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Blast resistance of stiffened sandwich panels with aluminum cenosphere syntactic foam

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ABSTRACT

The present investigation examines the response of the aluminum cenosphere syntactic foam core stiffened and unstiffened structures subjected to blast load. The blast is applied using blast load equations available in LS-DYNA by defining the charge and standoff distance to analyze the structures under a particular blast load. The dynamic response of the sandwich structures is studied in terms of quantitative assessment, which mainly focuses on the peak central point displacement of the back-sheet (opposite to the explosion) of the sandwich structures. The analysis is carried out with an objective of understanding the effects of the foam thickness, strain rate, and the stiffener configurations on the response of sandwich structure to the blast load. The results obtained indicate that the provision of the stiffeners and foam core considerably improves the blast resistance as compared to both, the unstiffened panels with foam core and without using syntactic foam core.

1. Introduction

Recent terrorist attacks on government, commercial, private and strategically important buildings all around the world have highlighted concerns about their safety and performance against blast induced loadings. As terrorism is becoming more prevalent throughout the world, blast resistant structures are required to protect the personnel and the facilities from the particular blast induced loading for which these structures are designed. Blast resistant structures are primarily constructed of pre-cast and cast-in-place concrete or steel frames with the use of sandwich structures more recently. In the past, polymeric foams, honeycombs and metallic foams have been developed and used as the core of sandwich structures for application in blast resistant construction. Use of sandwich structures with weak and light core has gained momentum due to their high energy absorption, lightweight and high specific stiffness. Hence, understanding the behavior of blast loaded sandwich structures is essential for successful protection of the personnel and the facilities with the developments of new metallic foams. Further, a detailed investigation into the deformation behavior of sandwich structures under blast load facilitates in designing these structures with enhanced energy absorption and improved blast resistance. There exist several experimental and numerical studies on the behavior of sandwich structures [1–13]. These studies mainly focused on dynamic behavior of different face- and back-sheets and core materials under varying blast intensities. Dharmesena et al. and Cui et al. independently studied the response of metallic lattice sandwich structures to impulsive loading using small scale explosive test and presented the deformation mechanism [14,15]. Hasan et al. studied the influence of varying core density on the blast resistance of cross linked PVC cores and aluminium alloy skins sandwich panels using a ballistic pendulum and concluded that damage within the sandwich panels becomes more severe as the density of the foam core is increased. They also used FE models and successfully predicted the deformed shapes of the panels after the blast experiments [16]. In year 2013, Langdon et al. reported an experimental and numerical investigation of sandwich panels with PVC foam cores and glass fibre reinforced vinyl ester face sheets under localized blast loading and proposed that composite only panels perform better than the sandwich panels with PVC foam core [17]. Shock tube tests and finite element analyses of corrugated steel plates were recently investigated recently by Zhang et al. [18]. They presented the energy absorbance and impulse transmittance capability of different parts of the structure [18]. Lately, Li et al. studied the dynamic response of

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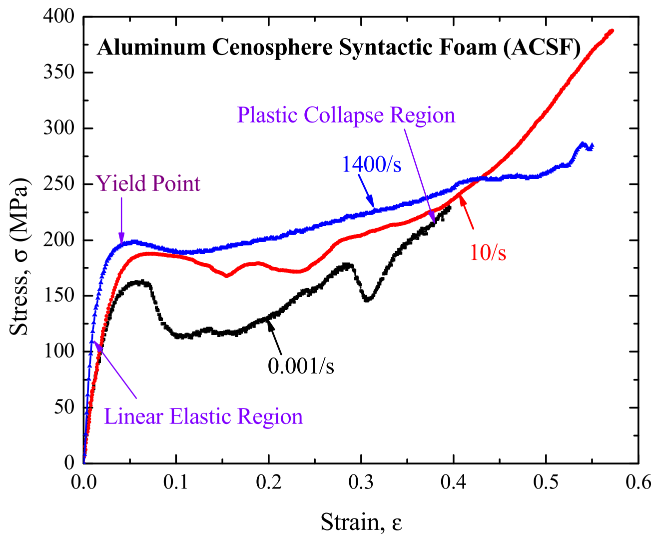

Fig. 1. Compressive stress-strain behavior of the ACSF at different strain rates for RD = 0.722.

corrugated sandwich panels under blast loading and deformation modes of panel along with the energy absorption capabilities [19]. Jing et al. recently carried out experimental investigation of cylindrical metallic foam sandwiched shell structures subjected to blast and studied the deformation modes along with the arrangement of different core layers for effectiveness in blast mitigation [20]. In yet another recent investigation, Balkan and Mecitoğlu proposed non-uniform pressure function for theoretical investigation of sandwich structures based on experimental investigation of panels under blast loading [21]. Recently, Qin et al. proposed the analytical model for yield criterion of a sandwich beam with soft core by a straight line [22]. In another very recent investigation by Wang et al. FE method is adopted to verify theoretical models for steel-concrete-steel sandwich panels under blast loading [23]. They also presented DIF in relation to strain rates which can be included in SDOF and Lagrange equation of the model [23].

