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DOUBLE LEAF SPRING GAUGE FOR THE CONTINUOUS MEASUREMENT OF THE DIAMETER CHANGE

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Abstract: The paper deals with the design and calibration of the double leaf spring gauge for the continuous measurement of the diameter change. The gauge can be combined with the load gauge for obtaining F-Δd curve used for the determination of modified Gurson model parameters. The sensitivity of the gauge is assessed and the calibration is performed.

Key words: gauge, electric resistance method, diameter change measurement, load vs. diameter change curve, Gurson model

Introduction

Ductile fracture in metals can involve the generation of porosity. Modified Gurson model [1, 2] encompassing nucleation, growth and coalescence of voids can be taken as a constitutional theory for describing the above phenomenon It takes into account local damage and describes the effect of constraint in a natural way.

For applying the theory a set of parameters characterising a particular material is needed. The Gurson model, because of its local approach, can be used for different specimen geometries. Some of the parameters of this model are often determined by fitting numerically obtained loading force versus diameter reduction curves [3] into the experimental results of tensile tests of notched bars (fig.1). The process of the diameter reduction can be recorded by a high-frequency camera and synchronised with the force record and the curve F-Δd (Fig. 2) can be obtained [4]. Another possibility is the contact gauge for measuring the change of the diameter. Such a device based on the single supported beam is described in [5].

This paper describes the design and the prototype of the measuring device based on two simple supported beams.

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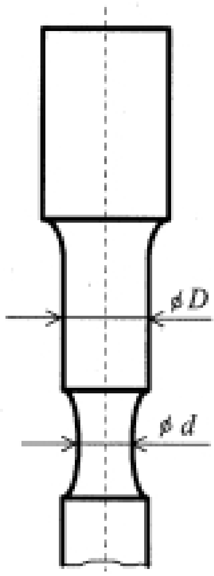

Fig. 1 Notched specimen

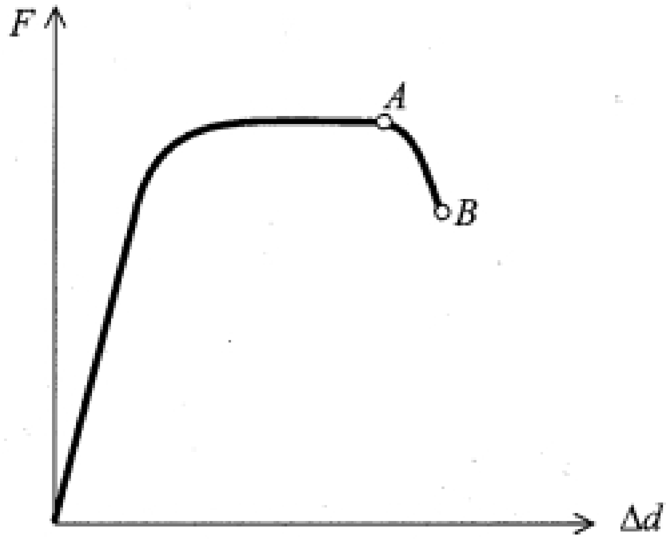

Fig. 2 F-Δd curve

Modified Gurson model

The continuum model of ductile material proposed by Gurson [1] assumes cylindrical and spherical voids surrounded by homogeneous, incompressible von Misses material (matrix). Hence, a homogeneous material on macro level is on micro level substituted by a set of micro voids in the matrix. The portion of voids in the material is expressed by void volume fraction.

The model takes only void nucleation and growth into account and combines plasticity and local damage by means of the yield function having now the following form. For cylindrical voids with parallel axes it holds:

$$\Phi = \left(\frac{\sigma_e}{\sigma_M}\right)^2 + 2f\cosh\left(\frac{\sqrt{3}}{2}\frac{\sigma_k^k}{\sigma_M}\right) - 1 - f^2 = 0$$

and for spherical voids it was derived:

$$\Phi = \left(\frac{\sigma_e}{\sigma_M}\right)^2 + 2f\cosh\left(\frac{1}{2}\frac{\sigma_k^k}{\sigma_M}\right) - 1 - f^2 = 0\,,$$

where f is void volume fraction, σ_M actual yield stress of the matrix material, σ_e von Misses equivalent stress and σ_k^k the trace the of Cauchy stress tensor.

