Fiber Metal Laminates Engine Hood for Pedestrian Head Protection.

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Abstract Pedestrians is a vulnerable group in traffic accidents, and have a high accident mortality rate. How to design an energy-absorbing and lightweight engine hood for pedestrian protection has been a key point for the automotive industry. Fiber metal laminates (FMLs) show great potential for pedestrian protection due to their strong impact resistance and excellent energy absorption. This study aims to introduce FMLs as an alternative material for the engine hood to achieve better pedestrian safety. Finite element models of the headform impactor and the FMLs hood were established and validated in the LS-DYNA software. Simulation results show that the FMLs hood can effectively reduce the head injury criterion (HIC) value considering three typical collision locations, due to the uniform deformation of the FMLs. This study can reveal the deformation mechanism of the FMLs and promote the development of a related protective structure for pedestrian protection.

I. INTRODUCTION

Pedestrians is a vulnerable group in human-vehicle collisions and are easily injured or even killed. Statistics show that head of pedestrians is the most injured body part [1]. After hitting the front of a car, the pedestrian head may sustain skull fracture, soft tissue injury, cerebral haematoma, concussion and diffuse axonal injury. Automotive engine hoods and windshields are frequent pedestrian head injury sources [2]. Most researchers have reduced the head injury by introducing new materials or microstructures to the engine hood [3]. However, pedestrian head injury is still high when the head hits near the edge of the engine hood, and it is urgent to design a new engine hood to improve the head protection performance considering the extreme collision area.

Fiber metal laminate (FMLs) was first proposed in the 1970s [4]. It is an ultra-hybrid structural material consisting of high-strength metal sheets and fiber prepregs alternately. Compared with aluminum alloy, the FMLs show lower density, higher strength, and the cost is only about 1/3 of the fiber reinforced composite materials with equal volume [5]. The FMLs perfectly combine the advantages of the fiber-reinforced materials and metals to provide more excellent mechanical properties, such as better impact resistance, higher specific strength, higher specific modulus and higher damage tolerance [6], which are applied in aircraft structure (fuselage), automobile panels like floor, firewall and rear wheel panels and electronic panel board [7]. The hot pressing forming is the mainstream method for preparing fiber metal laminate components, which is widely used in the preparation of large aerospace components.

In this work, we introduce FMLs as an alternative material for engine hoods to achieve better pedestrian safety. Finite element models of the headform impactor and the FMLs engine hood were established and validated in the LS-DYNA software. The response of the headform impactor and the hood at three typical collision locations were analysed, which revealed the moving posture of the headform impactor and the deformation mechanism of the FMLs engine hood.

II. METHODS

Head Injury Criteria (HIC)

Head injury criterion (HIC) [8] is used to evaluate the protective performance of the front components of the car. The HIC value can be obtained from the centroid acceleration-time curve measured by an accelerometer installed at the centroid of the dummy head:

$$\mathrm{HIC} = \max(t_2 - t_1)\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5} \tag{1}$$

where a is the acceleration value of the dummy head; t_1 and t_2 are the two moments in the collision. The difference between t_1 and t_2 should be between 3 and 36 ms, and the HIC value should be maximised.

Finite Element Modelling

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Pedestrian head protection for engine hoods is usually evaluated experimentally using a headform impactor. Based on the LS-DYNA explicit dynamic simulation software, a finite element model of an adult headform impactor was established, with an outer radius of 82.5 mm, an inner radius of 62.5 mm, and a mass of 4.5 kg, consisting of an outer synthetic skin part and an inner aluminum skull part. Both parts were meshed by hexahedral elements; the contact interface was processed by common nodes. Part of the synthetic skin layer polyethylene material uses the viscoelastic material *MAT_VISCOELASTIC constitutive model; the internal aluminum skull material uses the rigid body material *MAT_RIGID model.

Based on a commercialised engine hood, a FMLs engine hood with double-curvature sections was established as shown in Fig. 1. The overall size of the FMLs engine hood was about 1000 mm × 1500 mm × 1.9 mm, weighing only 6.20 kg, achieving a weight reduction of 17.7% compared to the mass of the aluminum hood with equal size (7.53 kg). The FMLs hood was composed of an aluminum upper panel, a carbon fiber middle panel and an aluminum down panel with thickness of 0.5 mm, 0.9 mm and 0.5 mm respectively, and these layers are bonded together with resin. Carbon fiber laminates contains six layers of unidirectional T700/3234 carbon fiber prepregs in a certain stacking sequence [0°/ 90°]. The aluminum panel material uses the material *MAT_JOHNSON_COOK model; the carbon fiber laminates material uses the composite model material *MAT_ENHANCED_COMPOSITE_DAMAGE model. The AUTOMATIC_SURFACE_TO_SURFACE_TIEBREAK contact algorithm was applied between the carbon fiber laminates and two aluminum panels to simulate the adhesive inertface.

