UNIFORM CRITERIA FOR AN ESTIMATE OF THE MATERIAL LOCAL STRESS STATE AT THE CRACK TIP

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ABSTRACT

Uniform criterions are proposed to estimate the local stress state of the material at the crack tip under various loading conditions (static, impact, high-speed impulse, cyclic and impact-cyclic). There are h_{max}/t - ratio of the maximum depth of the plastic zone under the fracture surface to the thickness of the specimen and β/β_c-ratio of the diffraction line width obtained at the fracture surface to the standard line width. Three fields of the local stress state are distinguished as follows: 1) the plane strain deformation (PD), 2) the plane stress state (PS), 3) Transition from the PD to the PS. It was shown that number of plastic zones at the crack tip is independent from the type of loading conditions. But it depends on the local stress state of the material. The plane strain deformation condition may be defined more precisely by use of the criterions h_{max}/t and β/β_o.

KEYWORDS

Plane strain deformation, plane stress state, plastic zone, diffration line width.

INTRODUCTION

The evaluation of the local stress atate is necessary for correct determination of the material static crack resistance, for diagnostic of industrial structurals failure to estimatethe failure stress.

If the plane stress state and the plane strain deformation at the crack tip are two extreme stress state, then specimens and structurals failure will be carried out between the two above stress states. It is necessary to provide a criterion for the local stress state evaluation in this transition region. It is also nacessary to give a uniform criterion for diferent types of loading conditions and to indicate the acceptable intervals where the stress state may be treated as either plane stress or plane strain deformation. The known criterion detailed in paper (Brown and Srouly, 1972) are not physically substantiated and do not cover all types of loading conditions. This paper presents criterions which satisfy the above requirements.

EXPERIMENTAL RESULTS

To control offered criterions, tests were performed under static, impact, high-speed impulse, cyclic and impact-cyclic loading conditions. Specimens were tested at the temperature interval ranging from -196 to 150°C. Standerd techniques were used. Fatigue tests were performed under two scheme of loading (Fig.1). The depth of plastic zones under the fracture surface was measured by X-ray diffraction method presented in the paper (Klevtsov and Botvina, 1984).

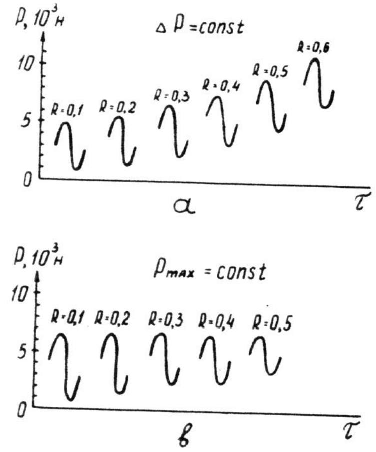

Fig.1. Scheme of specimens fatigue test

Steels 20,40,45, St3, 15X2MФA for the materials with the BCC-lattice structure, alloy D16 and austenitic steels 40Г18Ф, 40X4Г18Ф, 03X13AГ19, 07X13H4AГ20 for the materials with the FCC-lattice structure were used.

Earlier Klevtsov et al.(1988,1991) showed that the ratio of the maximum depth of the plastic zone under the fracture surface to the specimen thickness (h_{max}/t) can serve as such a criterion for the evaluation of the loal stress state at the crack tip under different types of loading conditions. Three distinct regions of the local stress atate may be distinguished. 1. Only one 'micro-plastic zone h_{yh} is formed under the fracture surface irrespective of the types of loading conditions and class of the material when the ratio of the maximum depth of the plastic zone to the specimen thickness $h_{max}/t < 10^{-2}$. In this case the failure of the specimen during the static crack resistance tests satisfies the conditions of the plane strain deformation according to fracture mechanics (Brown and Srouly, 1972). 2. Two plastic zones: a highly deformed micro plastic zone h_{yh} and a lowly deformed macro plastic zone h_y are formed under fracture surface when $h_{max}/t > 10^{-1}$. This is the region of the plane stress state (PS). 3. The region of transition from PD to PS takes place when $10^{-2} < h_{max}/t < 10^{-1}$. All the materials fracture in this region under the cyclic loading conditions. Materials with an FCC-lattice structure are fractured in this region under static, impact, impulse of loading conditions. The fracture as a rule is accompanied by the development of the "degenerated" lowly deformed macro plastic zone.

Let us compare the criterion h_{max}/t with the known criterion $t/(K/\sigma_{0,2})^2 \geq 2.5$ which shows the plane strain deformation

condition of specimens subjected to the static crack resistance tests (Fig.2).

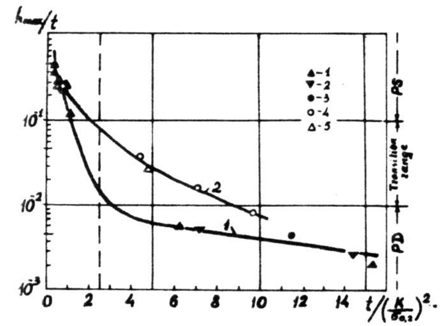

Fig.2. $h_{max}/t - t/(K/\sigma_{0,2})^2$ relation for materials tested for static crack resistance. 1-steel 20, 2-steel 40, 3-15X2MФA, 4-D16, 5-03X13AГ19.

