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Characterisation of aluminium matrix syntactic foams under drop weight impact

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ABSTRACT

It is a challenging task to develop a lightweight, and at the same time, strong material with high energy absorption for applications in military vehicles, which are able to withstand impact and blast with minimum injury to occupants. This paper presents a study on aluminium matrix syntactic foams as a possible core material for a protection system on military vehicles. Experimental work was first carried out which covers sample preparation through pressure infiltration and impact tests on aluminium matrix syntactic foams manufactured. Numerical models were then developed using commercial finite element code ABAQUS/Explicit to simulate the dynamic behaviour of the foam. The effect of strain rate on their compressive behaviour was investigated as these properties are vital in terms of the applications of these materials. Characterisation of the foam behaviour under low velocity impact loading and an identification of the underlying failure mechanisms were also carried out to evaluate the effective mechanical performance. It was found that samples subjected to drop weight impact offered a 20–30% higher plateau stresses than those of the samples subjected to quasi-static compression loading. The degree of correlation between the numerical simulations and the experimental results has been shown to be reasonably good.

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1. Introduction

The impact resistance of engineering structures subjected to blast and impact loads is of great current interest within the engineering community. This is primarily due to the urgent need for providing protection against possible terrorist attacks. The development of lightweight, strong and ductile materials for use in the manufacture of military vehicles is a formidable challenge facing the materials community. When subjected to blast or impact loading, a structure usually undergoes large plastic deformation, possibly leading to partial or total failure. The important characteristics of such a structural response are: (i) the deformation mode and associated failure modes, (ii) the impulse and shock wave transfer, and (iii) the energy absorption through plastic deformations [1].

Metal matrix syntactic foams are a new class of composite material, consisting of a metal matrix with implanted micro-spherical hollow or porous ceramic particles. A metal matrix can be made of aluminium, steel, titanium or magnesium. Ceramic micro-spheres can be either porous or hollow spherical structures, and the size of the spheres determines the porosity and, to some extent, the strength of these materials. These kinds of material frequently offer a light weight and a high energy absorption capacity, and have been used in automotive, naval, aerospace and other industrial sectors. They can also be used to reduce shock loading effects such as those associated with mine blasts on military vehicles.

Cellular materials are characterized by several parameters, such as the constitutive law, the mean cell diameter, relative density (porosity), cell size and shape etc. Gibson and Ashby [2] analysed constituents of cellular solids structure by using X-ray tomography, optical microscopy and scanning electron microscopy. The porosity was measured by simply weighing samples with a known volume. Metal foams, fully impregnated with an opaque epoxy were polished and then characterized using optical microscopy. It was also reported that the scanning electron microscopy (SEM) is the most informative technology for the study of open cell foams, rather than for closed-cell foams. However, the X-ray tomography technique was found to be a better way to identify and investigate the deformation modes in cellular solids [3]. According to the study, large specimens were required to be cut into small pieces due to the low X-ray absorption on those samples. Another advantage offered by this technique is the facility to monitor deformations non-destructively.

An earlier study [4] has shown that the compressive strength of a metallic matrix syntactic foam is controlled by the strength of

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metal matrix and the ceramic particles. Additionally, other parameters, such as the volume fraction, structure, distribution of the ceramic particles, etc., were found to influence the properties of the material [5,6]. For example, the compressive strength of a metallic syntactic foam decreases with increasing volume fraction of ceramic micro-spheres. It was reported that the compressive strength increases with increasing the size of ceramic micro-spheres [7,8]. It has also been predicted [9] that there should be a difference in the compressive strength for foams with different ceramic sphere sizes. Moreover, the thickness and the radius of the ceramic micro-spheres affect the compressive strength of the resulting metallic syntactic foam [10]. In contrast, the larger the size of ceramic micro-sphere is, the lower the strength of the ensuing metal matrix syntactic foam [11,12]. Palmer et al. [13] indicated that the lower compressive strength of a metallic syntactic foam is related to the large size of the micro-spheres. From this evidence, it is reasonable to conclude that the compressive strength of a metal matrix syntactic foam depends on three parameters: (i) the compressive strength of the metal matrix, (ii) the compressive strength of the ceramic micro-spheres, and (iii) the volume fraction of the metal matrix and ceramic micro-spheres. In addition, Orbulov and Májlinger gave a continuous mathematical description of response of metal matrix syntactic foams to compressive loading [14].

