Engineering Failure Analysis 56 (2015) 332–337

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Influence of the notch shape of pre-notched small punch specimens on the creep failure time

I.I. Cuesta [a,*], J.M. Alegre [a], T.E. García [b], C. Rodríguez [b]

[a] Structural Integrity Group, Escuela Politécnica Superior, Avda. Cantabria s/n, 09006 Burgos, Spain
[b] SIMUMECAMAT, University of Oviedo, Edificio Departamental Oeste 7.1.17, Campus Universitario, 33203 Gijón, Spain

ARTICLE INFO

Article history:
Received 30 September 2014
Received in revised form 22 December 2014
Accepted 13 January 2015
Available online 30 January 2015

Keywords:
Notch shape
Failure time
Creep behaviour
Small Punch Creep Test
Pre-notched specimen

ABSTRACT

Nowadays, there are standards for determining the creep-fracture properties of a material. However, a sufficient amount of material to be tested is usually required, something that is not always possible or convenient. In certain cases where not enough material is available for carrying out conventional tests to determine these properties of the material to be analysed, there are now several non-standard tests that can achieve this purpose. One of them, the Small Punch Creep Test (SPCT), basically consists of punching, under a constant load, a miniature specimen in which the sides of the specimen are clamped between two dies. One of the greatest challenges at present is to obtain the creep-fracture properties of a material from this type of test using pre-notched specimens. To achieve this initial notch in the SPCT specimen prior to creep-fracture testing, there are several techniques which are being used at present. The main objective of this paper is to analyse the differences between these techniques, taking into account the shape of the pre-notch obtained and the stress distribution at the pre-notch tip during the test. In this way, it is possible to determine which of them is the most appropriate for estimating the creep-fracture properties of the material used.

1. Introduction

Creep tests on a small scale have the potential to be used without significant removal of material or in areas where the available material is limited. The Small Punch Creep Test (SPCT) is a relatively new technique that has proven to be useful as a means for estimating mechanical properties such as the elastic limit or the yield strength and fracture properties such as the fracture energy of different materials [1–4]. It basically consists of fixing the periphery of a miniature specimen ($10 \times 10 \times 0.5$ mm) by embedding it between two dies, one a rigid lower die on which the specimen rests and the other an upper die screwed to the lower one. The miniature specimen is then pressed under constant load until fracture by means of a small punch. The experimental setup can be consulted in the CEN code of practice for small punch testing [5,6]. Typical SPCT curves for ductile materials can be seen in Fig. 1. The following typical parameters can be obtained: initial displacement (δ_0), minimum deflection rate ($\dot{\delta}_m$), time at which the minimum deflection rate is reached (t_m), failure time (t_f) and total punch displacement ($\delta = \delta_f - \delta_0$), where δ_f is the failure displacement.

The Small Punch Creep Test was developed in the nuclear field in the 1980s [7] and has been shown to be useful for the determination of creep properties [8–11] especially in those cases when there is not sufficient material to perform standard

* Corresponding author.
E-mail address: iicuesta@ubu.es (I.I. Cuesta).

http://dx.doi.org/10.1016/j.engfailanal.2015.01.008
1350-6307/

tests. It should be noted that almost all of this research has always used unnotched SPCT specimens. The use of conventional SPCT specimens does not seem appropriate for a direct determination of conventional creep-fracture parameters, which rely on the use of cracked specimens. To get an accurate prediction of creep-fracture properties, the use of pre-cracked/notched specimens could be a viable alternative in accordance with standard creep-fracture procedures that use notched Charpy and pre-cracked SENB or CT specimens [12–14].

SPCT pre-cracks/notches can be obtained using different techniques, and in this paper three of them have been compared: wire electrical discharge machining (WEDM), transverse laser-induced microcracking (TLIM) and parallel laser-induced microcracking (PLIM). The main objective of this paper is to analyse the differences between these three techniques, taking into account the shape of the pre-notch obtained and the stress distribution at the notch tip during the test. In this way, it is possible to determine which of these techniques is the most appropriate for estimating the creep-fracture properties of the material used.