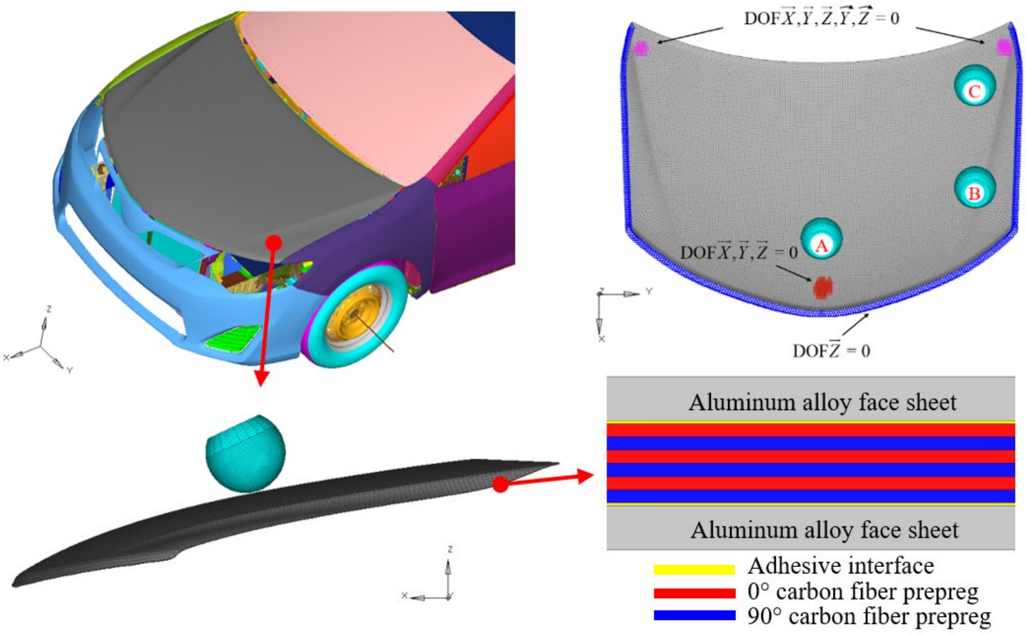


Fig. 1. Finite element model of the FMLs engine hood.

Pedestrian heads often suffer more damage when they hit the edge of the engine hood, especially near the hinges. Considering the severe working condition, set three typical collision positions of the headform impactor to the hood, A, B and C points, as shown in Fig. 1. The headform impactor was launched against the hood at a velocity of 9.8 m/s with an impact angle of 65° to the level. The AUTOMATIC_SURFACE_TO_SURFACE contact algorithm was applied between the hood and the headform impactor. Referring to the research of [9], the boundary conditions were set as the Z-axis displacement constraint along the hood edge, the X-, Y-, and Z-axis displacement constraints in the front hinge, the X-, Y-, Z-axis displacement and the Y-, Z-axis rotation constraints in two rear hinges, as shown in Fig. 1. The AUTOMATIC_SURFACE_TO_SURFACE contact model was used between the head impactor and the hood.

Model Validation

In order to verify the finite element modelling method, referring to the FMLs low-speed impact experiments performed by [10], a model with the same geometric dimensions and material parameters was established and simulated, including the same thickness of each layer, the same carbon fiber arrangement and the same specific mass of the section. Meanwhile, the impact speed of the drop hammer in the test and the impact speed of the headform impactor are similar, both belong to low-speed impact load. Fig. 2 is a comparison of the force-time curves of FMLs for a 10 J impact case obtained from the experiments and simulations. The trends and the peak values of two curves are basically consistent. Therefore, the finite element modelling method is considered to be correct and reliable.

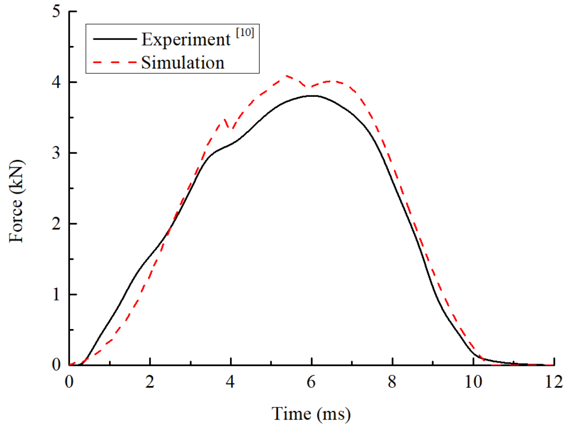


Fig. 2 Force-time curves of FMLs obtained from the experiments [10] and simulations.

