MICROSTRUCTURALLY INFORMED HIGH-VELOCITY IMPACT EXPERIMENTATION ON ADDITIVELY-MANUFACTURED METALLIC MATERIALS

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Abstract

This work presents a flexible experimental setup to study dynamic fragmentation of additively-manufactured metallic materials using two different configurations: (i) rapid *axial penetration* of thin-walled tubes, and (ii) rapid *radial expansion* of rings. In the first approach, the experiment consists of a light-gas gun that fires a conical nosed cylindrical projectile that impacts axially on a thin-walled cylindrical tube fabricated by 3D printing. The diameter of the cylindrical part of the projectile is approximately twice greater than the inner diameter of the cylindrical target, which is expanded as the projectile moves forward, eventually breaking into fragments. In the second approach, using a similar technique, a ring is inserted over a high-ductility tube, which expands after penetration by the conical projectile, pushing the metallic ring radially outwards, ultimately breaking into multiple fragments. The experiments have been performed for impact velocities ranging from 180 m/s to 390 m/s. A salient feature of this work is that we have characterized by X-ray tomography the porous microstructure of selected specimens before and after testing. Moreover, two high-speed cameras have been used to film the experiments and thus to obtain time-resolved information on the mechanics of formation and propagation of fractures.

1. Introduction

The ring expansion test developed by Niordson [Exp. Mech. 5, 1965] was a turning point in the experimental research on dynamic localization and fragmentation of metallic materials. In this impact experiment, a circular ring specimen is expanded at large velocities up to two or three hundreds of meters per second by detonation of an explosive charge [Diep et al., 21th Int. Symp. Ballistics, 2004] or by application of transient magnetic fields [Grady & Benson, Exp. Mech. 12, 1983]. In the magnetic loading technique the loading rates are readily controlled trough variation of the driving current pulse, it shows the drawback that, since it is based on the principle of opposing forces between primary and induced currents, Joule heating effects occur in the sample material. In order to overcome the disadvantages of working with high currents (in the case of electromagnetic loading), or explosives, other authors have made use of mechanical loading systems, such as gas guns – see for example the works of Stepanov & Babutskii [Strength of mat. 16, 1984] or more recently Neel et al. [Int. J. Imp. Eng. 140, 2020]. In this work, we have developed and demonstrated a novel experiment which consists of a 25-mm bore single-stage helium-driven gun, firing a conical-nosed cylindrical projectile that impacts axially on a tubular specimen -- see an overview of the experimental setup in Figure 1(a). Two different configurations are presented here.

2. Results

We present two different configurations for the test: rapid *axial penetration* of thin-walled tubes, and rapid *radial expansion* of rings. For the first configuration, a pyramidal support (made of printed PLA) standing at the end of the gas gun is bracing a thin-walled AlSi10Mg tube printed by Selective Laser Melting, which will be axially penetrated by the projectile at impact velocities ranging from 180 m/s to 390 m/s - see a detailed view on Figure 1(b). Since the cylindrical part of the projectile is larger than the diameter of the tube, this is expanded as the projectile moves forward, which eventually leads to the fragmentation of the specimen. Depending on the geometry of the specimen and the impact velocity, we have observed different fragmentation patterns, e.g., for a 12-mm diameter and 2-mm thick tube impacted at 193 m/s fragments tend to form the shape of a *petal* (as can be seen in Figure 2).

On our second configuration proposed (*radial expansion* of rings), a ring is inserted over a ductile tube standing in the pyramidal support – see Figure 1 (c). During the penetration by the conical projectile, the expands and pushes the metallic ring radially outwards, this ultimately breaking into multiple fragments.

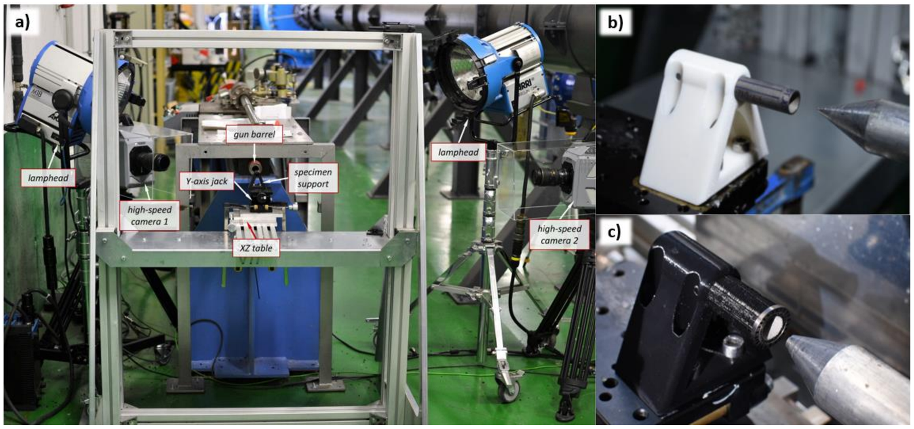

Figure 1 - Experimental setup to perform dynamic fragmentation on additively-manufactured metals: a) overview, b) detailed view of the pyramidal support used for axial penetration of tubes, and c) detailed view of the support used for radial exoansion of rings.

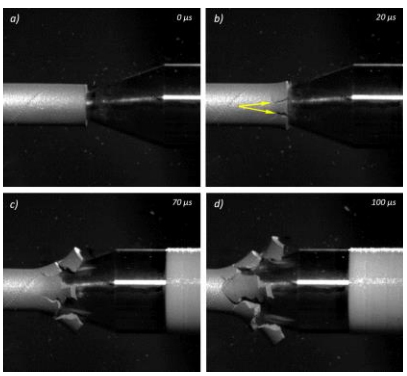

Figure 2 - Image sequence of the impact test corresponding to a tubular specimen for diferent loading times.

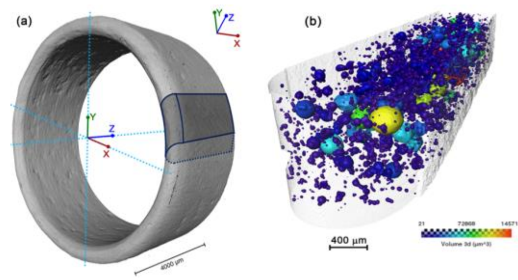

Figure 3 – 3D reconstruction of X-ray computed tomography scans showing all the pores within an arbitrary portion at the impacted end of the cylinders, corresponding to the shadowed region in (a). Subfigure (b) corresponds to a 6% porosity sample made of AlSi10Mg.

The material selected for both tubes and rings was AlSi10Mg, printed by SLM. Three-dimensional analysis of the tomograms has shown that the initial void volume fraction of the printed cylinders and rings varies between 1.9% and 6.1% - see for example the 3D reconstruction of an X-ray computed tomography scan corresponding to an AlSi10Mg printed tube with a porosity of approximately 6%.

3. Conclusions

We have presented a novel experiment to investigate dynamic fragmentation of additively-manufactured metallic materials. The setup comprises a gas gun that fires a conical projectile, which penetrates axially a standing tube at the end of the barrel. The specimen can be in the form of a thin-walled tube (which expands and breaks into fragments), or in the form of a ring (which is pushed radially outwards by a ductile tube, and finally breaks into fragments). X-ray computed tomography of pre- and post-portem samples gave an insight on the effect of porosity on localization and fracture.

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