photograph of isochromatic lines in sodium light

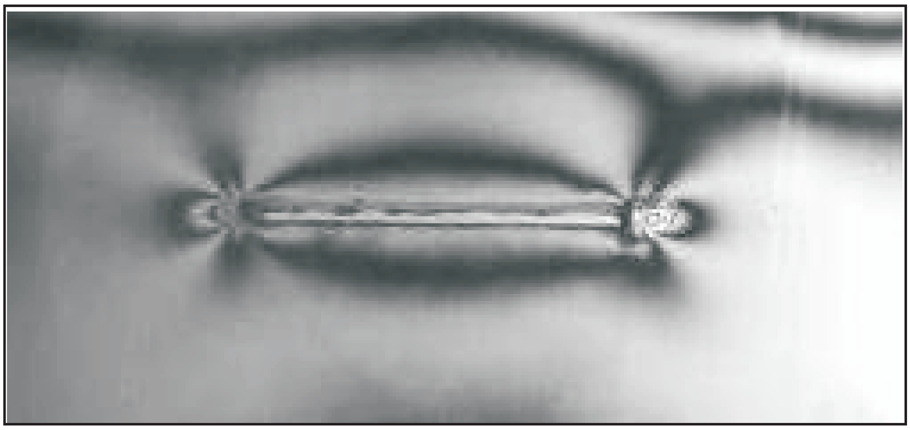

Figure 5 Photograph of isochromatic lines in white light

4. Calculation using the Finite Element Method

Based on the images of photoelastic 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.

The model with the central fissure (Fig. 8) was subjected to tension along the direction of the fissure. Fig. 8a shows the image of transverse strain, and 8b shows the distribution of stresses around the end of the fissure. Stress concentrations analogous to the image of isochromatic lines obtained using the photoelastic method are visible (Fig. 5).