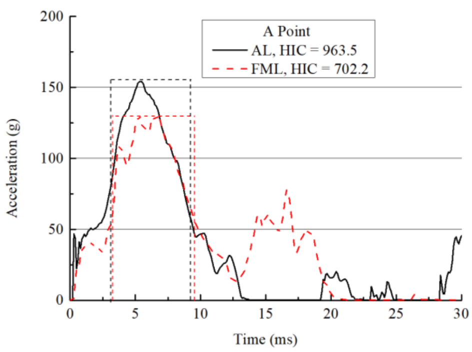
III. RESULTS

Fig. 3 shows the acceleration-time and the displacement-time curves of the headform impactor with the aluminum and the FMLs engine hoods at different collision locations. The trends of the acceleration and the displacement over time are different at different collision points, and the HIC values are also different. The acceleration peak of the headform impactor with the FMLs hood is always lower than that with the aluminum hood at different collision locations. The peak value with the aluminum hood is 154.2, 105.9 and 208.9 g at A, B and C collision points respectively, while the peak value with the FMLs hood is 129.5, 100.9 and 178.0 g. The dotted rectangle in the Fig. 3a, c and e represents the time window of HIC value calculated by Eq. (1). The time window with the FMLs hood always lags behind that of the aluminum hood.

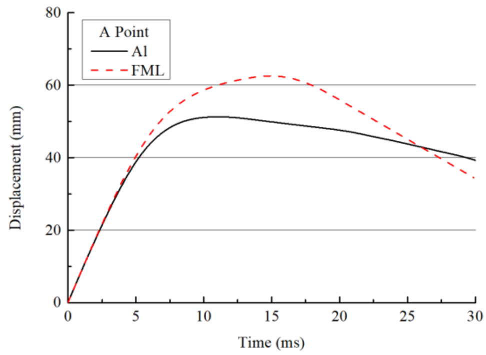
For the displacement peak of the headform impactor, the FMLs hood is 62.6, 101.1 and 46.5 mm at A, B and C collision points, respectively, while the aluminum hood is 51.1, 70.8 and 38.7 mm. For the HIC values, the FMLs hood is 702.2, 585.1 and 1368.0 at A, B and C collision points respectively, while the aluminum hood is 963.5, 922.2 and 2268.1, helping reduce the pedestrian head injury by 27.1%, 36.6% and 39.7%, respectively.

Due to the large local collision area of the headform impactor and the FMLs hood, there is no delamination in the layers and no failure of the carbon fiber. In order to investigate the deformation mechanism of the engine hoods, Von Mises stress nephogram of the aluminum and FMLs hoods with the A collision point at the moment of acceleration peak (5.4 ms) was drawn, as shown in Fig. 4. For the single panel of the aluminum engine hood, stress is mainly distributed in the collision area, while there is no obvious stress distribution in the non-collision area. For the upper aluminum and the carbon fiber panels of the FMLs hood, the range of stress distribution becomes larger, as shown in Fig. 4b and c. Due to the tension of the carbon fiber along the lay-up direction, the hood tends to deform overall. In addition, stress is concentrated to the carbon fiber panel, which reduces the stress distributed on the aluminum panel directly contacted with the headform impactor.

In summary, the introduction of carbon fiber laminates material results in the uniform stress distribution of the FMLs. The particular deformation mechanism of the FMLs engine hood increases collision time, increases collision displacement of the headform impactor, and reduces acceleration peak of the headform impactor, helping to improve the pedestrian head protection performance.



(a)



