Development and testing of additively manufactured bio-inspired structures for impact absorption

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Introduction

In what concerns vehicle design and engineering, the capacity of managing and attenuating the energy transmitted by a collision is a key factor for vehicle safety. The integration of energy absorption structures has become a practical mean to reduce the harm caused by accidents and increase passenger safety. These structures are intended to deform and absorb the energy in a controlled manner, thereby reducing the force transmitted to the occupants. Conventional processes are only able to manufacture relatively simple parts. The possibility of enhancing the crashworthiness performance through geometry tuning can be magnified when resorting to non-traditional manufacturing processes such as 3D printing [1]. This work aims to study the crashworthiness potential of bio-inspired 3D printed energy absorption structures (crash box) with functional stiffness grading. Hence two EAS concepts were developed and tested to compression under quasi-static and high-rate compression and impact.

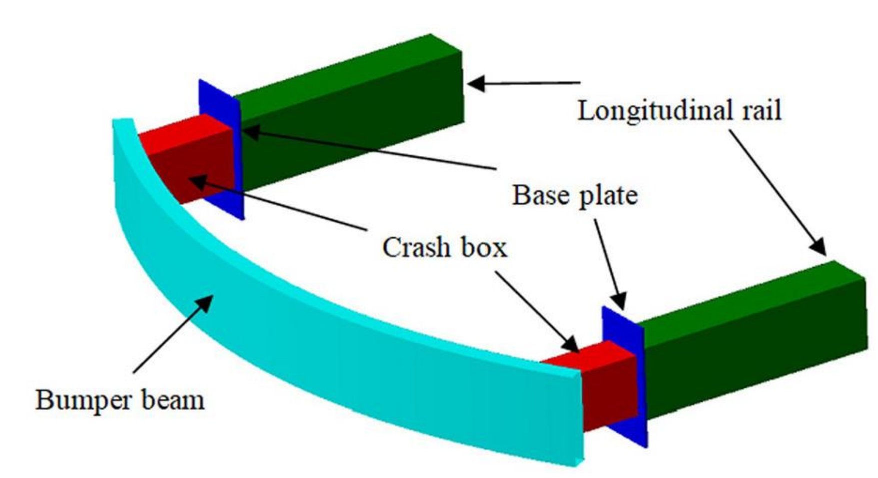

Figure 1 – Vehicle frontal energy absorption system (crash boxes in red).

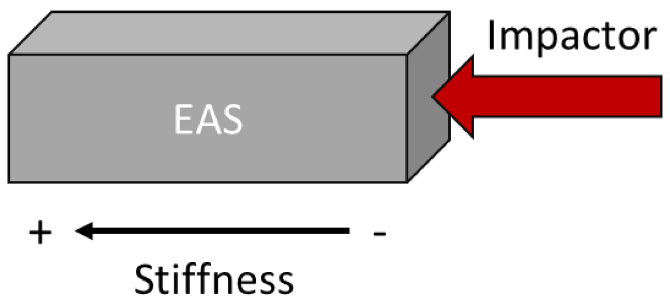

Figure 2 – Stiffness graded EAS representation.

EAS concepts

Different material parts were adhesively bonded to create a multi-material structure with a uniform honeycomb geometry, which was printed in two different sizes. These were directly compared to a uniform single material structure with the same geometry, and the size effect was assessed. On the other hand, a single material structure with a spider web geometry was developed. The stiffness grading of the latter was made through the variation of the structural density.

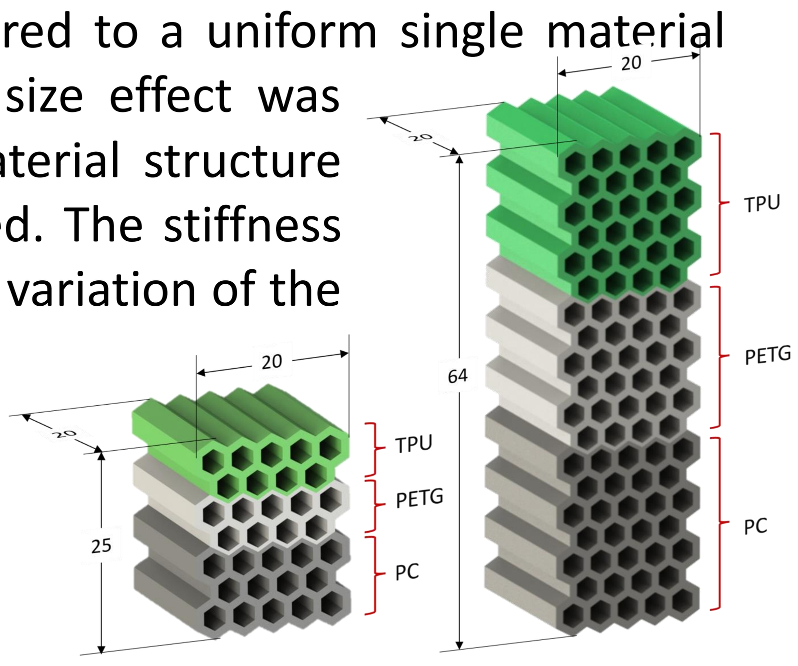

Figure 3 – Multi-material honeycomb EAS.

