NUMERICAL AND EXPERIMENTAL STUDY OF THE STRESS STATE AND THE POSSIBILITY OF CRACK INITIATION IN A FASTENING ELEMENT OF A HYDROAGGREGATE

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Abstract: In this paper, a combined numerical and experimental study on the stress state of a fixing element from the rotor of a hydroaggregate is presented. The photoelastic and chromoplastic methods, together with finite elements analyses were used. The study is focused on the areas with stress concentration, zones where cracks may develop. These cracks may propagate, leading to the failure of the structure. The moment of crack initiation was determined experimentally, on chromoplastic models loaded until failure. Conclusions are drawn regarding the numerical validation of the experimental models and the possible brittle failure due to crack propagation.

Keywords: chromoplasticity, photoelasticity, finite element, crack, brittle propagation

1. INTRODUCTION

In this paper, a combined numerical and experimental study of the stress state in a fastening element of the rotor pole from a hydroaggregate is presented. The research work is focused on the determination of the areas with strong stress concentration, zones where cracks may develop, affecting thus the integrity of the structure due to the possible crack propagation and failure of the part.

The stress state was experimentally obtained using a photoelastic analysis. A study of the development of the plastic zones was also undertaken, using a model made of a chromoplastic material. Chromoplasticity is an original experimental method, developed in Romania by Bălan et al. (1963). The chromoplastic material, a vynilic compound, is elastic and linear for stresses smaller than the yield limit, and perfectly plastic when plastic deformation appears. The chromoplastic phenomenon produces a change in the color of the material, which turns white when flow takes place under tensile stress, and black when flow is produced by a compressive stress.

The validation of the experimental results was obtained with numerical calculations, using the Finite element method. Linear elastic analyses were used to validate the photoelastic models and elastic-plastic calculations were done in order to establish the shape and size of the plastic zone and to compare it with the chromoplastic results.

Also, the possibility of crack initiation and growth in the areas with high stress concentration was studied. For this, the chromoplastic models were loaded till failure. Conclusions were drawn on the possibility of brittle failure in service, based on the spread of the plastic zone at the moment of appearance of the first cracks.

2. THE STUDIED STRUCTURE

In Fig. 1, the fastening element of the rotor pole from a hydroaggregate is presented. The part is made of steel with a thickness t = 7,5 mm, and having the following mechanical characteristics and elastic constants: yield limit σ_y = 448 MPa, ultimate tensile stress σ_0 = 638 MPa, Young's modulus E = $21\cdot10^4$ MPa and Poisson's ratio

$\nu = 0{,}3$. The geometry of the model is given by the dimensions b = 56 mm, b_1 = 102 mm, h_1 = 50,5 mm. In the experimental analyses, two values of the parameter h were used: 25 mm and 30 mm.

Both in the experimental determinations and in the numerical analyses, the structure was fixed on the upper side and a uniformly distributed load was applied as shown in Fig. 1. Two fillet radii were considered; R_1 = 1 mm and R_2 = 3 mm.