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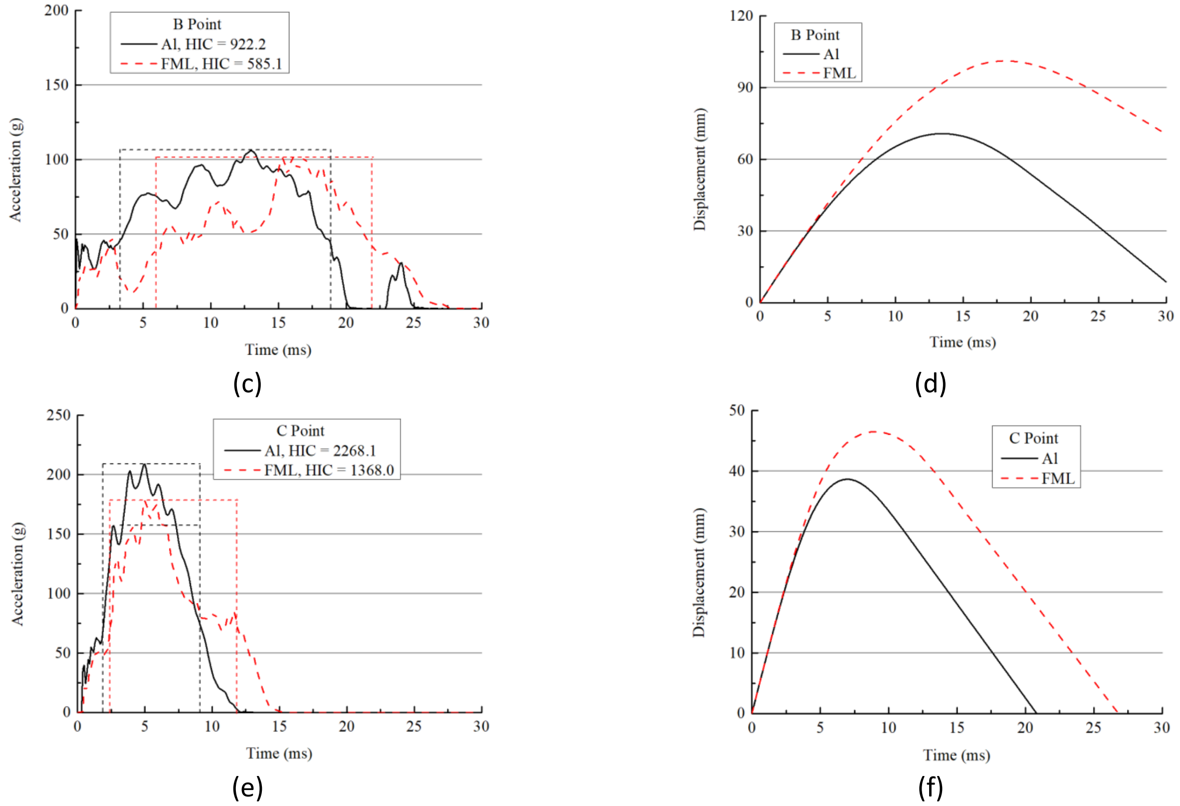

Fig. 3. Acceleration-time and displacement-time curves of the headform impactor with aluminum and FMLs engine hoods at different collision locations (a-b) A point; (b-c) B point; (d-e) C point.

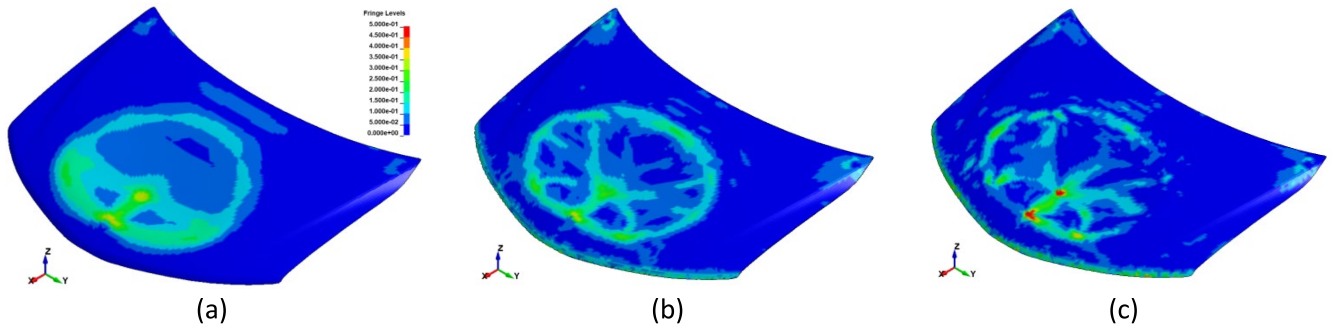

Fig. 4. Von Mises stress nephogram of the aluminum and FMLs hoods with the A collision point at the time of 5.4 ms (a) aluminum hood; (b) upper aluminum panel of the FMLs hood; (c) fiber panel of the FMLs hood.

IV. CONCLUSION

This work introduces FMLs as an alternative material for engine hoods to achieve better pedestrian safety. Finite element models of the headform impactor and a FMLs engine hood were established and validated. Results show that carbon fiber laminates material tends to increase the range of stress distribution, resulting in the uniform deformation of FMLs engine hoods. Compared with the traditional aluminum engine hood, the mass of the FMLs hood reduced by 17.7%, and the HIC value reduced by 27.1%, 36.6% and 39.7% at three typical collision points, respectively. Due to the particular deformation mechanism of the FMLs engine hood, the pedestrian head injury can be effectively reduced. This study can promote the development of related protective structure for the pedestrian protection and benefit automotive lightweight design.

V. REFERENCE

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