Assessment of EPP Material Form Helmet Liner

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Abstract: Studies have shown that bicyclers wearing helmets exhibit a significantly lower rate of sustaining head trauma than those not wearing helmets do, confirming the protection effectiveness of helmets. The shapes and material characteristics of liner play a crucial role in buffer performance. Many foam materials exist for liner. Selecting liner materials that are high in impact absorption capacity, light in weight, and environmentally friendly is essential to designing bicycle helmets. Studies have shown that bicyclers wearing helmets exhibit a significantly lower rate of sustaining head trauma than those not wearing helmets do, confirming the protection effectiveness of helmets. This study established and analyzed impact test models in LS-DYNA according to the helmet standards of EN 1078: 2006, CPSC: 16 CFR Part 1203, and SNELL B95. Currently, most bicycle helmets in the market feature expanded polystyrene (EPS) liner. To enhance the impact absorption performance of helmets, this study adopted a new liner materials-expanded polypropylene (EPP). The impact absorption performance of the helmet models employed in this study was analyzed and compared to evaluate the applicability of the new liner materials in bicycle helmets.

Key words: Helmet, liner, foam, expanded polypropylene, impact.

1. Introduction

Bicycles are energy efficient, environmentally friendly, convenient, and healthy vehicles and have become essential tools for commuting and recreational activities. However, bicycle accidents can lead to death through severe head trauma [1]. Bicyclers typically wear helmets to ensure their safety. In other words, it is necessary for consumers who ride bicycles to wear helmets to avoid head trauma due to collision. Studies have shown that bicyclers wearing helmets exhibit a significantly lower rate of sustaining head trauma than those not wearing helmets do, confirming the protection effectiveness of helmets [2]. To ensure the protective effect of helmets, these helmets undergo a series of tests before delivery. The most vital test verifies a helmet's buffer effectiveness against forces of impact. Standards have been established worldwide to ensure the effectiveness of these helmets for head protection. Especially notable are those formulated by countries with large bicycling populations (i.e., EN 1078:2006 in the European Union [3], Consumer Product Safety Commission (CPSC):16 Code of Federal Regulations (CFR) Part 1203 in the United States [4], and SNELL B95 in Australia [5]). These three standards comprehensively specify various bicycle helmet impact tests, such as impact absorption tests, device strength tests, retention tests, and field of vision tests. Studies on the impact absorption performance of helmets worldwide have focused on liner materials, sizes, and structures. Particularly, the shapes and material characteristics of liner play a crucial role in buffer performance. Many foam materials exist for liner. Selecting liner materials that are high in impact absorption capacity, light in weight, and environmentally friendly is essential to designing bicycle helmets.

Bicycle helmet research can involve designing helmets, analyzing head injuries, and developing test standards. Approaches employed in research include analysis of traffic accident statistics, impact tests, and computer-aided engineering. Studies on helmet resistance to impact are briefly described as follows. Kostopoulos et al. [6] applied LS-DYNA, a finite element analysis program, to analyze the relationship between the strength of composite shells of helmet models and head injuries during impact. Tinard et al. [7] also employed LS-DYNA to simulate helmet shells composed of various composite materials and to explore and verify the elasticity and fracture performance of the helmet shells. Blanco et al. [8] proposed an innovative structure for head protection; its lining comprised an acrylonitrile–butadiene–styrene combination and a conical design. The model was tested and verified through EN 1077 (ski cap standard of the European Union), and its performance was optimized through finite element analysis. Afshari [9] conducted a finite element analysis on human heads with and without motorcycle helmets and compared the kinematic parameters, such as head injury indices, head acceleration curves, and the pressure generated within the brain, through simulation. Cui et al. [10] employed ABAQUS to establish a motorcycle helmet finite element model, which was optimized and verified to investigate the relationships between the area, thickness, and plastic energy density of the liner stress distribution and the maximal head acceleration. Hansen et al. [11] analyzed linear head acceleration in the standard impact test, neck load and linear head acceleration in the oblique impact test, and effect of the angular impact mitigation system on the buffer effectiveness of the helmet. Fanta et al. [12] applied mathematical dynamic models to establish three distinct frontal vehicle parts and three human models with different driving methods, to simulate collision with bicycles, and to examine head injuries after collision.