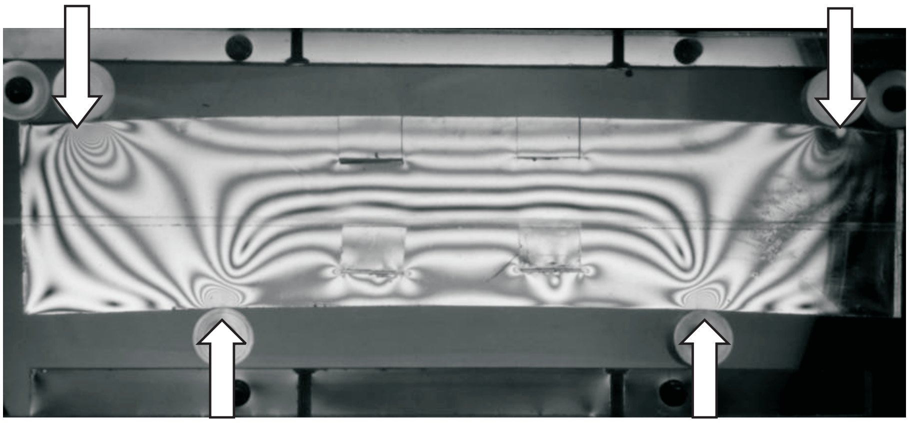

Figure 6 Model of a beam subjected to pure bending at a load of $P = 726$ N

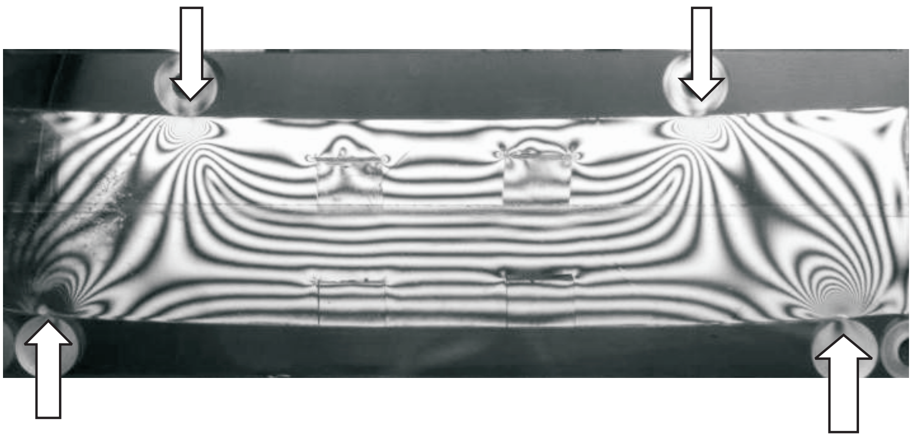

Figure 7 Model of a beam subjected to pure bending at a load of $P = 1,050$ N

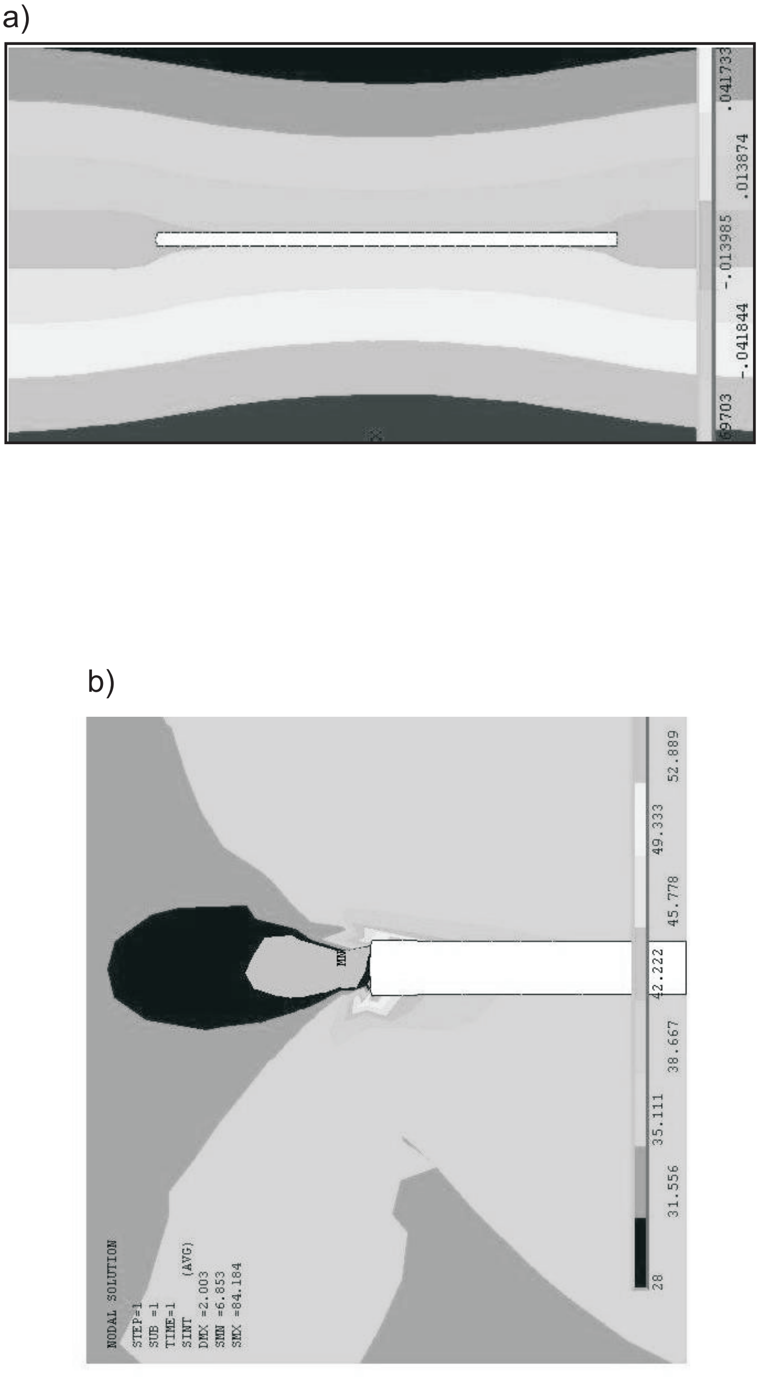

Figure 8 Results of numerical calculations: a)distribution of dislocations in the direction perpendicular to the fissure, b) intensity of stress around the vertex of the fissure

