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Testing of Energy Absorption Capability of Sandwich Structures Based on Metal Foams for Design of Protective Helmets

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Abstract: Purpose of this study is investigation of energy absorption capability of the sandwich structures composed of combination of polystyrene and metal foam element. Two types of the metal foams were experimentally tested: Alporas (Shinko Wire Ltd., Japan) and Aluhab (Aluinvent Plc., Hungary). Samples of the sandwich structure are composed of two layers: bottom expanded polystyrene (EPS 200S) layer and upper metal foam layer which are glued together. Prepared samples are tested using a drop tower experiment to measure sample response (acceleration, reaction force) at different strain rates and energies. From acceleration/time history the Head Injury Criterion (HIC) is calculated. Measured and derived characteristics are compared with EPS samples.

Introduction

Nowadays, expanded PolyStyrene (EPS) is the most common liner material used in protective helmets as energy absorbing element [1]. It is cheap to manufacture, light, easy machinable and has suitable crush characteristics. EPS represents crushable foams structures where the cell walls crush on impact and slow the head gradually. This deformation behaviour is ideal for helmets optimised for one hard impact. However, the protective effect depends on the portion of the impact energy which the structure is capable to absorb. If this rate is exceeded the rest of the impact energy is transferred to the head. Closed-cell metal foams as polystyrene also represent the crushable foam structures but in contrast with EPS the stiffness is significantly higher (with low specific weights) and thus are able to absorb more impact energy. In this study two sandwich structure composed from EPS and metal foam layer are tested and their extended energy absorption capability of the material is analysed.

Materials and Methods

All samples were machined using CNC device to obtain samples that perfectly fit on the headform impactor. Three types of structures were prepared: (i) Alporas sandwich (EPS layer thickness: 10 mm, Alporas layer thickness: 25 mm), (ii) Aluhab sandwich (EPS: 10 mm, Aluhab: 25 mm) and (iii) pure EPS (EPS: 35 mm). EPS and metal foam layers In in sandwich structure were together bonded by glue (UHU Por, UHU GmbH & Co. KG, Germany). Prepared samples were tested using a drop tower experiment to measure of the sample response at different strain rates and energies. The headform impactor was equipped with a triaxial accelerometer (EGCS3, Measurement Specialties, USA) with $\pm$ 1000 g measuring range and a bottom platen of the drop tower was equipped with an impact quartz force sensor (200C20, PCB Piezotronics, Inc., USA). Both sensors were time synchronised and analog input module (NI 9234, National instruments, USA) with 51.2 $\mathrm{kSs^{-1}}$ maximum sampling rate was used for fast read out of measured data. Acceleration/time history was used for Head Injury Criterion (HIC) [2] calculation:

$$HIC_{15} = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{\max} \qquad (1)$$

where t_1 and t_2 define time interval (limited to 15 ms) during which HIC attains a maximum value and a is acceleration in g.

Results and Discussion

Measured acceleration for pure EPS, Aluhab and Alporas sandwich samples is shown in Fig. 1. As can be seen in this figures Alporas is not good material for design of protective helmets because acceleration and HIC values are very high (e.g. HIC=1000 means 18% probability of a severe head injury, a 55% probability of a serious injury and a 90% probability of a moderate head injury). On the other hand with increasing impact energy the HIC value and the peak acceleration is progressively decreasing. This behaviour shows that Alporas takes effect for higher impact energy where protection

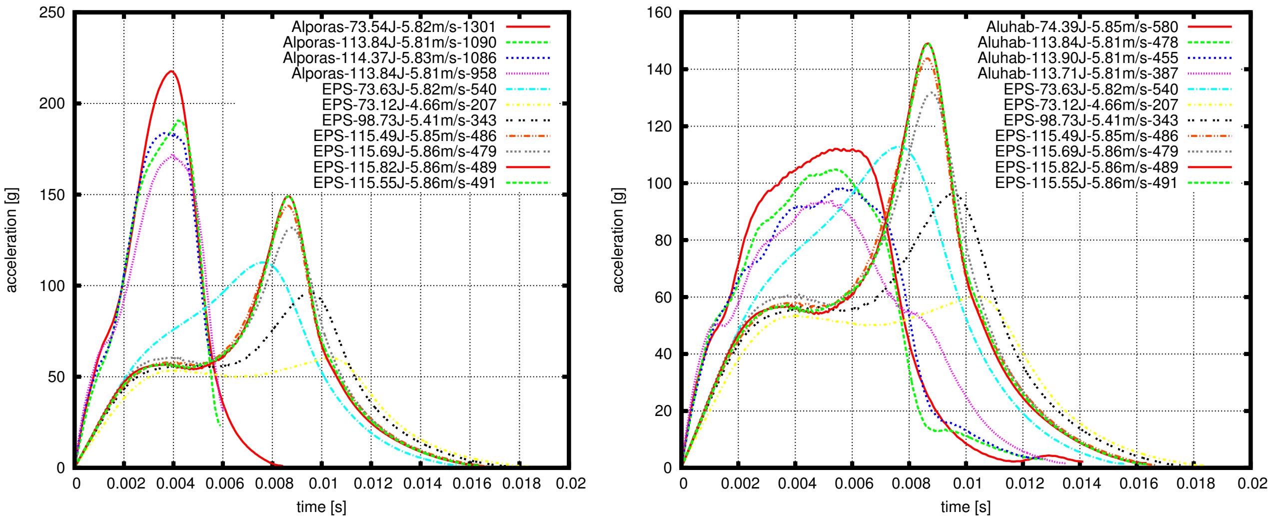

Fig. 1: Measured acceleration curves for Alporas (left) and Aluhab (right) compared with EPS (in legend: impact energy - impact velocity - HIC value)

ability is significantly increasing. The same trend was observed with Aluhab sandwich but in comparison to the Alporas the overal stiffness of the structure is lower and HIC and acceleration values are even comparable with values of the pure EPS. Moreover Aluhab sandwich can potentially absorb the significantly higher portion of the impact energy in comparison with EPS. As conclusion the Aluhab sandwich can be considered promising structure how to improve current protective materials in helmets however further optimisation of the structure properties (thickness, number of the layers, etc.) will be necessary.

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