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Experimental testing and numerical analysis of FDM multi-cell inserts and hybrid structures

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ABSTRACT

Modern transportation systems require light materials with an increased level of protection thus thin walled structures are in the focus of structural engineers. The latest developments in the field of manufacturing processes allow the use of Rapid Prototyping technologies for custom safety devices and Additive Manufacturing is a candidate that already captured some attention. In this work Fused Deposition Modelling method was used to manufacture samples for material characterization and multi-cell insert designed as safety devices and the material is ABS. Traction tests were performed and some SEM images complete the specimens' analysis. From this analysis, in order to define a simple material model for numerical analysis, a stacking configuration -45°/0°/45°/90° was selected. A model for material damage is also presented in this paper. Circular structures with rectangular multi-cell were manufactured and tested in compression. In order to improve the performances a hybrid structure was investigated. Aluminium tubes were added in order to enhance the performances of the printed structures. For each step of the experimental work a numerical companion is presented. Modelling techniques and parameters are presented and discussed in this paper. By adding the aluminium tube there is an increase in the performances of the structure. A progressive profile for the crushing force is obtained. By adjusting the support (outer aluminium tube) and designing multi-cell insert, structures for safety enhancement can be developed.

1. Introduction

Modern transportation systems require an increased level of protection thus, due to the increased number of add-on devices fitted on board the mass of the supporting structure should be as low as possible but at the same time it must provide the maximum level of protection during a collision. As a consequence, thin walled structures are in the focus of structural engineers especially when crashworthiness is addressed. These structures demonstrate a high energy absorption capacity for a relatively reduced mass, thus being a reliable solution when the total mass of the construction is critical. The modern analysis of thin walled structures with circular section has a strong background in work of Abramowicz and Jones [1], Hsu and Jones [2], Wierzbicki et al. [3] and Reid [4], while the structures with a rectangular cross-section were investigated by Abramowicz and Jones [5] and Wierzbicki and Abramowicz [6]. In order to improve the structural performance , multi-cell structures were designed and studied by Alavi Nia and Parsapour [7], Costas et al. [8], Jusuf et al. [9] Qiu et al. [10] and Zhang and Zhang [11–13]. A recent review paper of Baroutaji et al. [14] outlines the findings in field of thin-walled structures designed as energy absorbing devices. The use of multi-cell structure is an effective method to increase the energy absorption while keeping a reduced mass of the finished part. These structures can be manufactured by extrusion or, for research purposes, by cutting from a solid block. This work is focused on the investigation of circular multi-cell structures, previously investigated by developing a theoretical model for the evaluation of the crushing force [11,15]. The latest developments in the field of manufacturing processes allow the use of Rapid Prototyping technologies for custom safety devices. Rapid Prototyping includes sets of technologies used to produce complex parts [16] in limited series. The parts can be used for design and functional analysis and in some cases as structural components, like multi-cell structures that are in the focus of the present study. The performances of the finished parts are however dependent on the technology employed for the manufacturing process [17–19].

Among Rapid Prototyping technologies is Additive Manufacturing which consists in building parts layer by layer. Due to the relatively simplicity of the equipment, 3D Printers are widely used as Rapid

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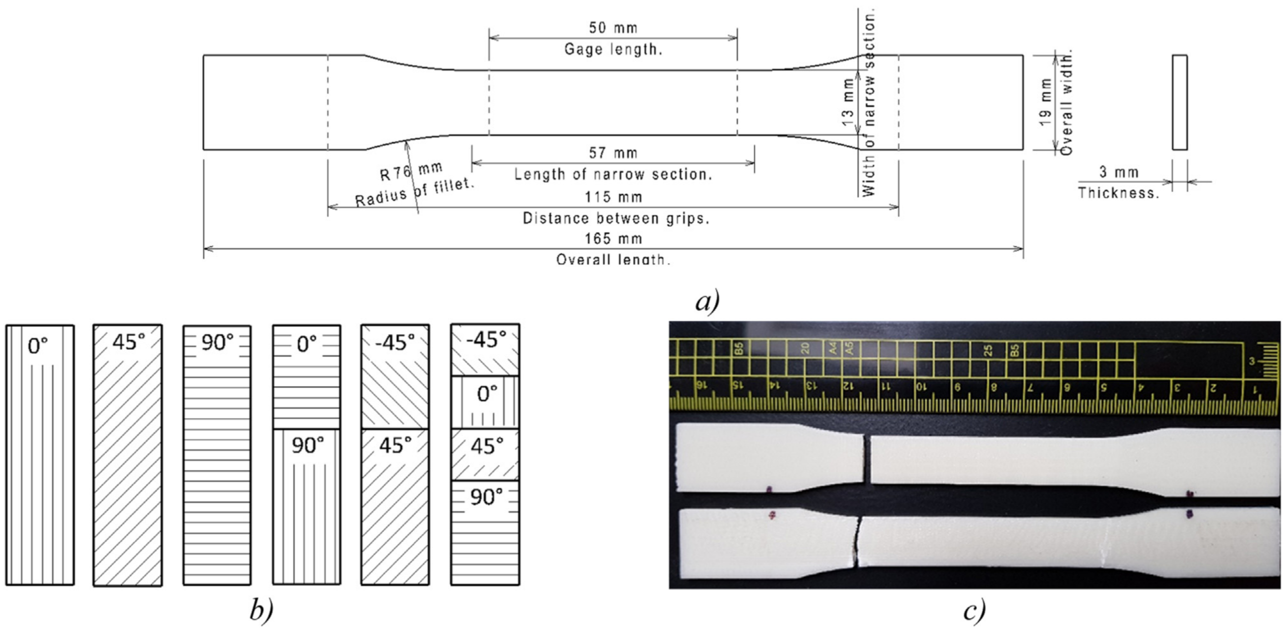