To substantiate bicycle helmet standards, impact tests are typically carried out through experimentation. However, relevant experiments involve complex processes and high expenses. Therefore, simulating helmet impact through a finite element analysis has become the trend of helmet performance evaluation. Data simulation is low-cost, shortens research and development time, and is highly repeatable. This study established and analyzed impact test models in LS-DYNA according to the helmet standards of EN 1078: 2006, CPSC: 16 CFR Part 1203, and SNELL B95. Currently, most bicycle helmets in the market feature expanded polystyrene (EPS) liner. To enhance the impact absorption performance of helmets, this study adopted two new liner materials, expanded polypropylene (EPP) and expanded polyurethane (EPU), in conjunction with EPS. The impact absorption performance of the helmet models employed in this study was analyzed and compared to evaluate the applicability of the new liner materials in bicycle helmets. The examination of the liner materials provides a reference for the future design of bicycle helmets in Taiwan; the helmet impact test models may also provide a crucial reference for enhancing helmet structures and developing safety equipment.

2. Standards and Models of Helmet Impact Test

2.1. EN 1078

EN 1078:2006 was established by CEN/TC 158, the Head Protection technical committee of the European Committee of Standardization. The dynamic impact test specified in this standard involves using a triaxial helmet impact testing machine. A head model equipped with a helmet is placed on a basket ring on a test platform. The model is dropped from 1.5 m to hit a flat anvil through freefall and dropped from 1.06 m to hit a kerbstone anvil through freefall. The acceleration of the gravity center of the model is measured; the peak value should not exceed 250 g. The numerical simulation of the helmet impact on the flat and kerbstone anvils was performed according to EN 1078:2006. The head model equipped with the helmet collided with the flat and kerbstone anvils at speeds of 5.42 and 4.57 m/s, respectively (Fig. 1). LS-DYNA was employed to calculate and record the head acceleration.

2.2. CPSC

CPSC: 16 CFR Part 1203 was established by the CPSC in 1994 with authorization of the United States Congress. The CPSC also collaborated with the American Society for Testing and Materials to propose two drafts. The standard was published in February of 1998. The dynamic impact test specified in this standard involves using a uniaxial helmet impact testing machine. A head model equipped with a test helmet is fixed on the ball arm or collar device on a test platform. The model is dropped along a rail at 2 m to hit a flat anvil,

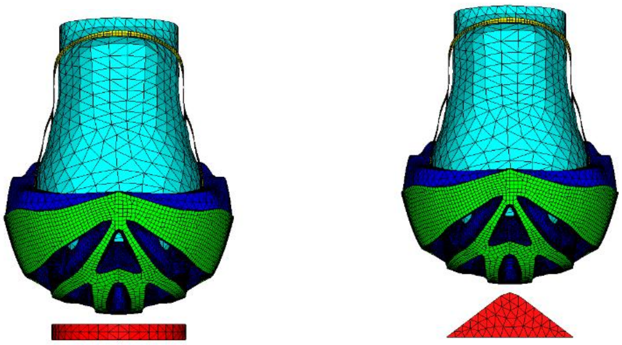

Fig. 1. EN 1078 Impact Test Model

at 1.2 m to hit a kerbstone anvil, and at 1.2 m to hit a hemispherical anvil. The acceleration of the gravity center of the model is measured; the peak value should not exceed 300 g. The numerical simulation of the helmet impact on the flat, kerbstone, and hemispherical anvils was performed according to CPSC: 16 CFR Part 1203. The head model equipped with the helmet collided with the flat, kerbstone, and hemispherical anvils at the speed of 6.2, 4.8, and 4.8 m/s, respectively (Fig. 2). LS-DYNA was employed to calculate and record the head acceleration.