The compressive strength of the material is related to the energy absorption capability of foams and is usually quantified by using measurable stress–strain relationship. The ductile foam materials collapse through the crushing of ceramic micro-spheres, whereas the brittle ones fail due to shear [10]. Three other factors which affect the failure behaviour of metal matrix syntactic foams are [15,16]: (i) the structure of the ceramic micro-spheres, (ii) the volume fraction of the ceramic micro-spheres, and (iii) the volume fraction of the metal matrix.

Moreover, metal matrix syntactic foams were tested under dynamic compressive loading [16–18]. The impact of the falling weight caused no obvious damage to the specimens. Instead, the impactor rebounded with some residual energy [19]. It was observed that at high rates of strain, the aluminium matrix syntactic foams exhibit a higher plateau stress and peak relative to the values measured during a quasi-static test [16,20]. This indicates that the dynamic energy absorption capability of the aluminium foam is higher than the quasi-static value [21].

However, research on the dynamic response of aluminium matrix syntactic foams subjected to impact loading is limited, especially dynamic modelling. This paper presents experimental work on aluminium matrix syntactic foam samples prepared through pressure infiltration and subjected to impact. The samples produced are based on different volume fractions of aluminium matrix and ceramic particles, with the latter having various sizes. Here, the influence of strain rate on the peak stress, plateau stress, ultimate displacement and energy absorption is investigated. Following this, finite element models are developed to simulate the dynamic response of aluminium matrix syntactic foams subjected to drop-weight impact. This work covers three types of the foam subjected to impact loading at different strain rates. The numerical modelling output is then validated against the corresponding experimental results.

2. Experimental work

2.1. Fabrication of samples

Aluminium matrix syntactic foam can be fabricated by either stir casting or pressure infiltration. The effect of pressure infiltration on the microstructure and properties of the material was investigated in this study [22]. Here, the pressure infiltration casting process was used in which the metal matrix was placed above the ceramic spheres and pressed so that the molten aluminium infiltrated into the ceramic spheres where it solidified to produce a metal matrix syntactic foam. The infiltration casting process was conducted by hydraulic press, as shown in Fig. 1. This method has the advantage that the matrix and ceramic spheres are well bonded and the micro-spheres are usually uniformly distributed.

In the present work, aluminium matrix syntactic foams with ceramic spheres in the size ranges of 25–75 μm (CM(I)), 100–250 μm (CM(II)) and 250–500 μm (CM(III)) in diameter were produced by pressure infiltration casting. The matrix was based on aluminium alloy Al7075-T. The volume fraction of ceramic micro-spheres within the foam was 66% corresponding to a weight fraction of 88%. Fig. 2 shows a micrograph of the aluminium matrix syntactic foam, which indicates that some ceramic micro-spheres were fully infiltrated with molten aluminium.

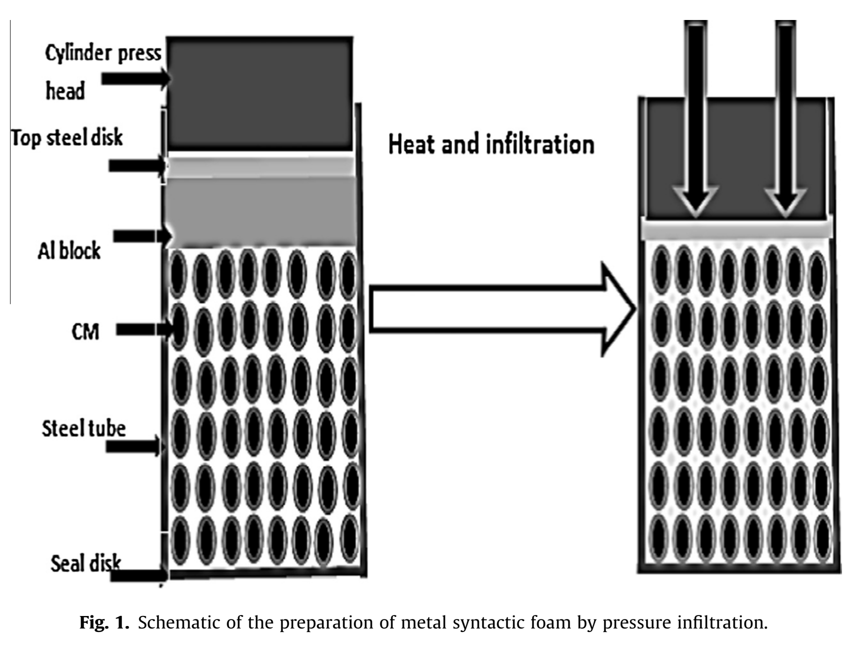

Fig. 1. Schematic of the preparation of metal syntactic foam by pressure infiltration.

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