Fig. 1. Fused deposition modelling samples (ABS). *a)* sample dimensions - ASTM D638 (Type I); *b)* stacking sequence; *c)* sample(s): top stacking sequence 90°, bottom stacking sequence 0°.

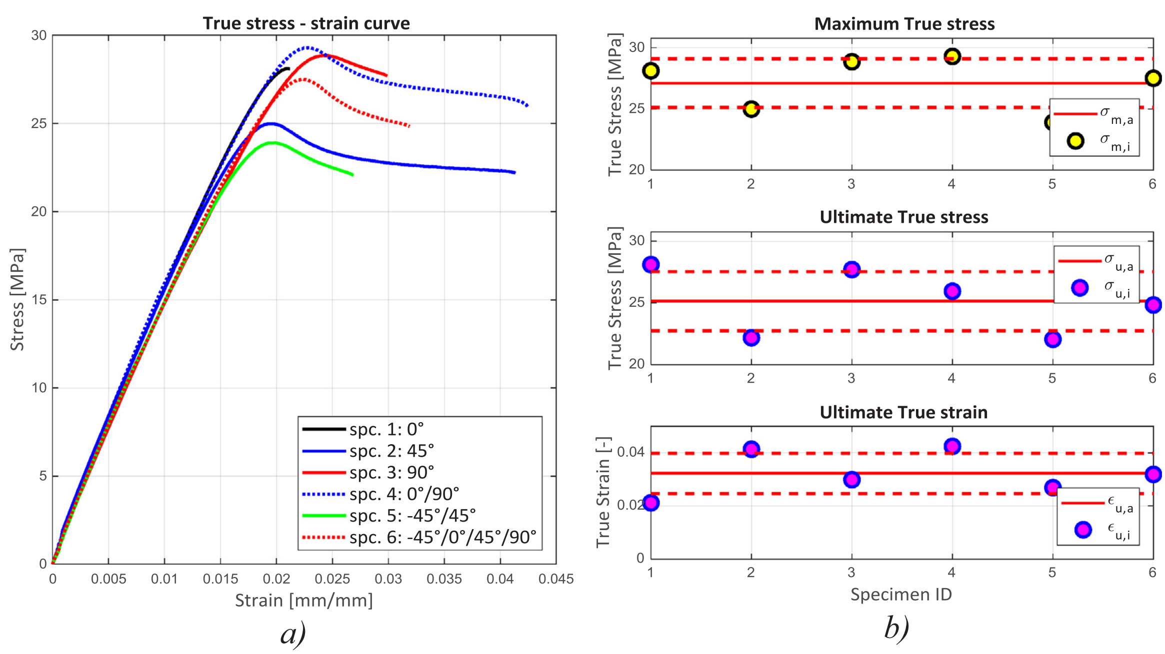

Fig. 2. Tensile test results. *a)* true stress – strain curves; *b)* synthesis of maximum stress, ultimate stress and ultimate strain.

Prototyping tools for general engineering or even beyond this field [20,21]. The manufacturing process is in the focus in order to improve functionality of the parts by applying optimization techniques [22–25]. Energy absorbing devices can be manufactured also by 3D printing by reproducing biostructures [26], designing specialized parts [27] or just by simple structures [28]. The work of Kucewicz et al. [29] investigates experimental data and modelling techniques for cellular structures manufacture by ABS.

Although the raw material exhibits a set of mechanical properties, the built parts may not display the same properties as the one manufactured by using a conventional process (e.g. injection moulding). A simple explanation is provided by the manufacturing process itself as the junction between subsequent layers is provided by locally melting existing material [30] with some possibilities to control this process by heating the build plate or conditioning the environment [31]. For the present work a conventional 3D printer, the MakerBot Experimental 2X [28,30,32], was used.

Individual components like an empty aluminium tube and an ABS multi-cell structure manufactured by Fused Deposition Modelling will be investigated. The shape of the metallic structure was defined as circular because it can collapse in an axisymmetric mode, while for the circular multi-cell structure it is a situation in which the structural performances, by the means of experimental methods, can be evaluated and results compared with theoretical solution [15]. Furthermore a hybrid structure [33–38] defined as a combination between an aluminium tube and the multi-cell insert was investigated as a solution to improve the crushing performances of the ABS multi-cell insert by constraining its collapse mode and recent work of Chen et al. [38]