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Technical Report

Deformation and impact energy absorption of cellular sandwich panels

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ABSTRACT

The response and energy absorption capacity of cellular sandwich panels that comprises of silk-cotton wood skins and aluminum honeycomb core are studied under quasi-static and low velocity impact loading. Two types of sandwich panels were constructed. The Type-I sandwich panel contains the silk-cotton wood plates (face plates) with their grains oriented to the direction of loading axis and in the case of Type-II sandwich panel, the wood grains were oriented transverse to the loading axis. In both of the above cases, aluminum honeycomb core had its cell axis parallel to the loading direction. The macro-deformation behavior of these panels is studied under quasi-static loading and their energy absorption capacity quantified. A series of low velocity impact tests were conducted and the dynamic data are discussed. The results are then compared with those of quasi-static experiments. It is observed that the energy absorption capacity of cellular sandwich panels increases under dynamic loading when compared with the quasi-static loading conditions. The Type-I sandwich panels tested in this study are found to be the better impact energy absorbers for low velocity impact applications.

1. Introduction

Structural crashworthiness is a multidisciplinary area which encompasses materials behavior, aspects of their structural elements, electronic data acquisition and its processing when subjected impact loads. Its applications range from low velocity vehicular collisions to high velocity impact of bullet shells and blast loads. Vehicular collisions are among the most serious issues that engineers in particular and society in general are facing today. These vehicular collisions are not only dangerous to the occupants of the vehicle but also to the impacted structures such as buildings, pillars which supports bridges, etc. Therefore, it is important to evolve collision protecting solutions which can maximize the protection without compromising structural efficiency and integrity. The rapid advancement of technology in recent years has renewed the emphasis on the design and development of Impact Energy Absorbers (IEAs), as these can dissipate kinetic energy of unwanted collision in a controlled manner to enable the master structure to survive a collision without suffering an unacceptable distortion or deceleration. The problem is, therefore, essentially of low velocity (from 3 to 15 km/h) to moderate velocity impacts (up to 100 km/h) [1].

In the case of vehicular collisions, the need is to interpose a sacrificial structure between the impacting bodies which can dissipate the kinetic energy by undergoing large plastic deformation in a predictable manner hence to bring the vehicle to stop in a controlled way. Such impact energy absorbers can also be used as protective claddings on static structures and buildings of public importance against any sort of accidental or designed impacts. In such situations, sandwich panels would be very suitable as impact energy absorbers.

A sandwich panel consists of light weight and compliant material core which is sandwiched between two face plates (skins) of comparatively stiffer and stronger material. A light weight core along with stiffer skins forms a structure which shows improved resistance to bending and buckling. Thus a lighter and stronger structure is synthesized from two entirely different materials or structures. It is because of this reason that, the sandwich panels are often used in applications where weight-saving becomes crucial [2]. Some of the applications are the rotor blades of helicopter, flooring and body panels of an aircraft, etc. Sandwich panels are increasingly used in transport (automotive, air craft and ship) industries because of their superior structural efficiency and energy absorbing capabilities. Usually, natural cellular solids (such as wood) or man-made (such as honeycomb, foam etc) are being used as core materials in structural sandwich constructions. However, the materials used for face plates in the construction of sandwich panels are made of either metallic or composite materials.