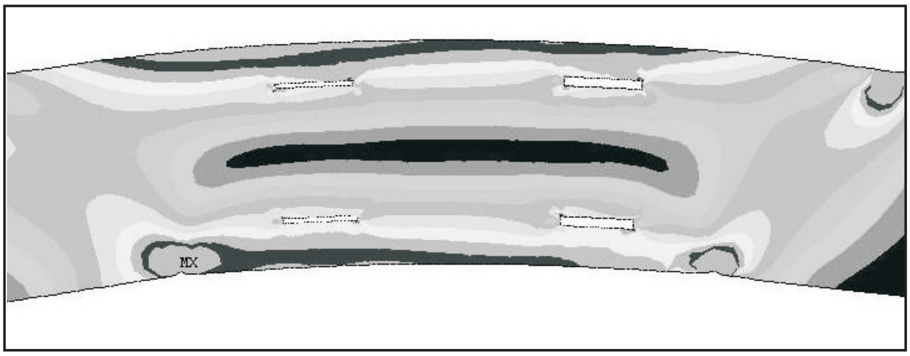

Figure 9 Model of a beam subjected to pure bending at a load of $P = 1,050$ N. Reduced stress distribution according to Huber's hypothesis

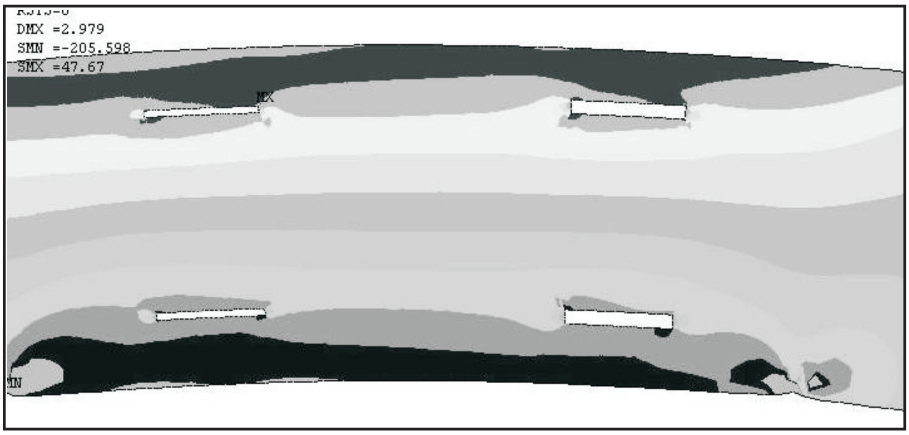

Figure 10 Model of a beam subjected to pure bending at a load of $P = 1,050$ N. Distribution of normal stresses σ_x

The models with four fissures were subjected to pure bending. Images of stress distributions are presented in Figs 9 and 10. Small stress concentrations are visible around the fissures only in the compressed area.

Fissures were modeled in the shape of narrow rectangles. Due to the various shapes of inclusions present in specimens, modeling of fissures in the shape of parallelograms was also performed. Results are presented in Fig. 11, and in this case, stress concentrations were significantly reduced.

