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High strain rate characteristics of nanoparticle modified blast energy absorbing materials

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Abstract

Due to explosion, and insufficient energy absorbing capabilities of civil building structures, many structures collapsed, which can be connected with losses of human lives and properties. One way how to improve the blast resistance of the structure is using of sacrificial cladding structures with the core made of high blast absorbing material. Foams based on lightweight porous particles and resins are materials with high potential of impact energy absorption. This article describes the mechanical properties of the foams reinforced with carbon nanofibers and nanotubes. Specific porous lightweight foam with high volume fraction of microspheres (70 vol.%) was prepared and modified by 1–5 vol.% of multi-wall carbon nanotubes and nanofibers (separately). The compressive and flexural strength tests were conducted at quasi-static load. Split Hopkinson Pressure Bar apparatus was used to obtain high velocity characteristics of the materials. The relative absorbed energy was calculated to assess the relation between the composition of the material and its shock wave attenuation capacity. The mixtures containing carbon nanofibers exhibited an increasing trend in the energy absorption capacity with increasing nanoparticle content up to 4 vol.%. The addition of carbon nanotubes also increased absorbed energy (again up to 4 vol.%, crossing this concentration, the significant drop was observed). Comparing the values of the relative absorbed energy, the carbon nanofibers composites prevail over the nanotubes modified ones.

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Keywords: Blast energy absorber; glass microspheres; carbon nanotubes; carbon nanofibres; Split Hopkinson Pressure Bar

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1. Introduction

Syntactic foam is a composite material consisting of hollow-sphere fillers dispersed in a matrix. These materials are able to absorb a significant amount of energy under compressive loading conditions due to the presence of porosity, which leads to large strain at a constant load level due to progressive crushing of particles [2]. Materials mentioned above found application in aerospace, marine and military [1].

Nomenclature

MWCNT	multi-walled carbon nanotubes
CNT	carbon nanotubes
CNF	carbon nanofibers
SHPB	split Hopkinson pressure bar

In the defense industry, this sort of materials can be used as shock absorbers to reduce the consequences of explosions – injuries and loss of lives [3]. In the presented research, a special type of foam was designed, consisting of a high proportion of glass microspheres and an epoxy resin. Several studies were conducted on mechanical and fracture behaviour of glass microsphere foams, when response to the quasi-static compressive, flexural and tensile loading. [4–6,12] Dynamic response of the glass/polymer foams with and without microfiber reinforcement was also investigated recently. Gupta at all. [7] analyzed the strain rate dependence of damage evolution in foams. It was found that the strength was 50–150 % higher at high strain rates compared to quasi-static values. Wall thickness and volume fraction of hollow particles used in syntactic foams played an important role in determining the failure mechanism. The studies mentioned showed the possibility of tailoring the properties of hollow-particle-based foams by several means. The selection of volume fraction of the filler and its wall thickness or size enable to prepare foam with very different material parameters (tensile and compressive strengths in the range of 10–100 MPa and modulus between 1.5–3 GPa [8]). Flexural and tensile strength of foams can be enhanced by incorporation of randomly dispersed short macro fibres. The effect of such reinforcement on both static and dynamic properties was investigated [9–11]. The effect of the addition of short fibre reinforcements on the flexural stiffness, compressive strength, fracture toughness and absorbed impact energy were studied on foam with a microsphere content of up to 50% and with fibre reinforcement up to 1.2 vol.% by Ferreira at all [11]. The addition of glass fibre produces only a slight improvement in the flexure stiffness and fracture toughness, while increasing significantly the absorbed impact energy. In contrast, the addition of a small percentage of carbon fibres produces an important improvement in both fracture toughness and flexure stiffness but do not improve the absorbed impact energy [11]. Experimental evidence shows that nanoparticles may bring significant improvements in stiffness, flexural and impact strength and impact energy absorption of composites, which characteristics are very important in protective structures [15]. Recently, nanoparticles were used also for modification of polymer/microsphere foams. The effect of nanofibers, nanoclay, nanosilica or nano $CaCO_3$ addition on energy absorption of modified foams was investigated. The addition of 0.25 wt. of carbon nanofibers resulted in enhancement of tensile modulus and strength [2]. However, these studies are mostly focused on quasi-static behaviour. Only very limited number of studies dealing with high strain rate properties of nanoparticle reinforced foams is available and cover nanoclay only. Studies covering the other promising materials, such as nanosilica, carbon nanotubes and nanofibres are still missing. Although several new nanocomposites were developed and an extensive research reveals their potential, the research on energy absorption capacity of nanoparticle-modified foams at high strain rates is still in the early stages. Presented study brings new findings contributing to the knowledge in the field, as it determines the influence of the carbon nanotubes and nanofibres incorporation on the glass/epoxy foam absorption capacity at high strain rates.