Theoretical and Applied Fracture Mechanics xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Theoretical and Applied Fracture Mechanics

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

Application of the Small Punch Creep test to predict times to rupture on magnesium alloys

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ARTICLE INFO

Article history:
Received 30 June 2016
Revised 2 August 2016
Accepted 8 August 2016
Available online xxxx

Keywords:
Small Punch Creep
Extrapolation techniques
Magnesium alloys

ABSTRACT

The Small Punch Creep (SPC) test, first introduced by Parker in 1993, has been in continuous development ever since. Currently, it has a widespread utilization in the nuclear and aerospace industry, being mainly applied to steel characterisation. Thanks to its potential, especially for the reduced size of the samples and shorter testing times than the conventional tests, its application in light alloys has been proposed. The use of light alloys in several sectors is growing continuously, since they contribute to reduce the weight of components. In this work, the behaviour of the magnesium alloy AZ31 has been analysed at temperatures between 398 K and 523 K. A relationship between conventional and SPC tests has been established, by comparing time to rupture, as well as the Larson-Miller (LM) and Orr-Sherby-Dorn (OSD) parameters. On the other hand, the LM and OSD parameters have been obtained from the results of the SPC tests (turned into their equivalent uniaxial values) and they have been compared to the ones derived from the conventional tests, confirming the potential of this testing technique and its accuracy for the extrapolation of times to rupture in creep conditions.

1. Introduction

The number of applications of light alloys is continuously growing, mainly due to their low-density values and specific resistance. Such a development is encouraged by the current search for lighter components, in order to improve efficiency and reduce the energetic consumption. As a result, these materials are taking the place of other traditionally used materials, such as steel, in diverse industrial sectors, as for example, the transportation industry.

Among light alloys, the magnesium-based alloys have an outstanding role, characterized by density values four times smaller than steel and a great specific resistance [1]. AZ31B is the most widely available of the magnesium grades. It is usually produced in plate or sheet form and it is employed for room temperature or relatively high temperature applications, mainly in the automotive industry [1]. This alloy, as generally all light alloys, exhibits a relatively low melting point, at approximately 600 °C. Consequently, it is vital to know the behaviour of these materials in relatively high temperature working conditions, since they can be affected by different phenomena, as creep.

In this work, the characterization of AZ31 alloy by means of the Small Punch Creep test has been proposed. This testing technique, developed in the 90s [2], allows the assessment of actual components using a limited volume of material. Therefore, it can focus on critical locations regardless of the components geometry, which would be impossible to achieve by means of conventional methods.

In order to characterize AZ31 alloy in creep conditions, conventional and Small Punch Creep tests have been performed at different temperatures, ranging in between 398 K and 523 K, at different stresses. Experimental results have been used to obtain a relationship between both testing techniques by comparing times to rupture, as well as the usual extrapolation parameters (Larson-Miller and Orr-Sherby-Dorn). Creep design curves have also been obtained from the Small Punch results, once they had been turned into their equivalent uniaxial values, confirming the suitability of the method to perform such assessments.

2. Experimental procedure

2.1. Material

AZ31 magnesium-based alloy has been selected for this study. The material was provided in plates, whose composition is shown

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http://dx.doi.org/10.1016/j.tafmec.2016.08.004
0167-8442/

Please cite this article in press as: D. Andrés et al., Application of the Small Punch Creep test to predict times to rupture on magnesium alloys, Theor. Appl. Fract. Mech. (2016), http://dx.doi.org/10.1016/j.tafmec.2016.08.004

in Table 1. The same material has been tested in two different ways, employing a 1 mm-thick plate for the temperatures ranging in between 398 K and 448 K, and a 20 mm-thick plate for the rest.

Regarding conventional uniaxial creep tests (UAC), two different specimen geometries have been used. 6-mm diameter cylindrical specimens and 1 mm-thick and 6 mm-wide flat specimens have been tested, both according to the recommendations of ASTM E139-11 [3]. Besides, several directions have been analysed: rolling direction, 45° and perpendicular to the rolling direction.

As for Small Punch tests, 10 × 10 mm square specimens have been employed, according to the recommendations of the European Code of Practice (CoP) [4] and to previous works [5]. Specimens have been obtained from the 1 mm-thick plate by means of waterjet cutting and by means of a liquid-cooled cut-off machine from the 20 mm-thick plate, as seen in Fig. 1, resulting in 0.55 mm-thick pieces in the latter. Afterwards, specimens have been ground until achieving the desired thickness of 0.5 ± 0.005 mm, according to CoP [4].

Table 1
Alloy composition (wt.%).

Al	Zn	Mn	Cu	Fe	Ni	Mg
3.1	1.05	0.54	0.0008	0.0035	0.0007	Bal.