For the description of the matrix material the following linear-exponential law is frequently used:

$$\varepsilon_M = \frac{\sigma_M}{E} \qquad \text{for}\ \sigma_M \le \sigma_y$$

$$\varepsilon_M = \frac{\sigma_y}{E}\left(\frac{\sigma_M}{\sigma_y}\right)^n \quad \text{for}\, \sigma_M \le \sigma_y ,$$

where n is hardening coefficient.
The void evolution consists of two terms, namely the nucleation a growth rates:

$$\dot{f} = \dot{f}_{nucl} + \dot{f}_{grouwth}$$

with initial condition

$$f(t_0) = f_0 .$$

The nucleation part of $\dot{f}$ can be controlled by deformation, in this case it holds:

$$\dot{f}_{nucl} = \frac{f_N}{s\sqrt{2\pi}} \dot{\varepsilon}_M^p e^{\left[-\frac{1}{2}\left(\frac{\varepsilon_M^p - \varepsilon_N}{s}\right)^2\right]},$$

where f_N is volume fraction of void nucleating particles, ε_N mean nucleation equivalent plastic strain, ε_M^p plastic equivalent strain of the matrix material and s standard deviation.

It can be also controlled by stress. In this case it was derived:

$$\dot{f}_{nucl} = \frac{f_N}{s\sigma_y\sqrt{2\pi}}\left(\dot{\sigma}_M + \frac{1}{3}\sigma_k^k\right) e^{\left[-\frac{1}{2}\left(\frac{\varepsilon_M + \frac{1}{3}\sigma_k^k - \sigma_N}{s\sigma_y}\right)^2\right]},$$

where σ_N mean nucleation equivalent stress and σ_y initial yield stress of the matrix material.

The growth rate is assumed proportional to hydrostatic part the stress tensor

$$\dot{f}_{grouwth} = (1 - f)\dot{\varepsilon}_k^{kp} ,$$

where $\dot{\varepsilon}_k^{kp}$ is the trace of the plastic equivalent deformation rate tensor.

Currently used model [3, 5] introduced by Needleman and Tvergaard [2] has void coalescence incorporated. The modified yield function has the form:

$$\Phi = \left(\frac{\sigma_e}{\sigma_M}\right)^2 + 2q_1 f^* \cosh\left(\frac{1}{2}\frac{q_2\sigma_k^k}{\sigma_M}\right) - \left[1 + (q_1 f^*)^2\right] = 0 ,$$

where q_1, q_2 are parameters and f^* is modified void volume fraction defined as follows:

$$f^* = f \qquad \text{for } f \le f_c$$

$$f^* = f_c + \left(\frac{f_u^* - f_c}{f_F - f_c}\right)(f - f_c) \qquad \text{for } f > f_c .$$

Here, f_c stands for critical void fraction for coalescence, f_F final void volume fraction when the material looses its carrying capacity and f_u^* is defined as

$$f_u^* = f^*(f_F) = \frac{1}{q_1}.$$

The key part of the theory is the relation between the microscopic quantities describing the behaviour of the matrix material (indicated with $_M$) and macroscopic quantities characterising the "continuum" material. The related quality is the plastic work:

$$\sigma\varepsilon = (1-f)\sigma_M\varepsilon_M .$$

Experimental determination of *F*-Δd curve

For comfortable obtaining the desired curve of loading force versus change of the diameter such a device is needed which makes possible the curve to be directly drawn by a plotter or the corresponding data to be stored in digital from in the computer memory and then further treated.