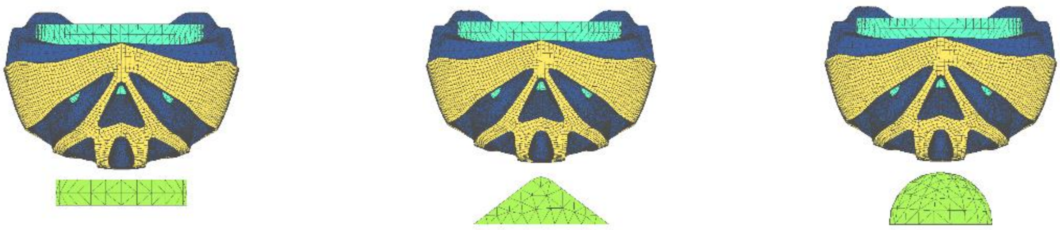

Fig. 2. CPSC Impact Test Model

2.3. SNELL B95

SNELL B95 was established and published by the Snell Memorial Foundation in 1995. The standard was revised in 1998 to satisfy helmet protection requirements in Australia for adults and older children. The dynamic impact test specified in this standard involves using a uniaxial helmet impact testing machine. A head model equipped with a test helmet is fixed on a ball arm or collar device on a test platform. The model is dropped along a rail at 2.2 m to hit a flat anvil, at 1.3 m to hit a kerbstone anvil, and at 1.3 m to hit a hemispherical anvil. The acceleration of the gravity center of the model is measured; the peak value should not exceed 300 g. The numerical simulation of the helmet impact on the flat, kerbstone, and hemispherical anvils was performed according to SNELL B95. The head model equipped with the helmet collided with the flat, kerbstone, and hemispherical anvils at speeds of 6.63, 5.37, and 5.37 m/s, respectively (Fig. 2). LS-DYNA was employed to calculate and record head acceleration.

2.4. Helmet Finite Element Model

A finite element model of the helmet employed in this study was constructed to resemble commercial Giant bicycle helmets. The helmet featured a 15-pore ventilation design and was applicable for human heads with circumferences of 58–63 cm. Fig. 3 illustrates the finite element model of the helmet, which consisted of three components, 50,332 nodes, 60,874 solid elements, and 3,960 shell elements.

Fig. 3. Finite element model of the helmet

3. Simulation Results

3.1. EN 1078

Fig. 4 illustrates a diachronic chart of the head acceleration when the helmet with EPP lining hit the flat anvil according to EN1078. The acceleration peaked at 181.01 g at 8.08 ms, within the limit of 250 g permitted by EN1078. Fig. 5 depicts a diachronic chart of the head acceleration when the helmet with EPP lining hit the kerbstone drill on the roadside according to EN1078. The acceleration peaked at 109.08 g at 11.32 ms, within limit of 250 g permitted by EN1078. Accordingly, the helmet met the EN1078 standards.

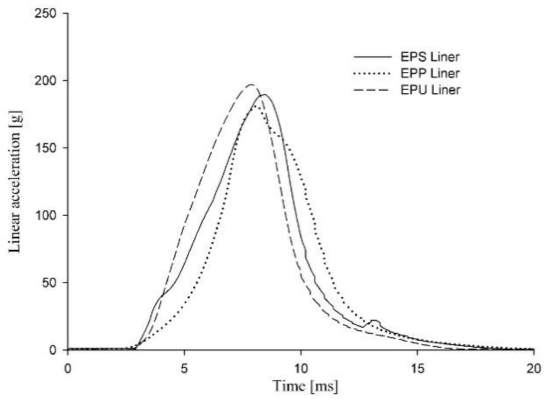

Fig. 4. Resultant translational acceleration for EPP liner on flat anvil based on EN1078

