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Determination of the creep crack initiation properties using pre-cracked small punch tests

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ABSTRACT

The use of pre-cracked small punch creep test specimens (*p-SPCT*) is analyzed in this paper as an alternative method to obtain the Creep Crack Initiation (*CCI*) time in those cases where there is not enough material to use *CT* specimens. The material selected was an AZ31B magnesium alloy. The geometry of the specimens used was 10×10 mm square with a thickness of 0.5 mm. An initial crack-like notch was created in the SPT specimens by means of a laser micro-cutting technique. Conventional compact specimens (*CT-20*) were tested at $T = 150\,°C$ as a reference for *CCI* determination. The definition of an equivalent load for *p-SPCT* was seen to be a good methodology, and a λ parameter was defined to convert the *p-SPCT* to an equivalent $C(T)$ load that produces the same CCI time. The influence of temperature and material on the λ parameter still remains to be investigated.

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1. Introduction

In order to assess the reliability of components continually exposed to high temperatures, such as those working in power generation plants, accurate methods to predict the time for Creep Crack Initiation (*CCI*) and the rate of the Creep Crack Growth (*CCG*) are required.

With respect to this, creep crack initiation and early growth constitute the most important part of the life of the piece under creep conditions. However, this initial stage of the creep process shows a large fluctuation of the crack incubation time and growth of small cracks. These fluctuations are mainly caused by the randomness in the grain size and are due to differences in local stress and local resistance to failure [1,2]. It is common practice to predict crack initiation in terms of creep damage accumulation in a process zone ahead of the crack tip. Another commonly used approach for creep crack initiation is based on the attainment of a critical crack opening displacement.

For creep-ductile materials substantial creep deformation accompanies the onset of fracture, and stress redistribution will occur at the crack tip that makes K not adequate to describe the local stress field at the crack tip. In those cases, the use of C^* integral has been widely used as a parameter for correlating *CCG* under steady-state creep conditions [3].

According to ASTM E-1457 Standard Test Method for measurement of Creep Crack Initiation and Creep Crack Growth in metals [4], the recommended specimen is the standard compact tension specimen $C(T)$ with $B/W = 0.5$ and pin loaded in tension under constant loading conditions. Side-grooved specimens are recommended to assure uniform crack extension across the thickness of the specimen [5]. Equations to obtain C^* from $C(T)$ specimens are well known and perfectly established.

Nevertheless, the use of geometries other than $C(T)$ are allowed provided the calibration functions for K, J or $C^*(t)$ are available. In any of the cases, data for other geometries must be compared to data obtained from $C(T)$ specimens, which is usually considered as the reference geometry.

On the other hand, the small punch test (SPT) is a relatively new technique that has been proven useful to obtain the mechanical and fracture properties of metallic materials [6–10], in those cases where there is not enough material for carrying out conventional tests. It has also been shown to be useful for the determination of creep properties [11–14]. Creep tests on a small scale have the potential to be used without significant loss of material or in areas where the available material is limited.

In this paper, the use of precracked miniature specimens is discussed in order to validate the Small Punch Creep Tests on pre-notched specimens (p-SPT) as an alternative creep crack initiation testing practice applicable in those cases where there is not enough

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material for the realization of conventional tests, such as the *C*(*T*) reference test.

Thus, the proposed approach involves establishing a correlation between the *p-SPT* and the *C*(*T*) standard tests so that the load applied in *p-SPT* creep test can be converted into an equivalent *C*(*T*) load. Consequently, the objective is not to calculate the $C^*(t)$ value for the miniaturized specimens, but to use the $C^*(t)$ well-known equations for *C*(*T*) specimens, using an equivalent load obtained from *p-SPT* tests.

2. Material data

The material considered in this work is an AZ31-B magnesium alloy. It has a poor creep resistance at temperatures above 125 °C. The chemical composition of this alloy is presented in Table 1 and the mechanical properties of the alloy at a temperature of T = 150 °C are summarized in Table 2.

The microstructure of the as-received material AZ31-B alloy is shown in Fig. 1. After polishing, specimens were etched using a solution of acetic-picral (100 ml of ethanol, 5 g of picric acid, 5 ml of acetic acid and 10 ml of water) to reveal second phases, twins and grain boundaries. The microstructure of the alloy consists of a matrix of α-Mg with fine particles that are homogeneously distributed. The fine particles were identified as $Mg_{11}Al_{12}$ phase by X-ray diffraction technique (XRD).

3. Creep crack initiation testing

3.1. Creep crack initiation testing on C(T) specimens

For creep crack growth testing the standard compact tension specimen *C*(*T*)-*20*, pin loaded in tension under a constant load was selected. The geometry and main dimensions of the *C*(*T*) specimen are shown in Fig. 2. The specimens were side-grooved to promote uniform crack growth across the thickness.