However, hardly any investigation has been reported on the blast resistance of stiffened sandwich structures except recent study of Guan et al. [24] wherein they used woven S-glass/epoxy skins and a crosslinked PVC core and I-section as stiffener. Further, it is to be noted that in the present investigation, stiffeners are on opposite face of explosion which has never been reported, except author's recent work on the response of the stiffened polymer foam sandwich structures under impulsive loading [25]. Further, to the best of the knowledge of the authors, although syntactic polymeric foams are investigated for their blast resistance, no investigations have yet been reported on the syntactic metallic foams (such as aluminum cenosphere syntactic foam) for their blast resistance.

In the present investigation, the in-house newly developed metal foam, i.e. aluminum cenosphere syntactic foam (ACSF) has been explored as a potential core material in sandwich structures for blast applications. Performance of the stiffened sandwich panel with the ACSF as blast resistance structure is presented here. The blast response of the sandwich foam panel (SFP) and the stiffened sandwich foam panel (SSFP) is studied using LS-DYNA in order to assess their effectiveness in the blast response mitigation. Numerical analysis carried out here in aims to study the effect of (a) stiffener configuration, (b) foam thickness, and (c) strain rate.

2. Foam, sheet material and model geometry

The aluminum cenosphere syntactic foam (ACSF) foams are developed by assembling micro pores (through the use of micro-balloons) in the metallic matrix through stir casting technique at CSIR-Advanced Materials and Processes Research Institute, Bhopal, India [26]. The properties of the syntactic foam (i.e. cell size, cells distribution and volume fraction of cells) are influenced by the characteristics and the quantity of micro-balloons used for making the syntactic foam. In these foams, cenospheres (hollow and spherical in shape) are used as micro-balloons. Cenospheres contain primarily alumina-silicates (mullite and selliminite) phases and trace amount of ferro-silicate, quartz, iron oxide, calcium carbonate and unburnt carbon. These substances make cenosphere chemically inert and stable up to temperature of 1100 °C and quite

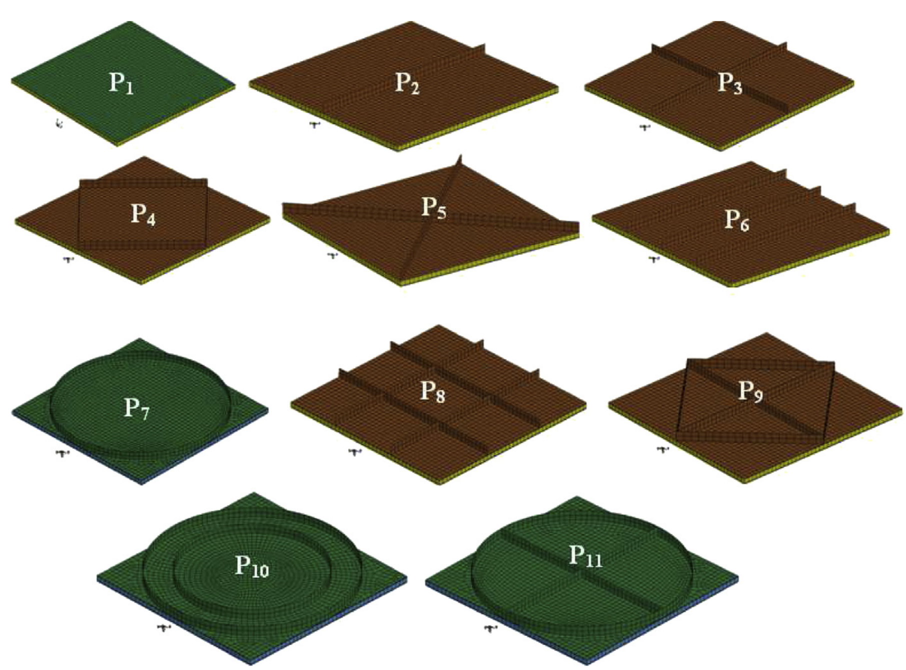

Fig. 2. Stiffened sandwich panel configurations arranged with increasing weights.