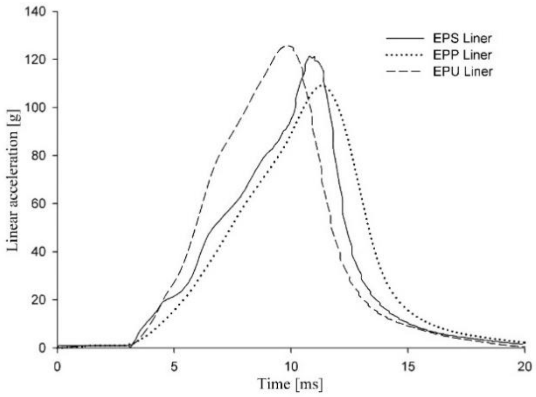

Fig. 5. Resultant translational acceleration for EPP liner on kerbstone anvil based on EN1078

3.2. CPSC

Fig. 6 illustrates a diachronic chart of the head acceleration when the helmet with EPP lining hit the flat anvil according to CPSC standards. The acceleration peaked at 237.85 *g* at 7.72 ms, within the limit of 300 *g* permitted by the CPSC standards. Fig. 7 depicts a diachronic chart of the head acceleration when the helmet with EPP lining hit the stone anvil on the roadside according to CPSC standards. The acceleration peaked at 150.49 *g* at 7.58 ms, within the limit of 300 *g* permitted by the CPSC standards. Fig. 8 illustrates a diachronic chart of the head acceleration when the helmet with EPP lining hit the spherical anvil according to CPSC standards. The acceleration peaked at 127.09 *g* at 7.2 ms, within the limit of 300 *g* permitted by the CPSC standards. Accordingly, the helmet met the CPSC standards.

3.3. SNELL B95

Fig. 9 illustrates a diachronic chart of the head acceleration when the helmet with EPP lining hit the flat anvil according to SNELL B95. The acceleration peaked at 266.21 *g* at 7.6 ms, with the limit of 300 *g* permitted by SNELL B95. Fig. 10 depicts a diachronic chart of the head acceleration when the helmet with EPP lining hit the kerbstone anvil on the roadside according to SNELL B95. The acceleration peaked at 176.03 *g* at 8 ms, within the limit of 300 *g* permitted by SNELL B95. Fig. 11 illustrates a diachronic chart of the head acceleration when the helmet with EPP lining hit the hemispherical anvil according to SNELL B95. The acceleration peaked at 152.98 *g* at 7.04 ms, within the limit of 300G permitted by SNELL B95. Accordingly, the helmet met the SNELL B95 standards.

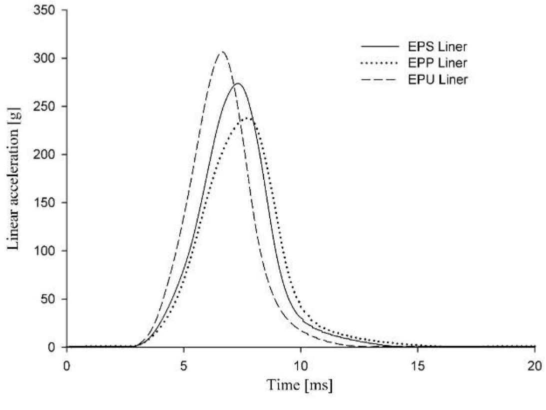

Fig. 6. Resultant translational acceleration for EPP liner on flat anvil based on CPSC

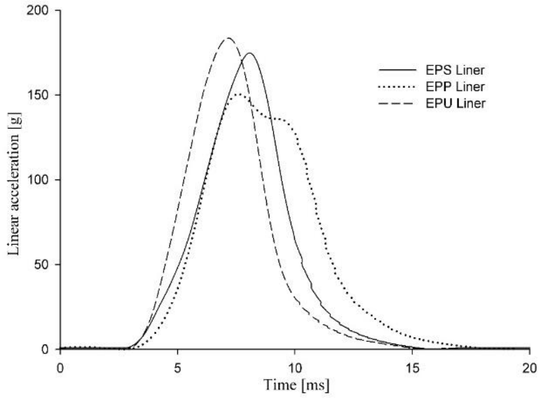

Fig. 7. Resultant translational acceleration for EPP liner on kerbstone anvil based on CPSP