Relation between criterion h_{max}/t and criterion $t/(K/\sigma_{0,2})^2$ are shown in Fig.2. Criterions coincide for materials with a BCC-lattice structure. The plane strain deformation condition take place only when $t/(K/\sigma_{0,2})^2 \geq 9$ for materials with a FCC-lattice structure. In this case, the ratio $h_{max}/t < 10^{-2}$. Only one micro plastic zone is formed under the fracture surface.

The plane strain deformation approaches when $t/(K_{max}/\sigma_{0,2})^2 \geq 3$ for all classes of materials under cyclic and impact-cyclic loading conditions (Fig.3).

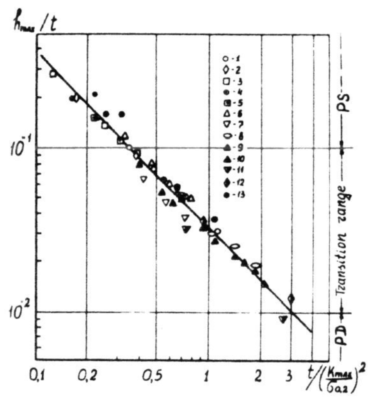

Fig.3. $h_{max}/t - t/(K_{max}/\sigma_{0,2})^2$ relation under cyclic (1...12) and impact-cyclic (13) loading conditions.
1- D16 ($t=10^{-2}$ m; R=0.1; ΔP=const).
2- D16 ($t=10^{-2}$ m; R=0.3; ΔP=const).
3- D16 ($t=10^{-2}$ m; R=0.5; ΔP=const).
4- D16 ($t=10^{-2}$ m; R=0.1; P_{max}=const).
5- D16 ($t=10^{-2}$ m; R=0.5; P_{max}=const).
6- D16 ($t=1.5\times10^{-2}$ m; R=0.5).
7- D16 ($t=3\times10^{-2}$ m; R=0.5).
8- D16 ($t=5\times10^{-2}$ m; R=0.5).
9- Steel 20 ($t=2\times10^{-2}$ m; R=0.5; T=20°C). 10- 07X13H4AГ20 ($t=2\times10^{-2}$ m; R=0.5; T=20°C). 11- 07X13H4AГ20 ($t=2\times10^{-2}$ m; R=0.5; T=-80°C). 12- 07X13H4AГ20 ($t=2\times10^{-2}$ m; R=0.5; T=-196°C). 13- Steel 45 ($t=1.2\times10^{-2}$ m; R=0; T=20°C).

The ratio h_{max}/t as a function of the ratio $t/(\Delta K/\sigma_{0,2})^2$ is described the series of parallel lines corresponding to the different values of R.

The change of the stress state at the crack tip affects both the plastic zones depth and the distortion of the materials crystal structure within these zones. The distortion may be evaluated by the diffraction line width. But it is better to use a nondimensional value - the ratio of the diffraction line width obtained on the fracture surface (β) to the standard diffraction line width (β_c), i.e. (β/β_o). The ratio h_{max}/t as a function of the ratio β/β_o for different materials tested under static, impact and impulse of loading conditions are shown in Fig.4.

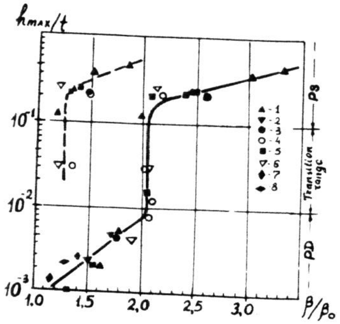

Fig.4. h_{max}/t - β/β_o relation for different materials tested under static, impact and impulse loading conditions.
1,2,3,4- static; 5,6- impact; 7,8- impulse.
1- steel 20, 2- steel 40, 3- 15X2MФA, 4- D16, 5,8- steel 45, 6- 40X4Г18Ф, 7- St 3.

It is evident that the ratio h_{max}/t as a function of the ratio β/β_o for materials fracturing without phase transformations are independent of the type of materials. Three regions may be distinguished in Fig.4. The ratio β/β_o increases to value of 2.0 in the plane strain deformation region (PD). The ratio β/β_c is a constant within the transition region, and increases again in the plane stress state region (PS). Thus, the ratio β/β_o is uniquely related to the parameter h_{max}/t, and it may be used or quantitative evaluation of the stress state at the crack tip under different types of single loading of the material. The relation between the criterion h_{max}/t and the criterion β/β_o is independent of the class of material and scheme of loading under cyclic and impact-cyclic loading conditions. The ratio β/β_c is a constant on the stable crack growth stage.

CONCLUSIONS

1. The ratio h_{max}/t and the ratio β/β_c may be used as uniform criterions for the estimation of the material local stress state at the crack tip under different types of loading conditions.

2. The plane strain deformation is realized when the ratio $t/(K/\sigma_{0.2})^2 \geqslant 9$ in materials with FCC-lattice structure tested under the static loading conditions.

3. Under the cyclic and the impact-cyclic types of loading conditions the plane strain deformation is realized when the ratio $t/(K_{max}/\sigma_{0.2})^2 \geqslant 3$.

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