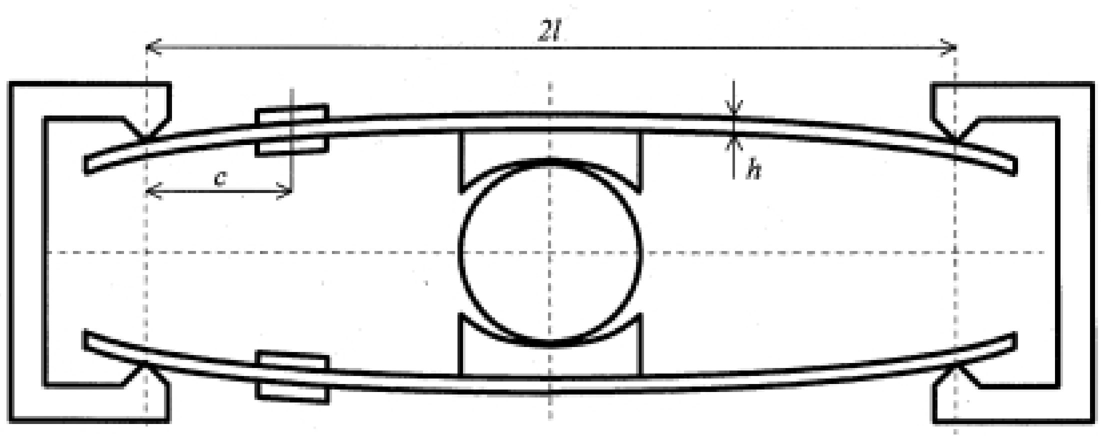

Fig. 3 Arrangement of the device

For the continuous measurement of the diameter change the arrangement with two simple supported beams with cemented electric resistant gauges was used (fig. 3). This arrangement is pre-stressed and is mounted to the specimen at the plane of minimum cross-section. Because of pre-stressing the device is self supported. Four gauges are cemented to the unloaded beams, which serve as springs to follow the reduction of the diameter. For each beam the defection at position *l* is equal to $\frac{\Delta d}{2}$. It can be shown by a simple calculation that the strain $\varepsilon(c)$ in the place *c* depends on the Δd as follows

$$\varepsilon(c) = \frac{3ch}{4l^3}\Delta d ,$$

where *c, l* and *h* are obvious from the fig. 3. Hence, the relation between $\varepsilon(c)$ and Δd is linear. For *l* = 80mm, *c* = 40mm, *h* = 0,7mm the sensitivity is $0{,}0025\frac{\text{mm}}{\mu\text{m/m}}$. Since the gauges can be arranged in the full -bridge (fig. 4) the sensitivity is four times higher.

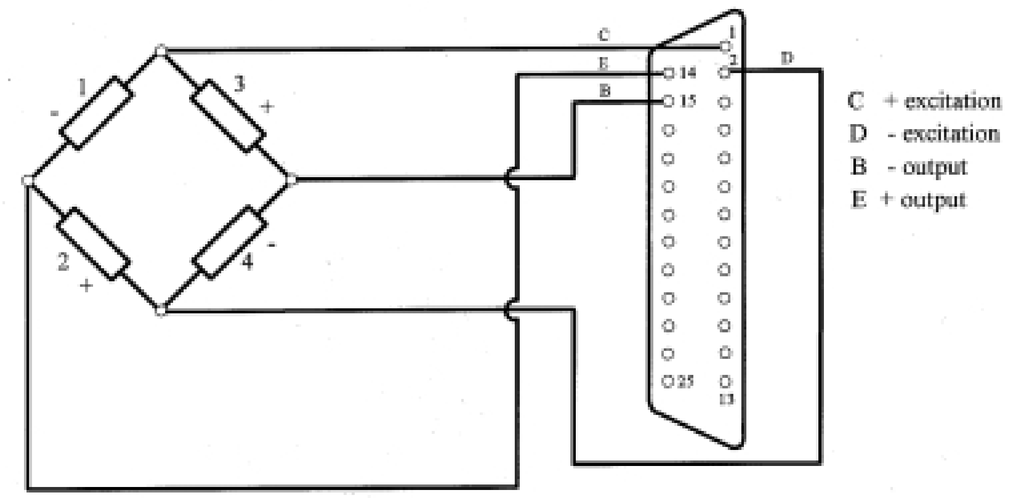

Fig. 4 Gauges arrangement

Because of existing disturbing influences such as influence of supports and probably different pre-stressing the calibration was performed. For this purpose a calibration bars with the step Δd =0,1mm were used and the function $\varepsilon(c) = f(\Delta d)$ was recorded and plotted and the linear regression was applied. The results are presented at fig. 5.

