ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 17 (2017) 365–374

Available online at www.sciencedirect.com

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

Original Research Article

Influence of heterogeneities introduced into the modelling of a ring compression test

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ARTICLE INFO

Article history:
Received 5 April 2016
Accepted 19 November 2016
Available online

Keywords:
Heterogeneous models
Plasticity
Elasticity
Ring compression test

ABSTRACT

This paper analyses the influence of heterogeneities introduced into the constitutive model of Aluminium alloy 6060. Two types of modelling are hereby presented: a standard phenomenological homogeneous model and a compartmentalized hybrid model, the formulation of which is based on the physical phenomena underlying plasticity. The mechanical parameters needed to establish such models are determined by two different experimental tests: a uniaxial tensile test and a ring compression test. The ability of such models to simulate a forming operation that differs from the operation used to determine their parameters will then be discussed.

1. Introduction

The use of phenomenological homogeneous models allows to simulate the behaviour of materials during a specific forming operation. The mechanical characteristics of the material, which are necessary to establish these models, are usually determined by experimental testing close to the process to be simulated. However, the scope of validity of such modelling remains limited. Its application appears to have little relevance as part of the simulation of a forming process that uses strain mechanisms that differ from those observed in the tests allowing to identify the parameters of the model. Indeed, the phenomenological models do not take into account, by definition, the physical phenomena causing strain in metallic materials. This paper highlights the risks involved in the use of a phenomenological model identified in a test to simulate a different test, switching from a tensile test to a radial ring compression test. The latter test has been selected because this study falls within a process of collaboration with the bar-turning sector, considering the tube is one of the most widely used source materials in this context. The simulation of the compression test is performed using two models: an elastic–plastic phenomenological homogeneous model in which work-hardening is described through the Hollomon's power law and a compartmentalized heterogeneous hybrid model. The latter is based on the consideration of a certain degree of local heterogeneity of the material which is intrinsic to the deformation mechanisms of metallic materials. A uniaxial tensile test simulation is also carried out by means of these two models. This is justified by the fact that tensile test is the most commonly used test to identify the mechanical

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http://dx.doi.org/10.1016/j.acme.2016.11.002

characteristics of a material. First, the parameters of the phenomenological model are identified both in the ring compression test and uniaxial tensile test. Second, the same procedure is used to determine the parameters of the compartmentalized hybrid model. Finally, each test is simulated using the set of parameters identified in the other test type. The comparison of the results allows to draw conclusions about the relevance and the capacity of each model to be transposed into the simulation of a forming operation that differs from the operation used in its identification.

2. Methods

The method used in this paper first consists of identifying the parameters of the elastic modelling of the material by means of the ring compression test. Then, the work-hardening parameters are identified by an optimisation procedure designed for two different types of modelling (phenomenological and hybrid) of either one of the experimental tests: the ring compression test or the uniaxial tensile test. For the ring compression test, the reference curve is the one that binds the force to the platen displacement. For the uniaxial tensile test, the reference curve is the one that binds stress to strain.

In this paragraph, the material is first presented. Then, the 2 experimental tests studied are detailed: the ring compression and the uniaxial tensile test.

2.1. *Material*

The material used for the study is a 6060-T6 Aluminium tube (AW-AlMgSi), outside diameter $r_0 = 100$ mm and wall thickness $t_0 = 5$ mm. The mechanical characteristics on the data sheet supplied with the material (manufacturer data) are shown in Table 1.

2.2. *Testing machine*

The SYMME laboratory developed a miniature testing machine to characterise the mechanical properties of materials. This project results from a real need of manufacturers in response to the variability of materials: batches of source materials, with the same designation, show however great differences in their material parameters (E, R_e, R_m, $A\%$) and their mechanical behaviour is therefore unlike during the production of parts. This leads to regular set-up phases of the production machines that mostly imply the expertise of set-up men. Therefore, this handheld testing machine was primarily designed to enable manufacturers to quickly and easily access the mechanical characteristics of their materials so that they can anticipate the set-up of their production means. The goal is then to use this characterization tool upstream of the production line to test the source material upon arrival. For instance, a strip of material is cut out into the source material batch. The material is then tested either by tensile testing or shear testing. Alternatively, a specific test may be developed according to a particular forming. This is the case, for example, of the radial ring compression test. The machine provides this testing option. Actually, a manufacturer/laboratory partnership was established during the machine development to work on the issue of the forming of thin-walled steel tubes by flow forming [1]. A speckle is applied on the specimen surface to measure synchronously the force and the displacement field by image correlation using the software 7D [2,3]. The speckle can be made with paint, as in this case, or using electrochemical marking. The test is filmed until failure by means of this camera, allowing with an appropriate post-processing to get the deformations across the specimen. The overall behaviour of the source material batch is thus exactly known and enables to automatically find out its elastic and plastic characteristics.

2.3. *Radial ring compression test*

The rings used in this study were machined by turning process from this source material. The geometry of the rings is defined by an outer radius r_0, a wall thickness t_0 and a tube length l_0. These dimensions were measured from the experimental samples and are shown in Table 2. Such dimensions are the same for all 3 rings subjected to the radial compression test.

The radial ring compression test is a characterization method which allows to analytically determine some mechanical properties of a tube-shaped material using experimental data. The test consists of compressing a ring based on its radial direction between two platens. There is a moving platen and a fixed platen. The principle behind this test is illustrated in Fig. 1a. When the moving platen moves, the ring deforms (Fig. 1c)) and the plastic deformation is mainly located in two areas which appear as hinges (C and D in Fig. 1a). It should be noted that regions A, B, C and D display an anticlastic bending phenomenon. In A and B, the deformed area is convex. In C and D, the deformed area is concave. Reddy and Reid [4–6] reveal that the values of the Young's modulus and the yield strength are determined using the force vs. displacement curve of the radial ring compression test. By varying the platen surface condition, they also show [6] that the friction coefficient value between the compression platens and the ring has minimal impact on the final geometry and the force value. This is due to the absence of sliding between the tube outer surface and the compression platens. The typical force vs. displacement curve of the ring compression test is shown in Fig. 2. In this curve, the ordinate of the point of intersection between the tangent for the elastic zone and the tangent for the plastic zone is noted P_{cr}. Its abscissa is noted δ_{cr}. P_e and δ_e are respectively ordinate and abscissa of a point

Table 1 – Mechanical characteristics of the material Al 6060-T6 (manufacturer data).

State	Wall thickness (mm)	R_m (MPa)		$R_{p_{0.2}}$ (MPa)		A (% min)	A_{50} (% min)
		Min	Max	Min	Max		
T6	≤15	160	–	120	–	8	6