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Influence of biaxial pre-deformation on fracture properties using pre-notched small punch specimens

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ABSTRACT

In recent years, the pre-notched or pre-cracked small punch test (P-SPT) has been successfully used to estimate the fracture properties of metallic materials in those cases where there is not enough material to identify these properties from standard tests, such as the CT or SENB specimens. The P-SPT basically consists of deforming a pre-notched miniature specimen, whose edges are firmly gripped by a die, using a high strength punch. The novelty of this paper lies in the estimation of the fracture properties using the P-SPT on a material previously subjected to a biaxial deformation by the Marciniak stretching test. The obtained results show a linear decreasing fracture toughness tendency under the influence of biaxial pre-strain in plane stress conditions.

1. Introduction

In recent decades, the reduction of CO_2 emissions by means of weight reduction in vehicle components has been and continues to be a main objective in the automobile industry. This usually means replacing traditional materials such as steel for lighter and newer generation materials such as light alloys.

Stamped aluminum alloy components tend to be the most commonly used of the light alloy components. For accurate design of these stamped components, it is necessary to know how the manufacturing process affects the mechanical and fracture behavior, because high strains are reached during the stamping process. It is well known that these high states of deformation may significantly affect the material properties [1–4].

As a consequence, it is necessary to know how the mechanical and fracture behavior of the material is affected by the deformation generated during the stamping process, which is generally in biaxial mode. This information can be obtained using the small punch test (SPT) since it is an optimum test, one developed in the nuclear field in the eighties [5], to evaluate mechanical behavior when there is not enough material to carry out standard tests. It basically consists of punching a small specimen embedded in a die, and it has been used successfully on numerous occasions [6,7] in which there is little material, such as in the case of welds or irradiated material. The experimental setup can be consulted in the CEN Code of Practice for small punch testing [8], and a diagram of the small punch test device can be seen in Fig. 1. The SPT has also been used to estimate material fracture properties [9], and in recent years even pre-cracked [10] or pre-notched [11,12] specimens have been used effectively for this purpose.

In this paper, pre-notched specimens have been used to estimate the fracture toughness based on energy parameters for different levels of biaxial pre-deformation. The Marciniak stretching test was used to reproduce the biaxial deformation

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Nomenclature

a, a_1, a_2	specimen notch lengths
D_d	lower die diameter
d_p	punch diameter
J, J_{Ic}, J_Q	fracture toughness
P_{max}	maximum load
r	fillet radius
U	absorbed energy by the specimen
U_1, U_2	energies under the load–displacement curve
v	punch drop rate
t	thickness of the specimen
ε	biaxial plastic deformation

occurring in the stamped component [13]. This test is used in sheet metals to obtain information about the maximum formability of the material indicated by the Forming Limit Curve (FLC). It uses a flat punch to deform the sheet, where it is possible to achieve a nearly homogenous biaxial strain/stress on the flat surface. Using this method, it is possible to obtain different levels of biaxial pre-straining by simply varying the height of the drawing test.

The novelty of this study lies in the combined use of the Marciniak stretching test and pre-notched small punch specimens to analyze the influence of the amount of biaxial pre-deformation reached during the stamping process on the fracture properties of an aluminum alloy.

2. Material

As a general rule, a cold rolled sheet of the 5000 series (aluminum–magnesium), which is characterized by a percentage of magnesium that can vary between 0.7% and 4.9% depending on the alloy selected, is the base material in stamped components in the automotive industry. For this study, AW 5083 H111 aluminum alloy with an initial sheet thickness of 1.5 mm was selected. Table 1 shows the chemical composition of this alloy.

The Marciniak test, following the ISO12004 standard [13], was used to obtain the biaxial pre-deformation. Square samples (200 × 200 mm) were deformed using a flat punch, 100 mm in diameter, to achieve different levels of biaxial plastic deformation ε (approx. 5%, 10%, 15% and 25%). Tests were carried out with a double-acting hydraulic press, with 1500 and 500 kN drawing capacity in the top and bottom pistons, respectively. The bottom piston is used to avoid material sliding (to prevent any drawing) and to achieve material stretching, while the top piston is used to deform the samples. The press-holder is equipped with a circular brake to avoid material sliding. All tests were done at 1.0 mm/s punch velocity. Strains were calculated using ARAMIS software, a system for optical 3D deformation analysis developed by GOM mbH. This software is based on two CCD cameras, which measure the deformation on the sample surface. A stochastic pattern must be applied (using spray paint) on the surface to accurately follow the deformation during the test [14].

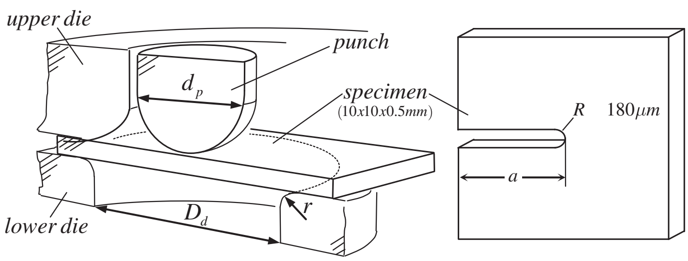

Fig. 1. Small punch test device and pre-notched small punch specimen.

Table 1
Chemical composition of AW 5083 H111 aluminum alloy.

Mn (%)	Si (%)	Cr (%)	Cu (%)	Pb (%)	Fe (%)	Ti (%)	Mg (%)	Al (%)
0.436	0.186	0.083	0.063	0.016	0.393	0.012	4.449	Rest