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STATIC STRENGTH CRITERION FIT FOR DUCTILE MATERIAL

STATICKÉ KRITÉRIUM PEVNOSTI PRO TVÁRNÝ MATERIÁL

Abstract

Failure in view of basic knowledge of physic of metals is given. Introduction of concepts "reference normal stress" and "reference shear stress" is discussed. From these the proposal of more precise definition of the multi-axial strength criterion has been developed. The criterion enables to estimate parameters of the strength surface in case of ductile materials. The validity of the developed criterion has been experimentally tested.

Abstrakt

Je popsáno porušení z hlediska základních znalostí nauky o materiálu. Je uvedena koncepce „referenčních normálových“ a „referenčních smykových napětí“. Odtud plyne návrh přesnějšího multiaxiálního kritéria pevnosti. Toto kritérium umožňuje pro tvárné materiály stanovit plochu mezní pevnosti. Platnost vyvinutého kritéria byla experimentálně testována.

1 INTRODUCTION

Usually two questions have to be answered: *1)* How the body is deformed in the influence of its loading, shape and properties of material, *2)* if the consistency of the body is violated under this deformation.

Strength criterion results from the requirements of the engineers to describe the failure of the material in dependence on the parameters of the loading especially then of the stress state. In the work [4] is mentioned the summary of strength hypothesis.

Existence itself of comparatively large number of dissimilar strength criteria already manifests the fact that many of them have nowadays just historical value. If we examine individual criteria, we can group them into several classes and speak thus of *"classical"*, *"octahedral"*, *"invariant"*, *"mixed"*, *"deformation"* and *"combined"* strength criteria - see Appendix in full version on CD.

Almost all of them were formulated regardless of physical processes accompanying failure of metal bond. They were formed as a result of efforts to substitute by some phenomenological description the *Haigh's critical line,* determination of that by experimental methods is very labor consuming and expensive. In last century there was achieved a considerable progress in the field of mechanics of elastic and plastic bodies and there was also discovered many findings concerning materials' structure. Strength criteria are related to both of the above mentioned disciplines.

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2 MATERIALS' STRUCTURE

Let's consider first basic knowledge of physics of metal.

Metals are *crystalline* materials with *KSC* (ferrite), *KPC* (austenite) or occasionally *HTU* lattice. They contain number of *spot defects* (vacancies, interstices, substitution atoms), *line defects* (edge-, screw-, combined- and partial *dislocations*), *volumetric defects* (precipitates, inclusions, etc.). Technical metals are mainly *polycrystalline* materials (grain boundary, size of the grains).

Ductile failure goes along with previous *plastic* deformation that is usually realized by *slip of free dislocations*. *Slip systems* are crystallographic conditioned and for realization of plastic deformation in the polycrystalline material is necessary to initiate at least *five different* slip systems (Mises). Plastic deformation depends on the value of *shear* stress in the *slip* planes. In case the movement of free dislocations is blocked - the escalation of stress does not lead to further plastic deformation but it initiates the *nucleus* of the crack.

The presence of normal *compression* stress in the slip plane *increases* reachable value of the plastic deformation while *tension* stress *reduces* the limit of plastic deformation.

Brittle failure is induced by the normal stresses, it is also crystallographic conditioned and can be characterized by the stress of *microcollapse* [11]. Our strength criterion is based on so-called *reference stresses* [4, 6].

3 IDEA OF REFERENCE STRESSES

Polycrystalline material contains lots of latent slip planes and slip directions. As already mentioned the plastic deformation requires at least five slip systems. It can be then expected that the *strength criterion of ductile polycrystalline material* will not be related with stress states only in one (slip) plane.

If all components of a *general stress state* are known then it is possible to calculate the principal stresses σ_1, σ_2, σ_3 and also the normal and shear stresses on a general plane ρ normal of which contains angles α_1, α_2, α_3 with directions 1, 2, 3 of principal stresses:

$$\sigma_\rho = \sigma_1 \cos^2 \alpha_1 + \sigma_2 \cos^2 \alpha_2 + \sigma_3 \cos^2 \alpha_3 , \tag{1}$$

$$\tau_\rho = \left[\left(\sigma_1{}^2 \cos^2 \alpha_1 + \sigma_2{}^2 \cos^2 \alpha_2 + \sigma_3{}^2 \cos^2 \alpha_3 \right) - \left(\sigma_1 \cos^2 \alpha_1 + \sigma_2 \cos^2 \alpha_2 + \sigma_3 \cos^2 \alpha_3 \right)^2 \right]^{1/2} . \tag{2}$$

Reference normal σ_R and *reference shear* stress τ_R can be then defined as:

$$\sigma_R = \lim_{R \to 0} \left[\int_{(S)} \sigma_\rho . dS / (4\pi R^2) \right] = \left(\sigma_1 + \sigma_2 + \sigma_3 \right) / 3 , \tag{3}$$

$$\tau_R = \lim_{R \to 0} \left[\int_{(S)} \tau_\rho{}^2 . dS / (4\pi R^2) \right]^{1/2} = (1/15)^{1/2} \left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]^{1/2} . \tag{4}$$

4 STATIC CRITERION OF DUCTILE FRACTURE

The criterion of *ductile* failure can be then searched in a formula [4, 5, 6, 7]:

$$\tau_R = f(\sigma_R) , \tag{5}$$

in the simplest form:

$$\tau_R = A - B . \sigma_R . \tag{6}$$

The *stress intensity* S_σ is created in engineering practice defined as:

$$S_\sigma = 2^{-1/2}.\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]^{1/2} \quad , \tag{7}$$

then the strength criterion can be rewritten in the another form, because S_σ is directly proportional to the value τ_R :

$$S_\sigma = f_1(\sigma_R), \tag{8}$$

in the simplest form:

$$S_\sigma = A_0 - B_0 .\, \sigma_R \; . \tag{9}$$

Here σ_R gives numerically equal value as the "*octaedrical normal stress*". Criterion (5) has been named *reference-stress criterion* and its usage can be expected both in the field of prediction of multi-axial *static* loading and also in the area of multi-axial *fatigue* loading.

5 USAGE OF REFERENCE CRITERION FOR PREDICTION OF STATIC FAILURE

The usage of reference criterion has been described for (see full version on CD):

- Evaluation of the strength criterion for CZ steel [1, 3, 7] – measured in the Department of Mechanics of Materials, VŠB – Technical University of Ostrava.
- Transformation of the *fracture strain diagram* into *High's diagram* with overtaken data from [9].
- Evaluation of the strength criterion of tempered cast iron with data overtaken from [10].

6 CONCLUSION

Three *applications* of *reference-stress* criterion (6, 9) for *static* multi-axial loading case including transformation of *fracture strain* diagram [8] into *Haigh's diagram* were shown.

The experimental laboratory at the Department of Mechanics of Materials, VŠB – Technical University of Ostrava is build-up for verification of mentioned ideas [2, 4, 6] and is continuously completed by special testing equipment [12, 13] according to own construction proposals.

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