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Validation of numerical model by means of digital image correlation and thermography

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Abstract

This paper presents experimental and numerical investigation of elasto-plastic-damage behaviour of aluminium alloys. The experimental procedure includes static and dynamic tensile tests at different strain rates as well as three point bending tests. Numerical modelling of deformation and failure process of the flat specimens is conducted by using non-isothermal elastoplastic damage constitutive model and two-dimensional plane stress finite elements. During the experiment the displacement and temperature distribution on the specimen's surface is measured by digital image correlation (DIC) method and infrared thermography (IR). This has enabled more precise calibration of material parameters in constitutive relations.

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Keywords: experiment; digital image correlation (DIC); aluminium alloy; thermography; finite element method; thermoplasticity

1. Introduction

New demands on reliability and safety, together with the applications of new materials and new production technologies, can only be realized by methods of advanced structural analysis and more realistic description of material behavior. Material plasticity and damage modeling is the basis of the integrity estimation, design and optimization procedures of structural elements. As with most other problems, the numerical simulations are increasingly replacing or complementing more expensive experiments. Application of the finite element method enables simulation of the deformation process of material up to complete fracture of structural component.

On the other hand, numerical simulations are as powerful as the physical and mathematical models behind them. Material model description, defined by constitutive relations as well as validity of the algorithm for solving constitutive equations at the integration point level, have significant influence on accuracy of numerical methods [1]. Detecting material deformation, plastic yielding and damage processes in material was always of great importance in experimental mechanics. For the precise

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determination of material parameters in constitutive models, the goal of the research presented in this paper is to perform an algorithm that allows a direct comparison of numerical results with experimental measurements. Here, the experimental results are obtained by optical measuring system ARAMIS 4M [2] (from GOM mbH) what enabled us to analyse the displacements and strains on the whole specimen surface [3]. This enables the derivation of new original and efficient numerical algorithms for modelling complex deformation processes of engineering materials, with which numerical simulation is brought closer to the real behaviour of structural components. Besides, the thermoelastic stress analysis (TSA) is used as a full field method providing stress distribution of elastically cyclic loaded specimen. In our previous work we have several times applied thermal imaging, based on fast cooled infrared (IR) camera, for tracing plastified zones in metals and metal foams [4-6]. In order to be more confident with our approaches in evaluation of plastic yielding, the IR method has been compared with the digital image correlation method. Both methods have been compared based on tensile tests, proving that IR thermography can be used as a full field method applicable for evaluating plastification processes in materials.

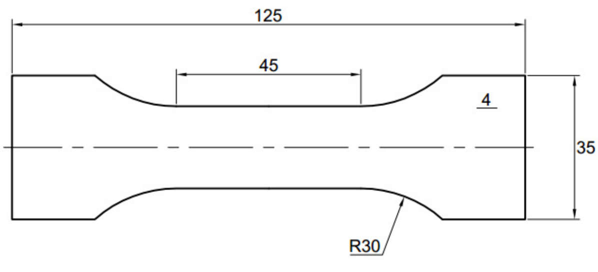
The paper is organized as follows. Section 2 contains a description of the experimental investigations. In Section 3, the numerical formulation is described. The detailed quantitative comparisons of the experimental and numerical results are summarized in Section 4. Finally, some concluding remarks are given in the last section.

Nomenclature

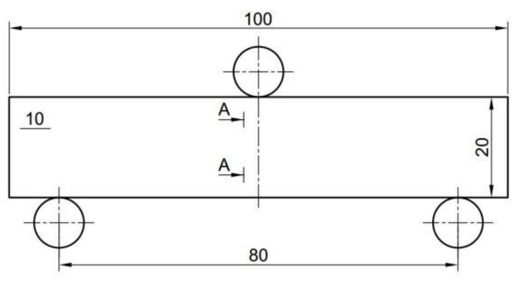
c	specific heat capacity
E	Young's modulus
α	coefficient of thermal expansion
λ	thermal conductivity
μ	friction coefficient
ν	Poisson's ratio
ρ	density
$\sigma_{0,2}$	yield stress
σ_{M}	tensile strength

2. Experiments

The two different aluminum alloys are investigated in this study. The flat specimens, whose geometry is illustrated in Fig. 1.(a) made from aluminium alloy Al2024-T3 are used in tensile tests. Chemical composition of alloy Al2024-T3 is as follows: 0.1Cr, 3.8Cu, 0.5Fe, 1.2Mg, 0.3Mn, 0.5Si, 0.15Ti and 0.15Zn. The tensile tests are conducted at the three different cross-head separation rates: 0.0125 mm/s, 1 mm/s and 10 mm/s. The specimens illustrated in Fig. 1.(b), used in three point bending test, are made from aluminium alloy AlCu5BiPb-T8 which has following chemical composition: 0.4Si, 5Cu, 0.7Fe, 0.4Pb, 0.4Bi and 0.3Zn. The tensile stress-strain curves are shown in Fig. 2. For quasi static tensile test mechanical characteristics of aluminium alloy Al2024-T3 are as follows: yield stress $\sigma_{0.2}$ = 385.9 MPa, tensile strength σ_{M} = 493 MPa, Young's modulus E = 72.56 GPa, Poisson's ratio ν = 0.33 and density ρ = 2780 kg/m^3. Thermal properties of material necessary for numerical simulation are taken from [7]: coefficient of thermal expansion α = 23.2 µm/K, specific heat capacity c = 875 J/(kgK) and thermal conductivity λ = 121 W/(mK). In addition, the mechanical properties of alloy AlCu5BiPB-T8 are taken from [8]: $\sigma_{0,2}$ = 305 MPa, σ_{M} = 400 MPa, E = 76.7 GPa and ν = 0.3.



(a)



(b)

Fig. 1. Specimen geometry: (a) tensile test flat specimen; (b) three point bending test specimen.