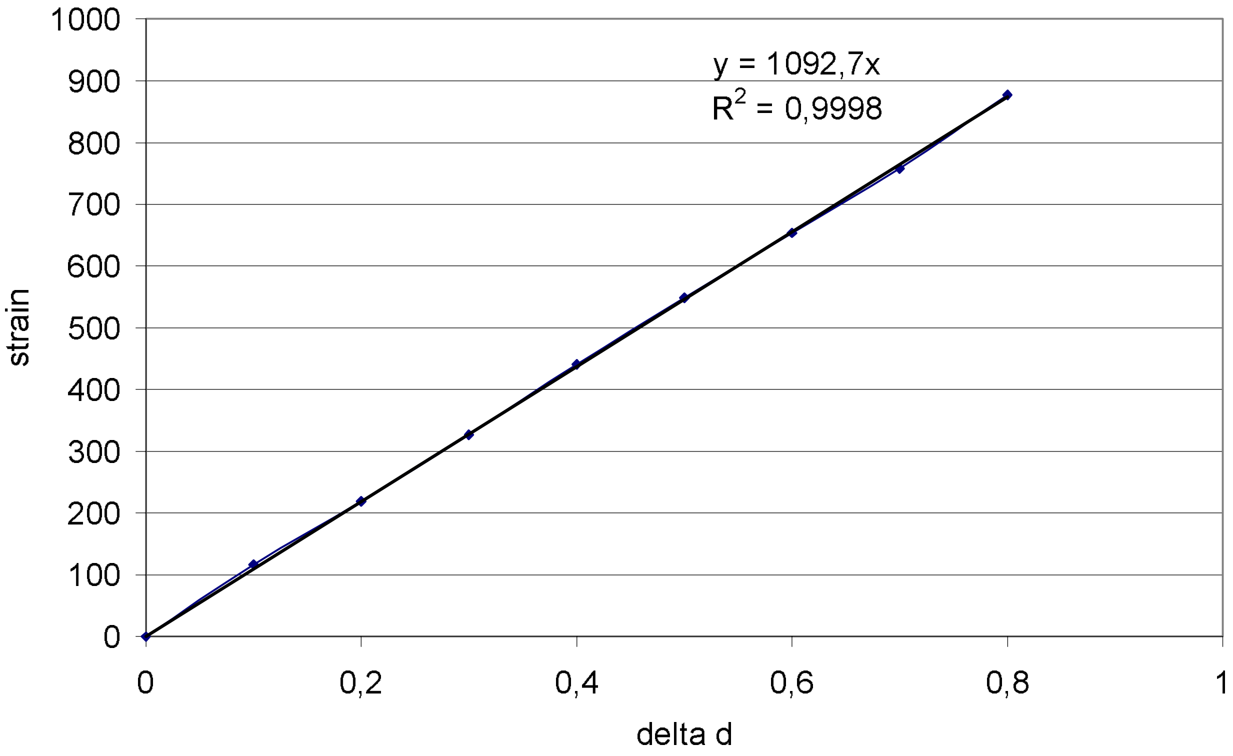

Fig. 5 Calibration curve – Strain vs. diameter change diagram

As follows from this figure, the linear regression proves to be correct. Now, for the calibration of the device the original diameter and the diameter after the rupture can be used. The signal taken from the amplifier can be directly combined with the signal of the force gauge and required curves can be plotted or the data can be stored in a digital form for further treatment.

Conclusions

A double single supported beam design for the continuous Δd measurement device based on the electric resistant gauges was suggested and the prototype of this device was produced and tested. The device proved to be sufficient for obtaining the F - Δd curve necessary for determining modified Gurson model parameters f_c and f_F by numerical fitting the calculated curve to the experimental one. The sensitivity of the arrangement is high enough and the calibration simple.

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