NUMERICAL AND EXPERIMENTAL STUDY OF THE PLASTIC ZONE IN THE VICINITY OF THE CRACK TIP BY THE OPTICAL CAUSTICS METHOD

Octavian Pop, Valéry Valle and Mario Cottron
Laboratoire de Mécanique des Solides – U.M.R. 6610 – Université de Poitiers
S.P. 2 M.I., Bd. M. et P. Curie, Téléport 2, B.P. 30179,
86962 Futuroscope Chasseneuil Cedex FRANCE
e-mail : Octavian.Pop@lms.univ-poitiers.fr

Summary In this paper we aim at demonstrating by numerical simulations, followed by experimental tests that for a ductile specimen SEN loaded in the mode I, the topological changes of the crack tip, due to plasticity, can be revealed by the optical caustics phenomenon.

INTRODUCTION

In industrial applications, knowing the morphology of the plastic region allows the prevention of crack propagation that may lead to serious crack extensions.
For real cracked structures, the topology of the field surrounding the crack tip is generally determined by the stresses and strains state [1]. In the case of fragile materials, the development of the plastic zone is ignored, but the same hypothesis does not apply to ductile materials. For these materials, when dealing with a stationary problem, we notice an important development of the plastic zone in the proximity of the crack tip, before reaching the rupture stress limit and before the crack begins to extend. We have to add that the plastic region keeps developping alongside with the crack extension. Assuming that the transition between the elastic zone and the plastic zone surrounding the crack tip implies a change in the displacements field configuration, we aim at approaching the influence of the plastic zone on the caustic shape by using the caustics method [2].

THE OPTICAL PHENOMENON OF CAUSTICS

Being associated to mathematical singularities, a caustic represents the image of a group of critical points, of lagrangian application, for which the rank of the derivative is inferior to its possible maximum value [3], [4]. In geometrical optics, the caustic curve stands for the envelope of a system of rays due to the deflection of an incidental light beam, which impinges on the outside boundary of the medium [5]. In our study, the outside boundary of the medium is reflective and in this case the only parameters influencing caustics are the residual strains field and the position of the image screen, determined in relation to the reflective boundary.
We know for a fact that in the case of elastic behaviour of the cracked medium, in the unloaded state, this one goes back to its initial state. Thus, the configuration area is reduced to a flat surface corresponding to the absence of caustics in the image screen (see, FIG. 1 (a)). According to this hypothesis, the appearance of a plastic zone in the proximity of the crack tip is accompanied by irreversible residual strains. When the depth of the configuration area is not zero, we have residual caustics due to residual strains.

NUMERICAL SIMULATION

In order to proceed to the numerical simulation, we have used finite elements modelling of a SEN ductile specimen with the size of 100x100x6 mm^3 and a length of the crack of 9.5 mm. The specimen is loaded in mode I beyond the initial elasticity limit. The behaviour model that we have associated to the discretized specimen is the von Mises model of kinematic linear hardening, while the mechanical characteristics of the material are experimentally determined for a polycarbonate known under the name of Makrolon [6]. Moreover, the kinematic boundary conditions imposed on the geometrical shape of the specimen require a plane stress state ($\sigma_{zz} = 0$).
In our paper, we assume that the plastic zone represents the node locus for which the stress state during the loading phase satisfies the plasticity criterion of von Mises [7].
The simulated caustics obtained in three image planes, for the unloaded state, are presented in FIG. 1 (b), (c) and (d).

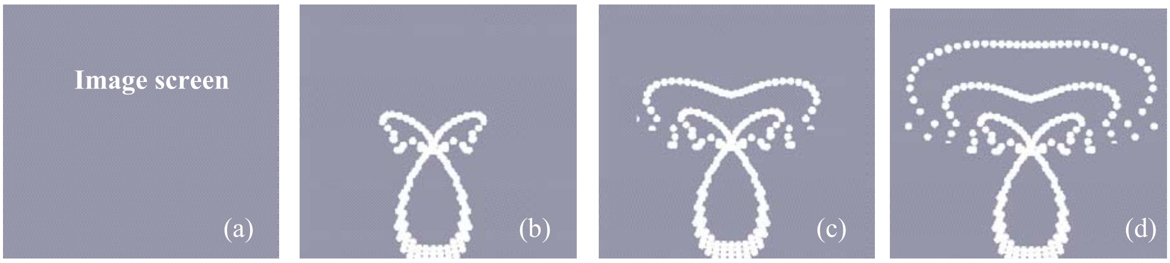

FIG. 1 - Simulated virtual caustics

EXPERIMENTAL TEST

The experimental test has been carried out for a SEN specimen of polycarbonate (Makrolon) having the same dimensions as the specimen used for numerical simulation. The loading of the specimen is done in the mode I beyond the initial elasticity limit. The reflective surface of the specimen is impinged on with a parallel beam by using a LASER source.