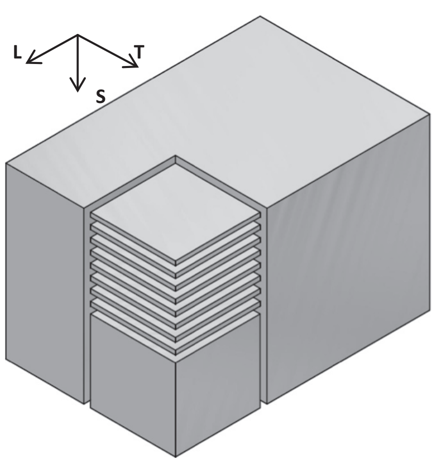

Fig. 1. Scheme of the orientation of the SPC specimens in the 20 mm thick plate.

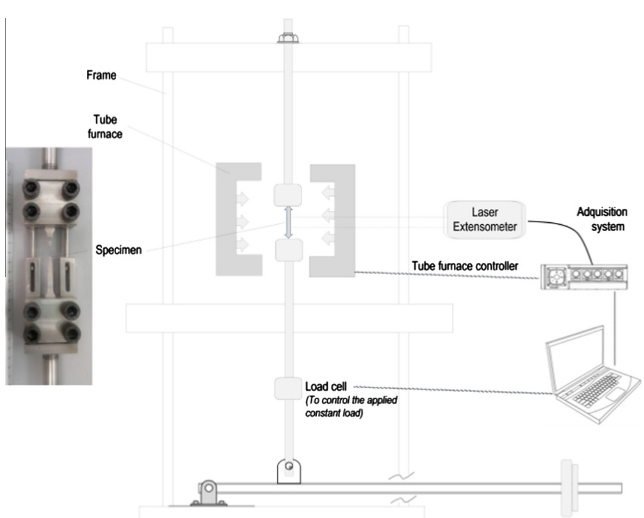

Fig. 2. Scheme of the applied set-up for UAC tests [6].

2.2. Experimental set-up

Conventional creep tests have been performed according to the recommendations of ASTM E139-11 [3]. Tests have been carried out in two different laboratories: temperatures in between 398 K and 448 K at the University of Burgos (UBU) and 473 K and 523 K at the University of Cantabria (UC). Experimental set-ups similar to the one shown in Fig. 2 have been used in both cases.

Regarding Small Punch Creep tests, tests have been carried out according to the recommendations of CoP [4]. Tests have been performed in a similar way to the UAC tests, both in UBU and UC. A scheme of the applied set-up is shown in Fig. 3.

3. Results

The obtained results can be seen in Fig. 4, where the different isotherm curves for both testing methods can be seen. Some scatter in the results is perceived, possibly due to the heterogeneities present in the material and to the scatter inherent to the creep phenomenon. Some parallelism between the curves obtained for each testing method can also be noticed.

As can be seen in Fig. 5, AZ31 exhibits a ductile failure in the analysed conditions. UAC specimens show a great cross-sectional area reduction and large strains. Rupture in SPC specimens has a cap appearance, which indicates a high ductility of the material. Besides, growth and coalescence of microvoids mechanisms can be seen in the rupture surfaces of the specimens.

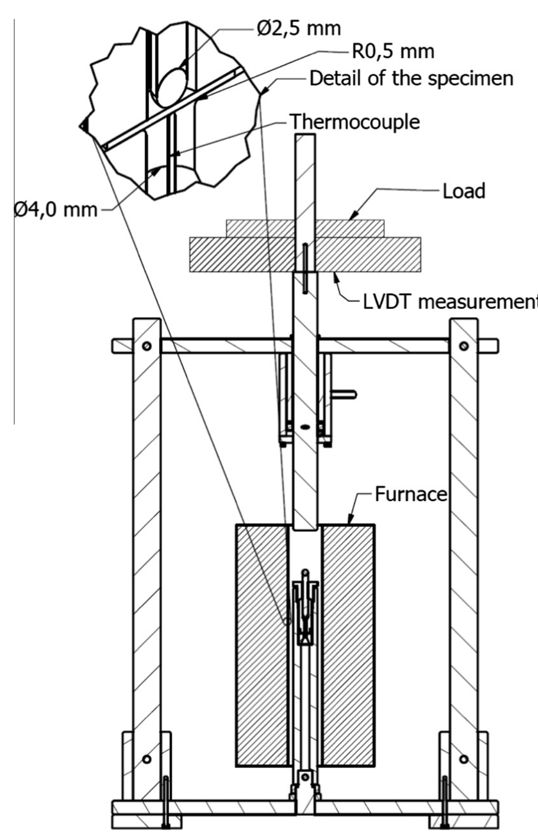

Fig. 3. Scheme of the applied Small Punch device.