SIMPLE CALIBRATION METHOD OF MIXED, STRAIN-STRESS FAILURE CRITERION FOR DUCTILE MATERIALS

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1. Introduction

Many failure criteria for ductile materials were proposed by researchers. A good review of the most frequently used criteria was given in [1]. Seven criteria mentioned in this paper were formulated in the space of stress, strain or mixed strain-stress. The most popular one for ductile materials (i.e. most of metal alloys) is constant equivalent stress criterion and its popularity can be attributed to simplicity of calibration and availability of the material data. On the other side this criterion is in conflict with well-known phenomenon described in the beginning of 20th century [2] that can be expressed in the following way: the ability of achieving permanent deformation is influenced by stress state. This experimental observation can be taken into account only in the case of mixed strain-stress criterions like, for example, widely used Johnson criterion [3]. The problem with this and other mixed criteria is that its calibration for particular material requires complicated testing associated by sophisticated computer simulations (see paper [1]). Moreover, as it was reported in this paper, result of the proposed procedure is questionable due to fact that during reported experiments stress state (or stress triaxiality) changes with progressing deformation due to evolution of the specimen gage part geometry and localization of strain. In spite of this it seems obvious that the use of particular form of failure criterion is limited by ease and credibility of calibration method.

2. Criterion and the calibration method

Thera are many definitions of mixed strain - stress criteria for ductile materials. Already mentioned Johnson – Cook criterion can be written in following form:

$$\bar{\varepsilon}_f = C_1 + C_2 \exp\left(C_3 \eta\right) \quad (1)$$

, where ε_f is the failure strain intensity and η is the stress triaxiality factor (ratio of first and second stress tensor invariants). This criterion was proved to fit well experimental data, but its calibration requires determination of three coefficients (at least three points on the ε_f - η plane have to be determined under three different stress states).

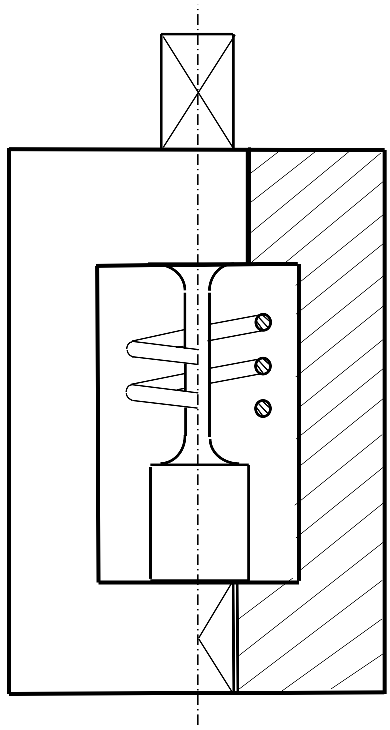

Fig. 1. Fixture for determination of failure strain intensity.

Simplified version of this criterion was given in earlier paper [4] in the following form:

$$\bar{\varepsilon}_f = \alpha e^{-\frac{3}{2}\eta} \quad (2)$$

Calibration of this criterion requires determination of only one coefficient α. This form of the criterion may not fit experimental data as well as Johnson – Cook criterion (1), but is far easier to calibrate and still stress-state sensitive. The easiest stress state to be produced to determine failure strain intensity is pure shear. For this stress state $\eta = 0$ and failure strain intensity value is equal to value of coefficient α.

In patent description [5] a method and accessory for calibration of the failure criterion in the form of equation (2) was given. Fixture shown in figure 1 is proposed to be used for calibration of that criterion at room and elevated temperatures. Test setup consist of constrained yoke with inductive coil for material heating inside. Specimen inserted in that yoke is heated to achieve required temperature and then twisted to rupture using some kind of hand tool (testing machine is not required to perform this test). The only result of the procedure is angle of twist, that can be easily re-calculated into failure shear strain and finally into failure strain intensity.

Fig. 2. Specimen after test.

The specimen after test is shown in figure 2. It can be seen that no strain localization changing stress state at the surface of the specimen occurs during test. It means that the stress state at the surface of the gage part of the specimen was kept constant and uniform during all the deformation process from beginning to failure and it can be described as the pure shear in the plane stress state. So, for all the deformation process stress triaxiality factor $\eta=0$ and the value of coefficient α equal to strain intensity at failure was determined credibly.

For the material of specimen shown in figure 2 (alloy steel), angle of twist of the gage part measured using microscope was found to be φ = 8,792 rad. For the geometry of the specimen used, shear strain angle is:

$$\gamma = \varphi \frac{r}{l} = 1{,}08\, rad \tag{3}$$

, and the failure strain intensity

$$\bar{\varepsilon}^f = \frac{\sqrt{2}}{3}\sqrt{\frac{3}{2}\gamma^2} = 0{,}622\ mm/mm. \tag{4}$$

So, finally failure condition for the alloy in question takes form:

$$\bar{\varepsilon}^f = 0{,}622^{-\frac{3}{2}\eta}. \tag{5}$$

Conclusions

Simple method and accessory for the calibration of mixed strain-stress failure criterion (2) was presented in this paper. Patented fixture [5] allows determination of failure strain intensity for all the stress states and wide range of temperatures without the use of sophisticated testing equipment (testing machine, specialized transducers). One of the most important advantages of proposed method is fact that the applied loading scheme allows to keep the same stress state at the surface of the gage part – experiment is performed for constant value of stress triaxiality factor η from the beginning of deformation to material failure.

References

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