In common practice for creep crack initiation and creep crack growth testing two different methods to provide the crack starter are used: (a) fatigue pre-cracking, and (b) the use of an electric-discharge machined notch. Although the influence of the crack starter type on the creep crack growth progress can be disregarded, it is an important factor for the evaluation of the creep crack initiation time. In this paper, the fatigue pre-cracking method was used on compact *C*(*T*) specimens at room temperature, to obtain an initial crack between $0.45 < a_0/W < 0.55$. The crack front obtained after pre-cracking, presented in Fig. 3, shows a uniform crack along the thickness of the specimen. The maximum force during fatigue pre-cracking was less than 60% of the load used during creep crack growth testing.

In order to obtain the required crack length during the test, the partial unloading compliance method was used. Details about the procedure of this method, using a servo-mechanical loading machine capable of maintaining a constant force can be found in ECCC Recommendations for Testing Practices For Creep Crack Initiation [1,3], in the ASTM E1457 Standard Test Method for Measurement of Creep Crack Growth Rates in Metals [4] and in the E 1820 Test Method for Measurement of Fracture Toughness [5].

Table 1
Chemical composition of AZ31-B Mg-alloy (ASTM B90/B90M), % weight.

Al	Zn	Mn	Si	Cu
2.5–3.5	0.6–1.4	0.2	0.1	0.05
Ca	Fe	Ni	Others	Mg
0.04	0.005	0.005	0.3	Balance

Table 2
Mechanical properties of AZ31-B Mg-alloy.

Sy (0.2%)	Su (MPa)	E (MPa)	A (%)
129 MPa	185	30,200	0.33

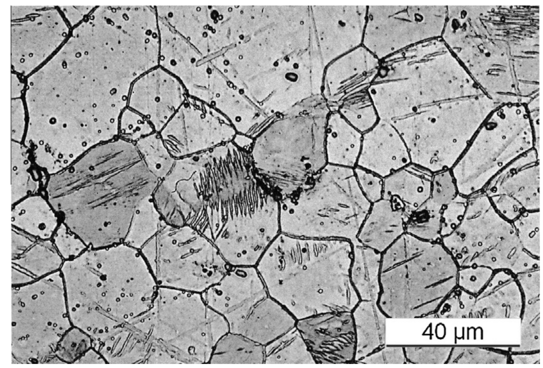

Fig. 1. Microstructure of AZ31B Mg-alloy.

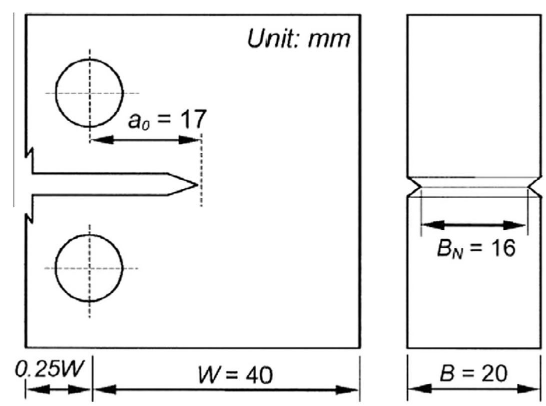

Fig. 2. Compact tension *C*(*T*), ASTM E1457-00.

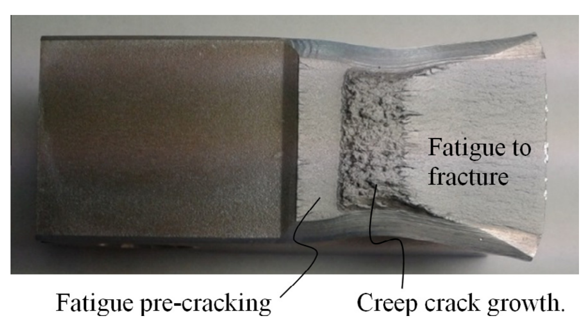

Fig. 3. Aspect of creep-crack-growth in a *C*(*T*) specimen.

Following these recommendations, during the tests the crack size and the load-line displacement versus time were recorded. For crack size determination along the test, a partial unloading was performed every 120 s, and using the slope of the load-line displacement the crack size is determined using the equations collected on Annex 2 of Special Requirements For Testing Compact Specimens (E1820) [5].

As unloading during the test for determining crack length can affect stress redistribution, and consequently the creep response of the material, the unloading-reloading process was carried out in a short period of time of 2 s and not exceeding a 20% of the

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