Development of Composites using Natural Fibre Reinforcement for Personal Impact Protection

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Introduction

- The goal of this project is to investigate the use of flax fibre reinforced composites for use in personal impact protection.
- Increase in helmet use, research concerning head injuries in sport and environmental issues leads to development of novel helmet technologies in the coming years.
- Key performance metrics are bending stiffness, energy absorption and retained flexural properties after impact.
- Naming conventions: All samples have 2x2 flax twill face fabric and ±45 rear fabric. FF - Flax face and flax rear, FG - Flax face and glass rear, CG - Carbon face and glass rear. Additional R indicates use of powerRibs and O or X indicates impact on rib opening or crossing respectively.

Layup Design

Composites that use an epoxy matrix, as is most common for high performance applications, show very little plastic deformation which is one of the main energy dissipation mechanisms in ductile materials. The main energy absorption mechanism in composites is through a few explicit damage modes, which generally occur in sequence as the impact energy increases. These include indentation, matrix cracks, fibre/matrix debonding, delamination and fibre breakage. Of these, delamination is the most relevant to energy absorption in impact loading, as it has the ability to create new large surfaces between the laminates.

Angle-ply composite have been often shown to promote delamination as a damage mode in low-velocity impacts due to the mis-match of bending stiffness in the plies. The delamination area for a given impact energy increases with ply angle with an approximately linear relationship.

Flexibiliser

A flexibilising agent, PPG-DGE, was used in the epoxy resin to reduce the bending stiffness of the composite enabling a thicker stronger laminate. Resulting bending stiffness did not follow the rule of mixtures and caused an effective reduction of fibre stiffness by 7.4% for 20% flexibiliser and 31% for 40% addition of flexibiliser without a difference in visual damage onset. This was caused by interlaminar shear and fibre buckling and is not considered as a likely benefit to impact properties.

Drop tower tests

Used 100x150mm ASTM geometry for the impact sample and a 40mm hemispherical impact head. The samples were tested with a 25mm thick layer of EPP foam and a steel was added plate behind the foam contrary to the ASTM to reduce the tensile forces on the foam, and better reflect the EN helmet standard. The impact energies were varied up to a nominal 60J (45J measured energy).

Despite difference in visible damage and damage mode, absorbed energy remained very similar across all samples, demonstrating dominance of foam contribution.

Peak force for FF sample at 45J high due to full perforation and compression of foam structure. This is a result of the low strength of flax fibres and is not good for personal protection. FG has reduced peak force at high energy due to presence of delamination and fibre breakage. This is a good result for personal protection as lower peak forces reduce the chance of head injury.

powerRibs™

powerRibs is a fabric made of non-woven flax yarns, held in place by a polyester thread and a polypropylene micromesh.

This fabric has the ability to provide a specific stiffness higher than carbon fibre to a composite. It was found that when combined with a foam backing in impact, the powerRibs cause a strong stress concentration and lower the threshold for visible and penetration damage in all layup configurations and particularly in O samples as shown in the above right 3D representation of deformation of an impacted powerRibs specimen.

Conclusion

In combination with glass fibres, flax fibres have the possibility to be used in non-motor sports helmets. Flax fibres have a good threshold for visible damage, and by using angle-plies, delamination can be promoted in hybrid composites.

The reduced stiffness of flax compared to carbon fibre can also be an advantage in distribution of stress into the foam layer.

By adjusting the layup according to desired impact performance, it should be possible to tune the helmet shell to show significant visible damage at similar impact energies to foam damage and therefore indicate the end of life of the product.

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