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Several uni-axial quasi-static and dynamic experimental investigations have been carried out by many experts in this field to study the deformation modes of constituents of a sandwich panel and to determine the energy absorption capacity [3,4]. Goldsmith and Sackman [5] have experimentally investigated the behavior of sandwich panels with static and dynamic loading to determine the energy dissipation and force level transmission characteristics. Mouring et al. [6] have studied the effect of impact damage under edgewise compression tests on composite skin and honeycomb core sandwich panels. Castanie et al. [7] have worked on modeling of low velocity impact on Nomex honeycomb sandwich panel structures with metallic skins. They represented honeycomb core by a grid of non-linear springs and have pointed out both the structural behavior and influence of core-skin boundary conditions. This discrete approach accurately predicts the static indentation on sandwich structure on a rigid flat support. Dharmasena et al. [8] have conducted explosive tests to study the dynamic mechanical behavior of sandwich panels with honeycomb core and composite skins. It was seen that cell wall buckling and core densification increased with the impulse. Zhao et al. [9] have made an experimental study on perforation of aluminum foam core sandwich panels under impact loading. They devised a method which compares impact piercing force–displacement curves with static ones. Paulius and Leisis [10] have studied sandwich structures made of polyvinylester core and glass fiber composite skins experimentally and numerically. They have also analyzed the energy absorption of core and skins. Nemat-Nasser et al. [11] have conducted quasi-static and dynamic tests on sandwich panels made from aluminum foam core and structural steel skins. They used high speed photography to understand the deformation behaviors of core and skins under high rate inertial loading. Yanze Song et al. [12] have studied the dynamic response of 3D-cellular foams and invented that, the energy absorbing capacity of the foam can be improved by increasing appropriately the degree of cell shape irregularity. Victor Iliev Rizov [13] has conducted low velocity impact tests on ductile polyvinylchloride foam panels to develop the damage tolerance design approach for structural foams. Mamalis and Papapostolou [14] have carried out experimental investigation of strain rate effects on the crushing characteristics of composite sandwich panels. Altenaiji et al. [15] have studied the effects of strain rate on the compressive behavior of aluminum matrix syntactic foams under low velocity impact loading and found that the specific energy absorption increases with strain rate. Borsellino and Bella [16] have studied the sandwich structures made of biomimetic cellular cores of recycled paper to evaluate the mechanical properties under flatwise and edgewise compression tests. Reddy et al. [17] have carried out perforation and penetration tests on composite sandwich panels using hemispherical ended and conical nosed projectiles under quasi-static, drop weight and ballistic impact conditions. Ballistic limits and perforation energies were determined and a classification of the responses based on the panel thickness to projectile diameter ratio was deduced from the test data. Ariel Stocchi et al. [18] have fabricated honeycomb core made of natural-fiber reinforced composite with vinylester matrix reinforced with jute fabric. They have suggested that, jute reinforced cores have the potential to be an alternative to standard cores in sandwich panel technology. Ude et al. [19] have reviewed the applications of natural fibers in composite plastics in the current automotive industry, a shift of paradigm towards a "green-out look" for more environmentally friendly vehicles. Also experimental studies on some of the woods grown in the western world, like oak, red wood, pine, balsa etc., are reported by Reid et al. [20], Gibson and Ashby [2], Vural and Ravichandran [3,4] and others. However, very few studies were carried out on the energy absorbing characteristics of woods grown in the tropical region of Indian subcontinent. Available literature indicates that, there is very little experimental work done on sandwich panels made of cellular materials for both the core and face plates to examine their crushing characteristics and to evaluate the energy absorbing capacities. The present study uses sandwich panels in which silk-cotton wood is used as face plates and aluminum honeycomb as core material.

This paper presents the data from two series of experiments carried out on Type-I and Type-II sandwich panels under quasi-static and low velocity impact loading conditions. The load-deformation response data, photographic evidence of progressive deformation and energy absorption capacities of the specimens are provided and discussed. An indigenously designed and fabricated drop weight test facility is used to carry out the low velocity impact tests. The results of low-velocity impact tests carried out on specimens of Type-I and Type-II sandwich panels is presented and discussed A comparison of energy absorbed by each type of sandwich panel for the three impact velocities of 6.7 m/s, 7.4 m/s and 8 m/s is made. Further, a comparison of dynamic and quasi-static energy absorption is presented. The energy absorption capacity of cellular sandwich panel increases under impact loading condition in comparison with the quasi-static loading.

2. Materials and methods

2.1. Specimens

Silk-cotton wood plates of nominal dimensions of $100 \times 100 \times 16$ mm were prepared from a well-seasoned timber log. The planar surfaces of the specimens were machined and inspected with care to ensure good end surface quality. The surfaces of wooden plates were then polished using 320 grit sand papers. Moisture content tests were conducted on the specimens of the silk-cotton wood as this has significant effect on both density and energy absorption properties of wood. The specimens were heated in a furnace for about 2 h at 80 °C in the first cycle and 60 °C for another 2 hours in the subsequent heating cycle. At the end of each cycle, the weight of the sample was measured and the moisture content was calculated. The procedure was repeated until the weight was nearly a constant and the moisture content varied from 7% to 12%. This is the typical range values for well-seasoned dry woods [15]. The specimens of hexagonal cell aluminum honeycomb of $100 \times 100 \times 50$ mm size were used as the core material. The honeycomb structure is made of aluminum alloy Al-3003 material in foil form with a thickness of 0.068 mm and a cell size of 6.3 mm. The edges of cells in the core were carefully trimmed to ensure that, the de-bonding of aluminum foils do not occur. Araldite glue was applied onto the contacting surfaces of wood skins and the honeycomb core. The joining surfaces of the core and wood skins were then aligned and the structure was held firmly by using a suitable external pressure for about 10 min to establish an effective bonding between them. Thus Type-I and Type-II sandwich panels were fabricated using silk-cotton wood skins and aluminum honeycomb core with its cell axis parallel to the direction of loading was sandwiched between the two wooden skins. In the case of Type-I sandwich panels, the wooden skins had their grains oriented along the axis of loading where as in Type-II sandwich panels, and the wooden skins were placed with their grains oriented transverse to the loading axis. The overall nominal dimensions of a typical sandwich specimen are $100 \times 100 \times 82$ mm. Quasi-static compression tests were conducted as per ASTM: C-365-03, which is the standard test method for flat wise compressive properties of sandwich cores. The load–displacement behavior of the individual constituents of sandwich panel is as shown in Fig. 1.