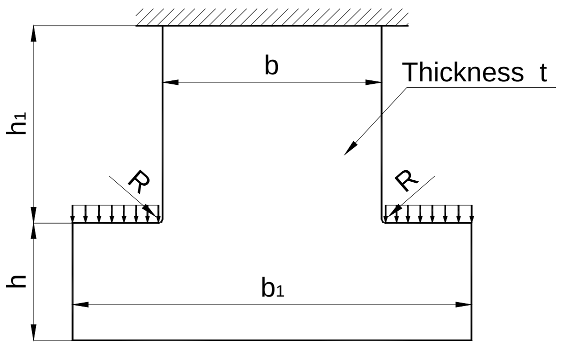

Fig. 1 The studied structure

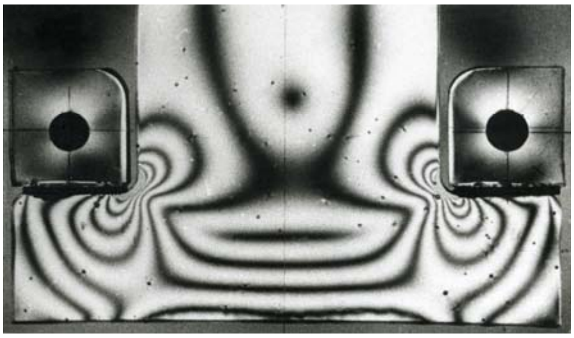

Fig. 2 The isochromatic fringes for R_2 = 3 mm

3. DETERMINATION OF THE STRESS CONCENTRATION COEFFICIENT USING PHOTOELASTIC MODELS

The stress state was investigated using plane models made of photoelastic material. An araldite plate with a thickness of 5.9 mm was used in order to manufacture two models, at a scale of 1:1 and with h = 25 mm. The first model had a fillet radius R_1 = 1 mm, while the other had a radius R_2 = 3 mm. The models were loaded in tension as shown in Fig. 1. A polariscope with monochromatic circular polarized light was used to emphasize the isochromatic fringes. Using the photos of the isochromatic field, the distribution of the principal stress σ_1 was drawn on the contour of the models in the fillet area, where the stress concentration is important and cracks may initiate. In Fig. 2, the isochromatic field obtained in the model with R_2 = 3 mm is shown, for a total load of 1162 N. The device through which the load was applied may be observed also in this figure.

Numerical analyses using the finite element method were undertaken in order to validate the photoelastic models. Owing to the symmetry, a plane model with triangular six-nodded isoparametric elements was developed for half of the structure. The model, which had 7158 nodes and 3469 elements, is shown in Fig. 3 together with the boundary conditions and applied load.

The distribution of the principal stress σ_1 in the fillet area is presented in Fig. 4. One can observe the stress concentration in the middle area of the fillet, with a maximum value on the contour of 41.166 MPa. The comparative plot (numerical versus experimental values) of the stress σ_1 is presented in Fig. 5. For convenience, the contour of the part was presented unfolded. The diagram was plotted as a function of the distance x from point O, also represented in Fig. 5. One can observe that different values were obtained with the two considered method in the area of the loaded shoulder, but a good concordance was obtained in the fillet area, where stress concentration is elevated.

The maximum value σ_{1max} of the principal stress was used in order to calculate the stress concentration coefficient, with the well-known relationship

$$\alpha_k = \frac{\sigma_{1\max}}{\sigma_n}, \tag{1}$$

where σ_n is the nominal traction stress, given by:

$$\sigma_n = \frac{P}{b \cdot t}, \tag{2}$$

P being the total applied load.

The values obtained for the stress concentration coefficient are listed in Table 1.

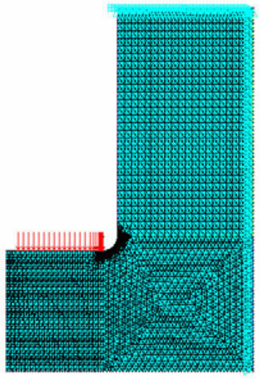

Fig. 3 The finite element model

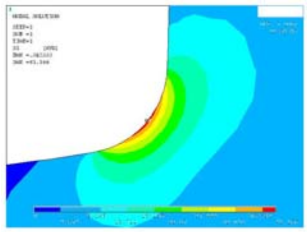

Fig. 4 The distribution of the σ_1 stress in the fillet area

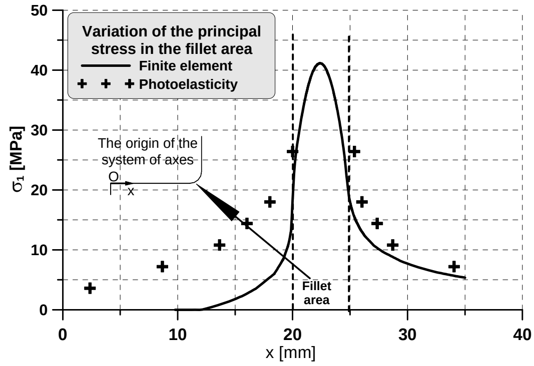

Fig. 5 Variation of the σ_1 stress on the contour of the model in the fillet area

Table 1 The stress concentration coefficient

Model nr.	Fillet radius [mm]	Applied load [N]	Stress concentration coefficient α_K	
			Experimental	Numerical
1	3	1162	9,2	11,7
2	1	948	11,0	12,9

3. DETERMINATION OF THE SHAPE AND SIZE OF THE PLASTIC ZONES USING CHROMOPLASTIC MODELS

In order to establish the plasticity behavior of the studied structure, the photoelastic investigations were followed by experimental analyses using models manufactured from a chromoplastic material. Thus, important information was obtained about the appearance of the first plastic deformations, the areas where yielding occurs first and the corresponding limit load.