2. Material and experimental methodology

To carry out this study, a magnesium alloy AZ31B-O was selected, because recently this type of alloy is gaining interest for the manufacturing of stamped components in the automotive industry. Generally, the base materials in these components are cold rolled sheets, and in the case of this study, a 1 mm thick sheet of AZ31B-O was used, with a composition (in wt.%): 3.1 Al, 0.9 Zn, 0.7 Mn and Mg making up the rest. 10 × 10 mm small punch specimens were extracted from the alloy sheet. All of the specimens required the surface to be abrasively ground and polished until a 0.5 mm thickness was attained.

Then, a pre-notch has to be made on the SPCT specimens. In this study, the type of pre-notching used on the specimens was of the through-thickness crack type, from the middle point of one side to a point just passing the centre of the specimen. As noted earlier, this pre-notching was done using wire electrical discharge machining (WEDM), transverse laser-induced microcracking (TLIM) or parallel laser-induced microcracking (PLIM).

The first technique, WEDM, once properly adjusted, yields a pre-notch in the desired position in one step. In the other two techniques, TLIM and PLIM, a laser beam is applied in several passes, using a 30 μm diameter Nd:YAG pulse beam (50 W and 1064 nm), working at a frequency of 7500 Hz and a linear displacement rate of 15 mm/s. The only difference between these two last techniques is that in TLIM the laser is applied perpendicularly to the notch direction, while in PLIM the laser is applied parallel to the notch direction. The notch shape resulting from these techniques can be seen in Fig. 2 with a tip notch radius of 370 μm in/for WEDM and 58 μm in TLIM. Note that the notch obtained in PLIM is much sharper, resembling a perfect crack without a rounded tip.

Once the initial notches of the SPCT specimens were achieved, the tests were conducted using a punch diameter of d_p = 2.5 mm under a constant load of 150 N, while the hole in the lower die had a diameter of D_d = 4 mm and a fillet radius of r = 0.5 mm. The dies were located within a furnace in order to perform the test at 150 °C, with two temperature control zones that allowed for a temperature variability of ±1 °K. Additionally, a thermocouple was placed near the specimen to monitor the temperature during testing. The displacement of the punch was measured within a precision of 1 μm by coupling a clip-on displacement gage (extensometer). A schematic drawing of the complete experimental set up is presented in Fig. 3.

The failure time in these tests is defined by the moment of the complete break of the specimen, which is considered to be when the punch passes completely throughout the thickness of the specimen.

3. Results and discussion

For constant load and temperature conditions used in this study, 150 N and 150 °C respectively, Fig. 4 shows the most characteristic deflection-time curves obtained in the SPCT's for the pre-notched specimens. In the same figure, it can be

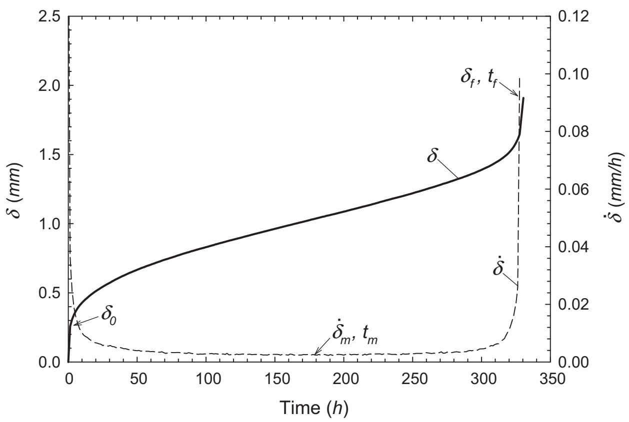

Fig. 1. Typical SPCT curves for ductile materials.