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Introducing composite lattice core sandwich structure as an alternative proposal for engine hood

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ABSTRACT

Pedestrian protection capability is critical for lightweight design of automotive engine hood. Here, a novel and lightweight composite sandwich hood including two fiber reinforced composite panels and a lattice core was proposed and the corresponding pedestrian protection performance was evaluated via Head Injury Criterion (HIC). The novel double-curvature composite sandwich hood with a pyramidal lattice core was designed based on a commercialized product with a weight reduction by 25%, and fabricated using interlocking approach. A homogenized constitutive model was developed for the pyramidal lattice core and utilized in the following headform-to-hood impact simulations with LS-DYNA. The stiffer sandwich hood revealed better pedestrian safety performance compared with the corresponding baseline hood without lattice core where secondary collision happened. Also, effects of geometrical variables, material selection and core types were discussed. The variation of panel thickness played a more important role in the average HIC values compared with that of core geometries. Among various material selections, hoods designed with carbon fiber reinforced composite (CFRC) panels and a flax fiber reinforced composite (FFRC) lattice core achieved the minimum head injury. Additionally, lattice core outperformed traditional honeycomb and foam in sandwich hood design. The present study demonstrates the feasibility of employing lattice materials in lightweight design of hood and other car body coverage.

1. Introduction

In vehicle-to-pedestrian accidents, head trauma is one of the fatal damage forms and head injuries account for 31.4% of 3305 Abbreviated Injury Scale (AIS) 2+ injuries [1]. Statistics show that the impact on front side of cars is the major cause of pedestrian deaths (83.5%) [2]. Automotive hood and windshield are frequent pedestrian head injury sources and should be designed for pedestrian safety [3,4]. A well-designed hood can modify the acceleration response of head impact and thus mitigate head injury [5]. Pedestrian impact tests are performed according to regulations provided by Euro NCAP (European New Car Assessment Programme) and HIC value is commonly used as the criterion to evaluate the severity of a possible head injury. Wu and Beaudet proposed an ideal acceleration-time history waveform peaking rapidly and decaying exponentially to achieve HIC < 1000 [6].

Energy and environment sustainability restricts the development of traditional automotive industry. Lightweight design, including lightweight materials selection and structural optimization, has become a hot topic to solve these problems [7]. Fiber composite material has shown greater specific properties with respect to their metallic counterparts such as aluminum and steel commonly used in traditional car body, and has attracted lots of attentions of OEM (Original Equipment Manufacturer). Moreover, sandwich structures consisting of two face sheets and a low-density core (such as honeycomb and foam core), are also popular in car body for lightweight design and crushing protection [8]. Several studies have been dedicated to the new design concepts of hoods based on pedestrian protection behavior. For example, previous research showed that the average HIC values of carbon fiber composite hoods were lower than those of steel and aluminum hoods [9]. Zhou et al. focused on sandwich hood and proposed an novel corrugated core hood design [10]. Peng et al. also evaluated the integral stiffness and pedestrian protection behavior of sandwich hoods with a honeycomb core [11].

Architected materials, as known as lattice materials, were termed as the most potential lightweight material of the next generation because of their high structural efficient and multi-functional advantages

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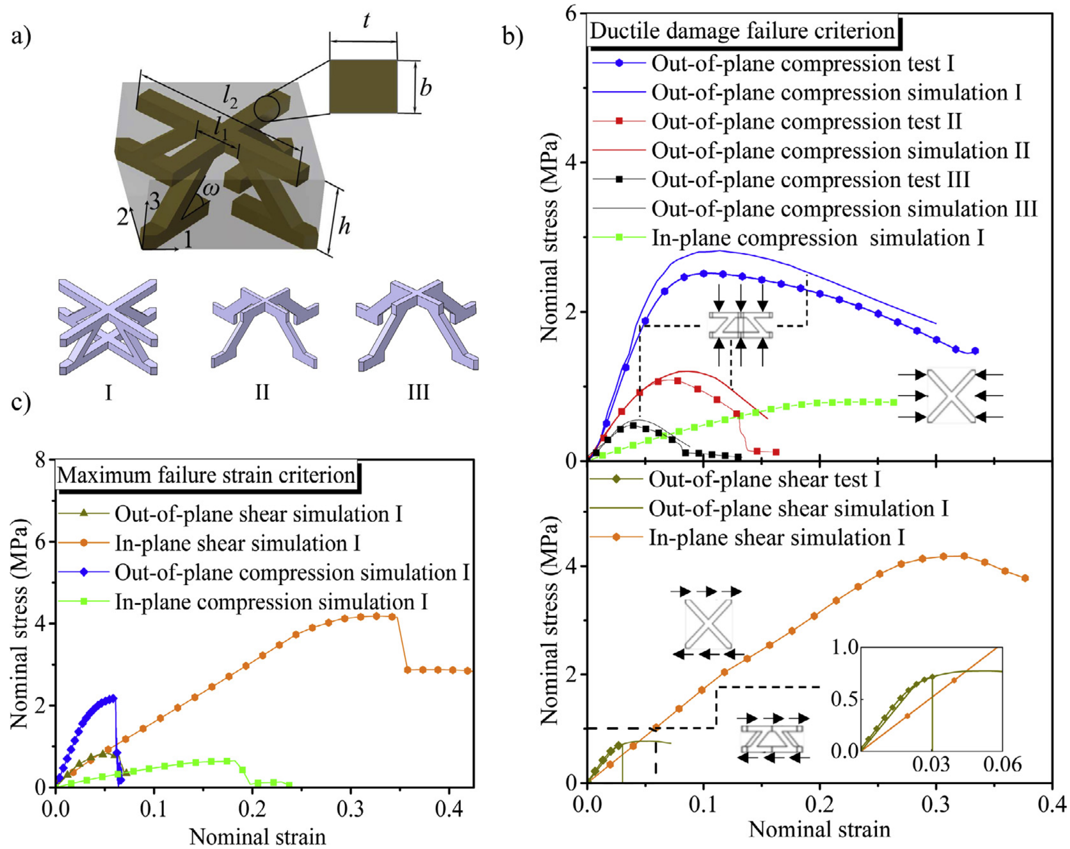