The model was manufactured also at a scale of 1:1 from a SDP-1 chromoplastic material (Bălan et al., 1963), with the following mechanical characteristics and elastic constants: ultimate tensile stress σ_{0t} = 54 … 60 MPa, ultimate compressive stress σ_{0c} = 60…70 MPa, yield limit σ_y = 45 MPa, Poisson's ratio ν = 0,41 and Young's modulus E = 2500 MPa. The model, having a fillet radius R = 1 mm and the height h = 30 mm, was loaded in traction using a special device. The loads were progressively increased in order to observe the development of the plastic zones as a function of the applied forces. The shape and size of the plastic zones were obtained for loads between 5000 and 9500 N (Fig. 6).

The model was further loaded, observing the development of the plastic zones, till yielding occurred on all the section of the structure, forming thus a plastic hinge. In this phase, the first cracks appeared in the fillet areas (Fig. 7).

The moment of crack initiation is important for establishing the possibility of brittle fracture in service. Since the maximum stress in service is less than the yield limit, yielding may occur only on very small areas near the zones with high stress concentration. There is no danger of generalized yielding and thus no danger of crack initiation, phenomenon that in this case occurs when a plastic hinge is formed.

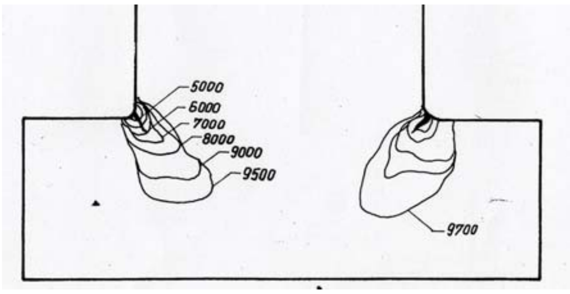

Fig. 6 Development of the plastic zones for different loads

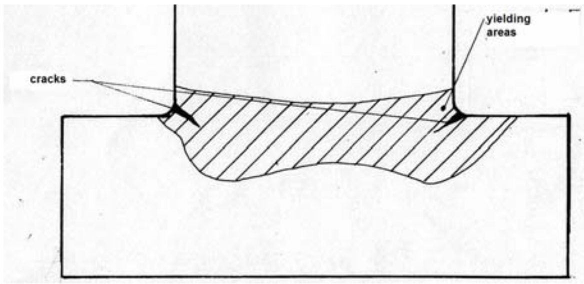

Fig. 7 Generalized yielding and appearance of cracks

A calculus model was developed also in this case, in order to validate the experimental results. An elastic-plastic incremental analysis was performed using triangular isoparametric elements with six nodes. The model had 4835 nodes and 2334 elements.

The shape of the plastic zone, obtained with the plastic incremental analysis is presented in Fig. 8, for a load of 5000 N. A comparison between the experimental and numerical plastic zone shape for three different loads is shown in Fig. 9, where the finite element results are represented with dashed lines. A good agreement between the results may be noticed.

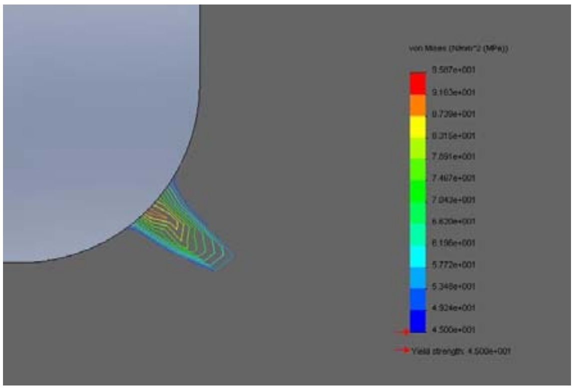

Fig. 8 Development of the plastic zone for F = 5000 N

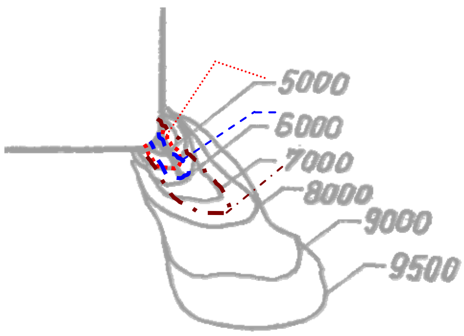

Fig. 9 Numerical and experimental plastic zone shape

4. CONCLUSIONS

The combined numerical and experimental analyses of the stress state in the fastening element of the rotor pole confirms the stress concentration effect of the fillet, where cracks may appear and develop.

The chromoplastic experimental study showed the shape and size of the plastic zones for different loads, and also that the cracks initiate in the fillet area but only when generalized yielding occurs.

The results of the undertaken research showed a good agreement between the numerical and experimental results, validating thus the experimental models that can be used in the analysis of structural integrity of different fastening elements.

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