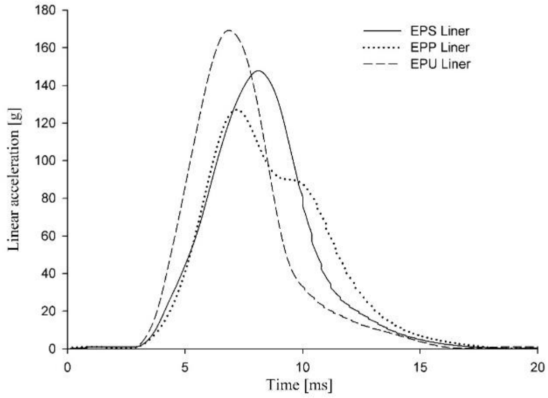

Fig. 8. Resultant translational acceleration for EPP liner on hemispherical anvil based on CPSP

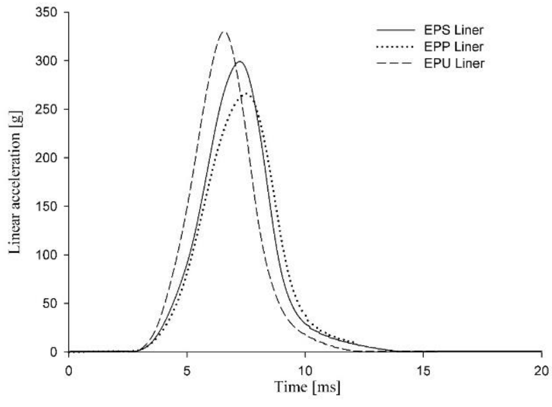

Fig. 9. Resultant translational acceleration for EPP liner on flat anvil based on SNELL B95

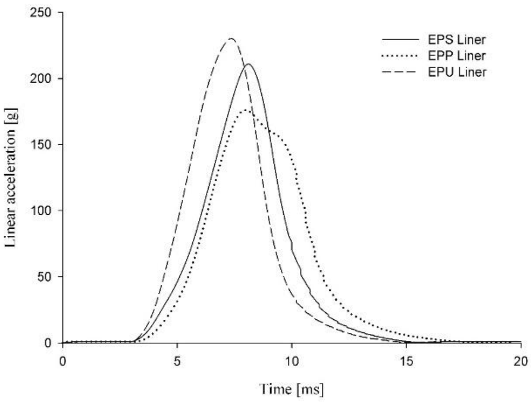

Fig. 10. Resultant translational acceleration for EPP liner on kerbstone anvil based on SNELL B95

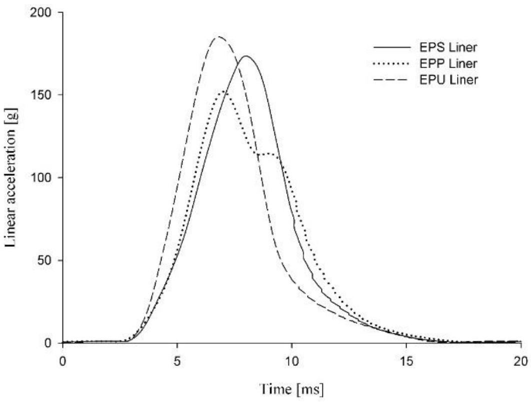

Fig. 11. Resultant translational acceleration for EPP liner on hemispherical anvil based on SNELL B95

4. Conclusion

This study explored the applicability of new liner material EPP for bicycle helmets through constructing impact testing models based on bicycle helmet safety standards. Impact test data of the helmets were evaluated according to the standards of EN1078:2006, CPSC: 16 CFR Part 1203, and SNELL B95 to confirm safety and applicability of EPP liner material. The numerical models established in this study are expected to provide a reference for bicycle helmet impact simulation.

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