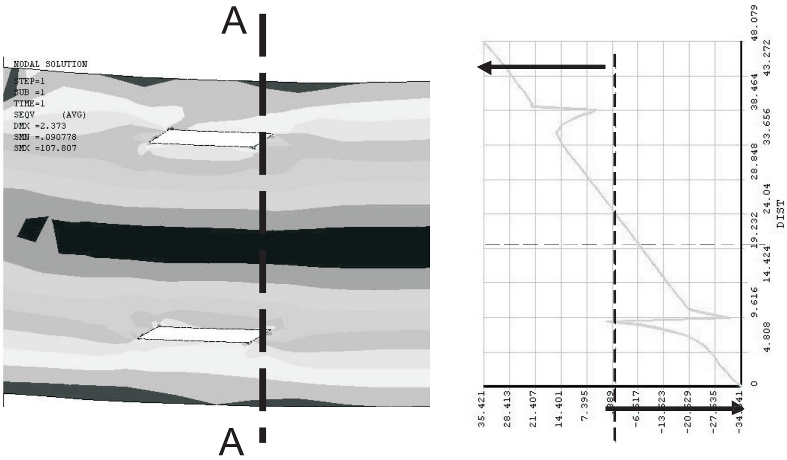

Figure 11 Model of bent beam – magnification of the fissure area: a) Normal stress σ_x distribution along cross–section A – A, b) Normal stress σx distribution along cross–section A – A

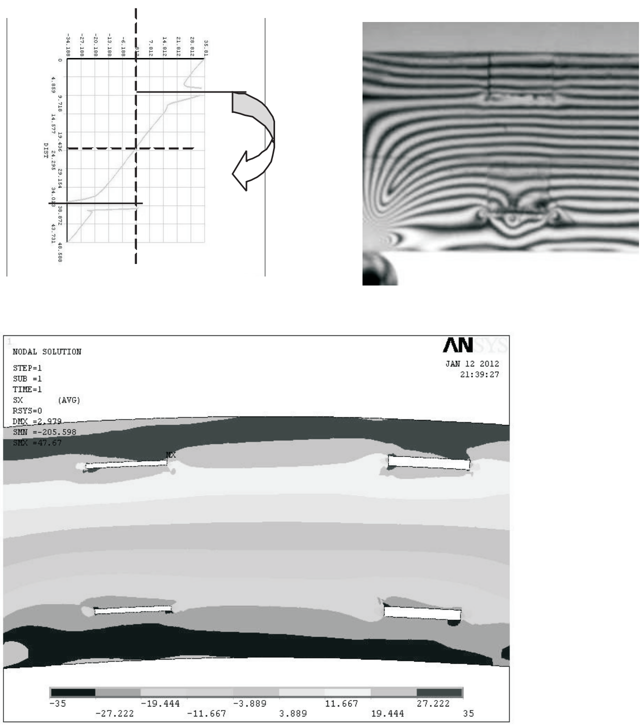

Figure 12 Results of experimental studies with the application of the photoelastic method

5. Conclusions

Two research methods were used for these studies: the photoelastic method and the finite element method. These two methods supplement each other very well. Results obtained using each of these methods can be easily compared. This is especially clear in the case of the image of isochromatic lines of the entire studied field, which is obtained from experimental studies using the photoelastic method. An analogous isochromatic line image is obtained using the numerical method, as a field of principal stress differences.

The photoelastic method can also be used to validate the numerical model made on the basis of the finite element method.

The potential for the joining of non–metallic inclusions, voids, and initial cracks was studied in the direction parallel to the exterior surface of the sheet (so–called "terraces" are formed) and at an angle (so–called "jogs" are formed); this leads to the formation of lamellar cracks.

In further works, other arrangements of inclusions and cracks, as well as their development under fatigue loading conditions, will be examined.

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References

[1] **Blum, A. and Niezgodziński, T.**: Pęknięcia lamelarne, *Wydawnictwo Instytutu Technologii Eksploatacji – Monografie*, Radom, **2007**.

[2] **Niezgodziński, T. and Kubiak, T.**: Über den Bruch von geschweißten Stahlblechen – Lamellenbrüche, VDI Berichte, 1757, 11–18, **2003**.

[3] **Neimitz, A.**: Mechanika Pękania, *PWN*, Warsaw, **1998**.

[4] **Jaroniek, M. and Niezgodziński, T.**: Application of photoelasticity for study of lamellar cracks, *Materials of the XXIV Symposium on Fatigue and Cracking Mechanics*, Bydgoszcz, **2012**.