ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 16 (2016) 211–216

Available online at www.sciencedirect.com

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journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

Extended evaluation of Erichsen cupping test results by means of laser speckle

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ARTICLE INFO

Article history:
Received 24 January 2015
Accepted 28 October 2015
Available online 8 December 2015

Keywords:
Erichsen cupping test
Laser speckle
Localized necking
Fracture
LN-IE

ABSTRACT

Erichsen cupping test has usually been used to determine the height of the cup at the moment of sheet metal fracture, defined as the Erichsen Number IE. The paper presents a proposal of using Erichsen cupping test to determine the additional parameter – the height of the cup LN-IE at the moment of localized necking in sheet metal, which usually precedes fracture of sheet metal. For this purpose, a method of localized necking detection was developed. It is based on the phenomenon of laser speckle. The results of height measurements were presented for three different grades of sheet metals used in the automotive industry: 5754 H22 aluminum alloy, DC04 deep drawing steel, and Dogal 800DP high strength steel. The differences in cup heights at the moments of localized necking (LN-IE) and fracture (IE) of the tested sheet metals were in the range of 0–8%.

1. Introduction

Sheet metal formability tests have been for a long time of interest of industry in order to ensure effortless manufacturing and good quality of products. Generally, formability describes the ease of shaping a sheet metal through plastic deformation. One of the first special methods to determine the quality of sheet metal and strip was the cupping test invented by Erichsen over 100 years ago [1]. This so-called Erichsen cupping test has become one of the basic methods for assessing the formability of sheet metal. It involves pressing the spherically ended punch into the tested sheet metal clamped between the die and the blank holder, until the crack appears throughout the sheet. This test, which is described in the ISO standard 20482:2013 [2], allows to verify the formability of the given sheet metal for stamping processes and comparison of different grades of sheet metals. The result of this test is presented as the Erichsen Number (IE). It is the way given in millimeters that the punch must take from the moment of initial contact with the sheet metal specimen until the fracture of cup. The batch production of parts made of sheet metal would have been quite difficult without this test. Dimensions of punch, die and blank holder (Fig. 1) have been the ISO standard.

Modern tools and testing machines made it possible to get additional information as a result of the Erichsen test such as elongation or tensile strength [3]. The Erichsen cupping test in

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http://dx.doi.org/10.1016/j.acme.2015.10.007

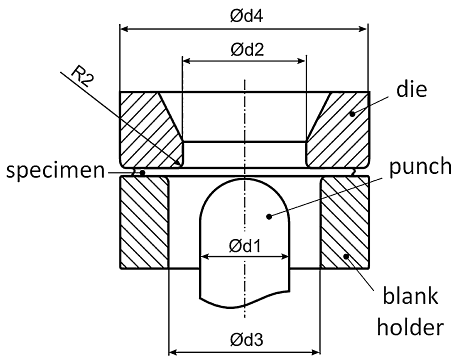

Fig. 1 – Dimensions of tools used in the Erichsen cupping test: d1 – 20 mm, d2 – 27 mm, d3 – 33 mm, d4 – 55 mm, R2 – 0.75 mm

connection with a numerical inverse analysis has also been used to determine the parameters of constitutive equations describing the tested material [4] or to verify the numerical model predicting the fracture [5].

Usually, the moment of fracture is determined by using the visual method, which may cause errors in its subjective assessment. In automated systems, fracture is detected by taking into account the assumption, that the fracture is connected with a decrease in the process force. The method proposed by the authors [6] with the usage of the laser speckle, enables determination of the moment when the strain localization begins. It is also possible to follow the process of developing the necking until the crack appears.

2. Laser speckle phenomenon

When the optically rough surface is illuminated with a coherent light, the laser speckle phenomenon arises. It results from the interference of the light waves reflected from the micro-irregularities of the surface, which looks like a granular structure composed of bright and dark spots. Typical speckle image is shown in Fig. 2. Laser speckle looks similar to a stochastic speckle pattern sprayed on the surface with paint.

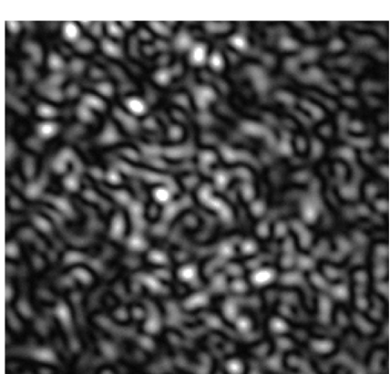

Fig. 2 – Typical speckle image registered by the vision system.

The laser speckle effect may affect the results of measurements where the coherent light sources are used. However, the properties of laser speckle may be used in various ways [7] as in the measurements of surface roughness [8], flow and displacement [9] or deformation [10].

The speckle analysis may be subjected to both static speckle images as well as their changes over time. As a consequence of the illuminated surface activity (movement, deformation or changes in the orientation), the speckle image is also subjected to changes. This speckle image activity allows to detect any, also small changes of illuminated surface.

3. Vision system

Cupping tests were carried out on a universal hydraulic testing device produced by Erichsen Company. The vision system installed over the top of the testing device head allows the observation of the sample surface during the cupping process. The basic components of the vision system are shown in Fig. 3. Details on the testing device are given elsewhere [6].

The method of creating a process image, which is used to detect the localized necking and cracking, consisted of recording a sequence of digital images of the sample surface illuminated by coherent light during the cupping test [6]. The frequency of the image recording was 10 Hz. Single lines of pixels passing through the axis of the deformed cup were taken from recorded images. The location of the lines was the same for all the recorded images. All of the obtained lines of pixels were subsequently connected with one another to form a single image where each subsequent line of pixels provided another column of pixels of the new image toward the right side. An example of such image is shown in Fig. 4.

There are certain specific areas in the process image created by the chosen method and it can be related with characteristic stages of the deformation process of the cup during the Erichsen cupping test. Fig. 4 shows the process image created for DC04 steel. Before contacting the punch with the sample, the sheet metal surface is fixed and the process image does not change because the lines of pixels derived from the subsequent recorded images are identical. This condition

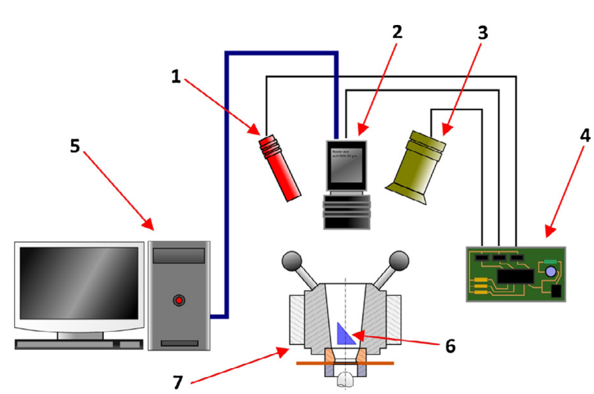

Fig. 3 – Vision system applied in the experiments [6]: 1 – laser line generator, 2 – camera, 3 – LED illuminator, 4 – releasing system, 5 – image recording PC, 6 – prism used for measuring the height, 7 – hydraulic testing device head.