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Aluminum honeycomb sandwich for protective structures of earth moving machines

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Abstract

The design and the assembly of the vehicles subjected to the risk of crushing from falling objects have to consider such danger and provide the operators with suitable safety systems. Generally, falling object protective structures for earth moving machines consist of vertical elements, connected by transversal elements, covered by a roof. The latter has the aim to protect the operators from falling objects and it is usually made of a steel skeleton with a metal plate. In this study, sandwich panels were proposed as technical solution for the impact protection from falling objects in earth moving machines. A very light and cheap aluminum honeycomb core (AA3003 alloy and cell size = 19 mm) was considered as design solution and was subjected to static and dynamic full-scale tests. The results were analysed according to the performance requirements of ISO 3449 standard. The experimental results confirmed that the honeycomb structures are well suitable for designing absorber devices in vehicles protective structures in order to ensure occupant safety.

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Keywords: Aluminum honeycomb; Lightweight design; Impact behaviour; Full scale tests; Crashworthiness; Earth moving machines.

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1. Introduction

Earth moving machines are of great importance in industrial, agrarian, and construction applications. The mechanization of human activities through these devices, lead to acceleration and simplification of work, in comparison to manual methods, increase in production capacity, reduction in work costs and improvement in safety (Budny et al., 2009). The application fields for earth moving machines are inherently hazardous, both for machines' integrity and for operators' safety. These devices are involved in risky activities, such as heavy and large objects handling - for example concrete blocks, earth, construction tools - and the activation of several tools, for example hammers, mills, buckets (Bonanno, 2008). In order to reduce the risks to which the operators are exposed, earth moving machines are provided with protective structures integrated in the cabins, which demand strict safety and ergonomic requirements, since they represent the work place for the operators. Indeed, safety issues in construction sites and mines are often related to falling objects on cabins. According to INAIL guide regarding risk reduction in earth moving activities (INAIL, 2003), the first cause of injury is the fall of objects. As a result, the introduction of appropriate protection systems for cabins is of primary importance. These structures are named Falling Object Protective Structures, or FOPS. The urgency for prevention of risks in work places resulted in the development of rules and regulations, which establish some requirements for earth moving machines, in terms of falling object impact resistance. The international standard, which defines test procedures for the evaluation of FOPS characteristics, is ISO 3449 (ISO, 2005). The Standard distinguishes two impact protection levels. Level I defines the protection from small falling objects, as bricks or small tools; first level protection structures must resist the impact of a round object falling from a height sufficient to develop an energy of 1365 J. Level II defines the protection from large falling objects, such as trees, concrete blocks, rocks, etc.; in order to ensure a second level impact protection, a structure must resist the impact of a cylindrical test object falling from a height sufficient to develop an energy of 11600 J.

As stated by the International Standard, falling object protective structures are systems of "structural members arranged in such a way as to provide operators with reasonable protection from falling objects (trees, rocks, small concrete blocks, hand tools, etc.)". Such protective structures may be integrated in the vehicle or provided separately.

The design and the assembly of the vehicles subjected to the risk of crushing from falling objects have to consider such danger and provide the operators with suitable safety systems. Generally, protective cabins for earth moving machines consist of vertical elements, connected by transversal elements, covered by a roof. The latter has the aim to protect the operators from falling objects and it is usually made of a steel skeleton with a metal plate (Karliński et al., 2008), possibly with a polymeric cover with an aesthetic function. Protective cabins may have an open or closed structure, their height may be adjustable and they can be an integral part of the vehicle or can be an optional. A representative case of falling object protective structure is described in the patents EP 2 763 873 B (Merli, 2016) and EP 1 728 689 A1 (Chun-Ho and Jin, 2006). The combination of safety issues and acoustic comfort for earth moving machines' operators, led to the invention protected by patent US 6 322 133 B1 (Yantek et al., 1999). Even in the earth moving machines market greater attention is put on the aesthetic features of the vehicles, which must be combined with safety requirements and weight-saving solutions. This led to the idea of producing the protective structures with polymeric materials (Bonanno, 2008).

The current study is aimed at introducing innovative and engineered materials for falling object protective structures, in order to improve and optimise their purpose, reducing the weight of the vehicles.

Aluminum honeycomb sandwich structures are considered particularly suitable for this aim, since they present excellent energy absorption properties combined with low density. In order to achieve an efficient design of a protective structure with honeycomb sandwich, the mechanical properties of the materials need to be analysed, considering that the dynamic response of sandwich structures depends on numerous variables and presents significant non-linearities, which make it difficult to describe in a theoretical form. Consequently, experimental investigation of their impact behaviour is of primary importance in order to obtain information to aid the design of lightweight impact absorbers.

The theoretical evaluation of the energy absorption capabilities of honeycomb sandwich structures is a crucial point in the design of impact protective elements. A recent model was proposed by Wang et al. (2016), who