The acquisition of caustics is obtained through the reflexion of a CCD camera, in several measurement planes determined in relation to the reflective surface of the specimen. The depth variation in the measurement plane is obtained by moving the CCD camera in a perpendicular direction to the free surface of the specimen. Following the image acquisition stage and taking into account the magnification of the CCD camera, we can deduce the diameters of the caustics in mm.

We have showed in FIG. 2 the experimental caustics obtained in three image planes. These three image planes are situated at 0.25, 0.5 and 0.7 cm in relation to the reflective boundary of the specimen.

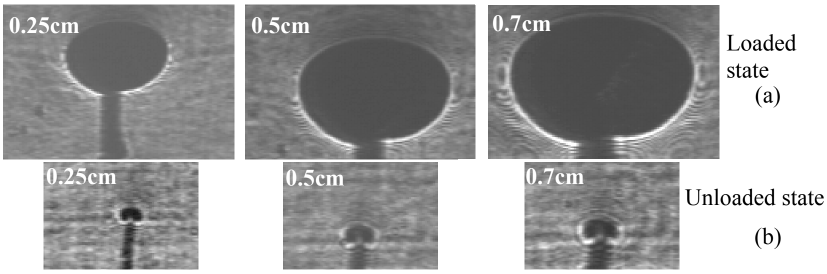

FIG. 2 - Experimental virtual caustics obtained for an image-plan situated at 0.25, 0.5 and 0.7 cm from the refractive boundary of specimen

DISCUSSION AND CONCLUSIONS

We have to specify that the caustics obtained through reflection and shown in FIG. 1 and 2 are virtual caustics [5].

Analysing FIG. 2 we can notice a difference in the shape of caustics observed in the loaded state of the specimen and those corresponding to the unloaded state. The caustics show in FIG. 2 (a) are generated by rays coming from the area of elastic behaviour of the specimen, whereas caustics in FIG. 2 (b) stand for the envelopes of rays reflected by the plasticity-affected area.

We can also note that in FIG. 1 and 2 the shape of caustics depends on the position of the image screen, that is to say on the topology of the residual displacement field.

In the case of the unloaded configuration of the specimen, FIG. 1 (b), (c), (d) and FIG. 2 (b) show that the residual strains, entailed by the plasticity phenomenon, can be revealed by residual caustics.

Attention should be drawn to the fact that visualised caustics for a residual strains field present standard singularities. In this context, the analysis of the caustics' shape allows us to find the locus of the critical points (i.e. reconstruct the residual displacements field) in order to determine the boundaries of the plastic zone.

References

[1] J. Lie, N. Recho, Rupture par fissuration des structures, Hermès, Paris, 1995.

[2] R.A. Tomlinson, E.A. Patterson, The effects of surface topography on the method of caustics, Experimental Mechanics, **39 (4)** 335-342, 1999.

[3] V. Arnold, A. Varchenko, S. Goussein-Zadé, Singularités des applications différentiables 1ère partie, Éditions Mir, Moscou, 1986.

[4] M. Born, E.Wolf, Principles of optics. Electromagnetic theory of propagation. Interference an diffraction of light, Pergamon Press, 1980.

[5] J.F. Kalthoff, Static and dynamic photoelasticity and caustic, in: A. Lagarde (ed.) CISM Courses and lectures 290, Springer, New-York, 1987.

[6] R. Tié Bie, J.C. Dupré, Optical techniques for the thermomechanic study og polymers, International workshop on video – Controlled materials testing 181-184, 2000.

[7] B. Haphen, J. Solençon, Elasto-plasticité, Presses de l'école nationale de ponts et chaussées, Paris, 1987.