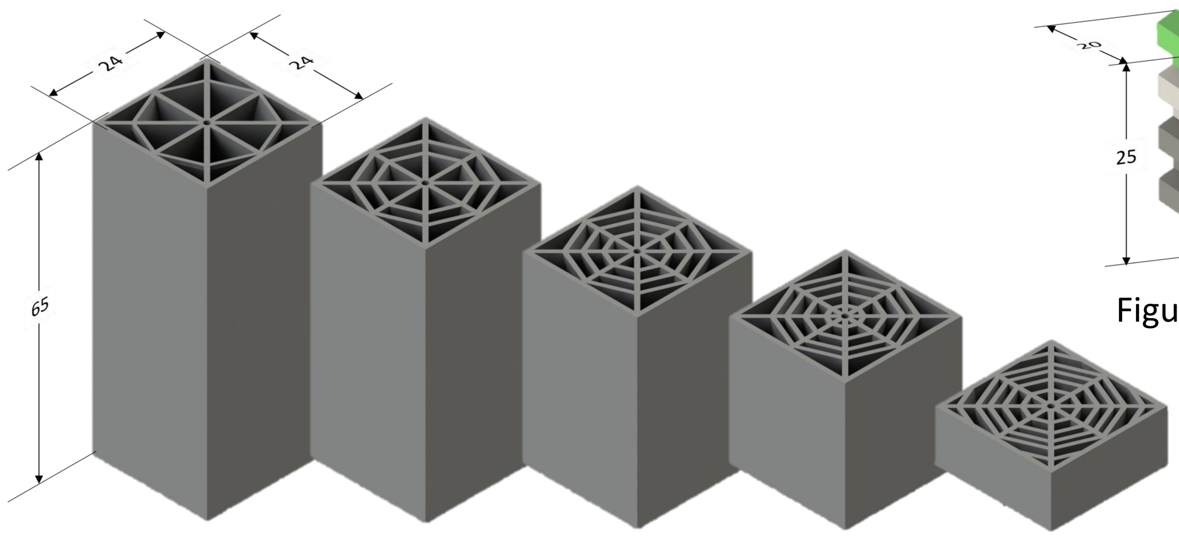

Figure 4 – Single material EAS cross-section views.

Collapse behaviour

As a result of the stiffness grading, a staggered compression was observed during the quasi-static (Figure 5) and high-rate compression of both honeycomb and spider web graded structures. For the honeycomb multi-material structures, 3 distinct compression stages can be identified (Figure), corresponding to the compression of each material. the structures started to collapse on the lowest stiffness region, with a progressive deformation of the adjacent, higher stiffness ones.