Fig. 1. a) Schematic of a pyramidal lattice unit cell with controllable geometric parameters and models of three design points I to III in Ref. [24]; b) stress-strain curves of pyramidal lattice unit cells under compression and shear loading condition by experiments and simulation with ductile damage failure criterion; c) stress-strain curves of unit cell analysis with maximum failure strain criterion.

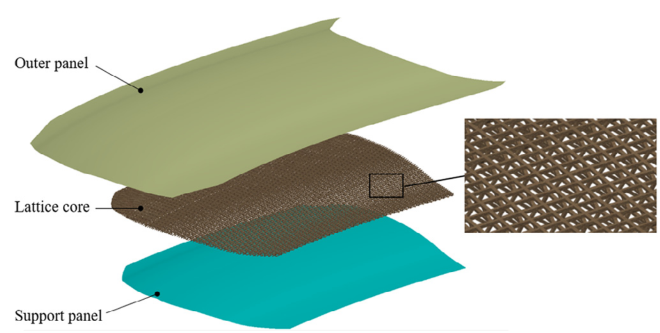

Fig. 2. Exploded view of lattice core sandwich hood.

[12,13]. Some composite structures, such as liquid filled lattice structures [14,15] and soft energy absorption structures [16] were proved to possess good energy absorption capability. Crashworthiness of fiber reinforced composite lattice structure was also investigated in the previous literature [17]. Numerical methods including homogenization modeling [18,19] and detailed modeling methods [20] were proposed to accurately evaluate the mechanical properties. Pyramidal lattice, for example, showed their excellent mechanical properties together with energy absorption capability at ultra-low density [21], which could be promising for vehicle lightweight applications. Interlocking approach has been used to construct a single-curvature lattice structure, and pyramidal lattice cylinders shell has been investigated [22,23]. Additionally, a low-cost and recyclable approach by employing natural flax fiber as reinforcement in the lattice materials was investigated by Gao et al. [24]. FFRC could be a cheap and eco-friendly choice for automotive hood manufacturing [25].

The aim of this study is to evaluate the pedestrian protection capability of a novel lattice core sandwich hood. The sandwich hood containing a composite pyramidal lattice core was designed and fabricated using interlocking approach. Subsequently, headform-to-hood impact simulations were conducted according to Euro NCAP standard [26]. Effects of material selection and geometrical variables were also discussed for head injury mitigation strategies and further hood design guidance.

2. Lattice material modeling

For a lattice core sandwich hood, the detailed explicit model contains approximately 6000 representative volume elements (RVE), which is computationally prohibitive and time-consuming to regenerate the entire model when local designs change. In the present study, a homogenization method for lattice materials will be utilized referring to previous studies [27,28]. The lattice geometry is simplified into an equivalent continuum which replicates the volumetric average stress and strain fields under general loading conditions. Thus, the simulation results will only contain volumetric average terms but not the field variation within each individual lattice truss member, which will greatly simplify large-scale structural analysis of lattice materials.

2.1. Constitutive model of lattice material

The pyramidal lattice materials have special symmetry as shown in Fig. 1 and can be termed orthotropic which have nine independent elastic constants. The elastic constitutive function of pyramidal lattice can be described as Eqs. (1) and (2) with elastic strain tensor and stress tensor (with Cartesian indices):