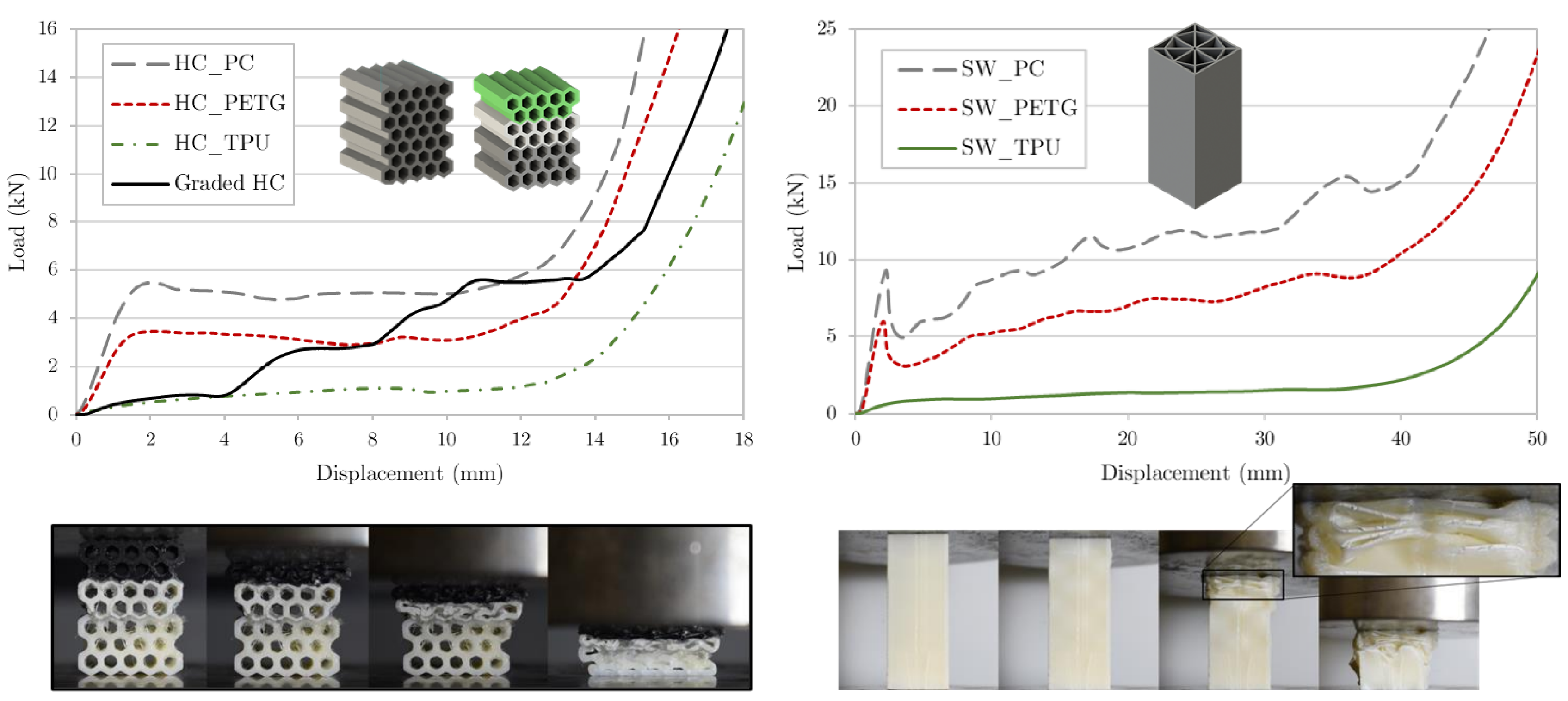

Figure 5 – Collapse behaviour of multi-material (left) and single material developed EAS

Impact

The developed structures were submitted to impact tests to assess their behaviour under close to real-world conditions and crashworthiness potential. The PETG and TPU uniform honeycomb structures couldn't absorb the impact energy without densifying, leading to a very high peak stress. The multi-material counterpart performance was hampered by the brittle failure of the PETG portion. Nevertheless, the integration of lower stiffness materials allowed to decrease the initial peak force generated by the impact, when compared to the PC uniform structure. Regarding the spider web EAS, the TPU counterpart was able to absorb the impact energy in a more gradual manner, performing better than the other materials counterparts for the used energy of impact.

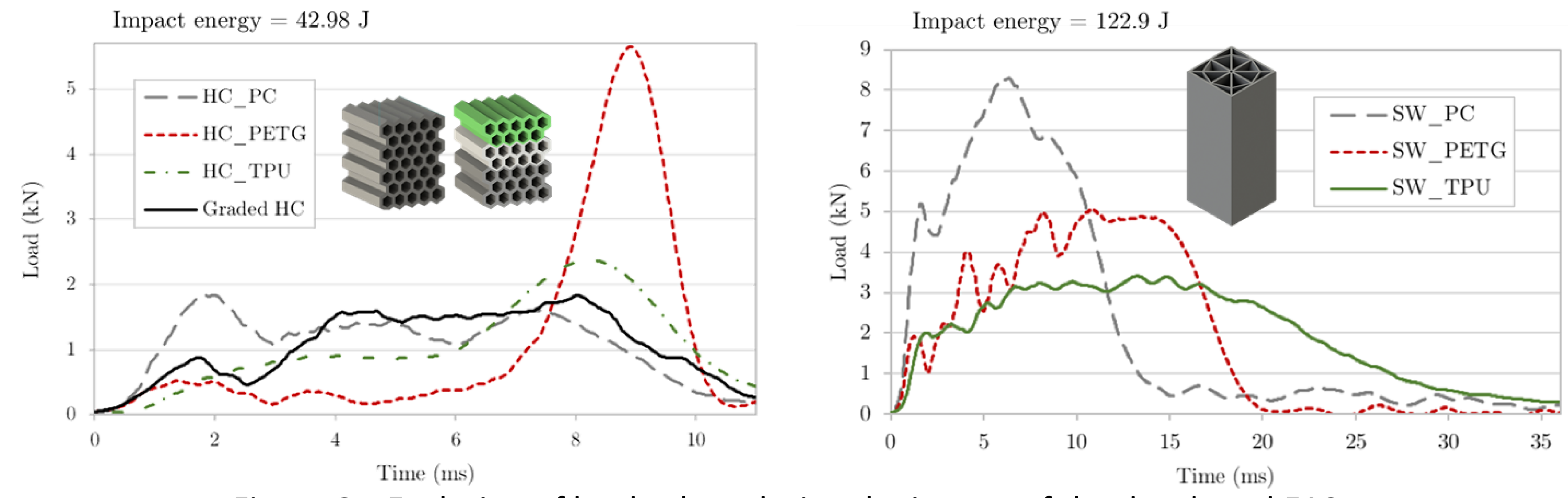

Figure 6 – Evolution of load values during the impact of the developed EAS.

Crashworthiness

Multiple crashworthiness parameters were calculated to assess the crashworthiness of the developed EAS. Among these, the specific energy absorption – SEA – quantifies the energy absorbed per unit of mass. On the other hand, the crushing force efficiency – CFE – consists of the ratio between the mean crushing force and the peak crushing force during the impact and measures how gradual is the energy absorbed by a structure. Figure 7 shows the comparison between the values of these crashworthiness parameters for the multi-material honeycomb and the spider web graded structures.

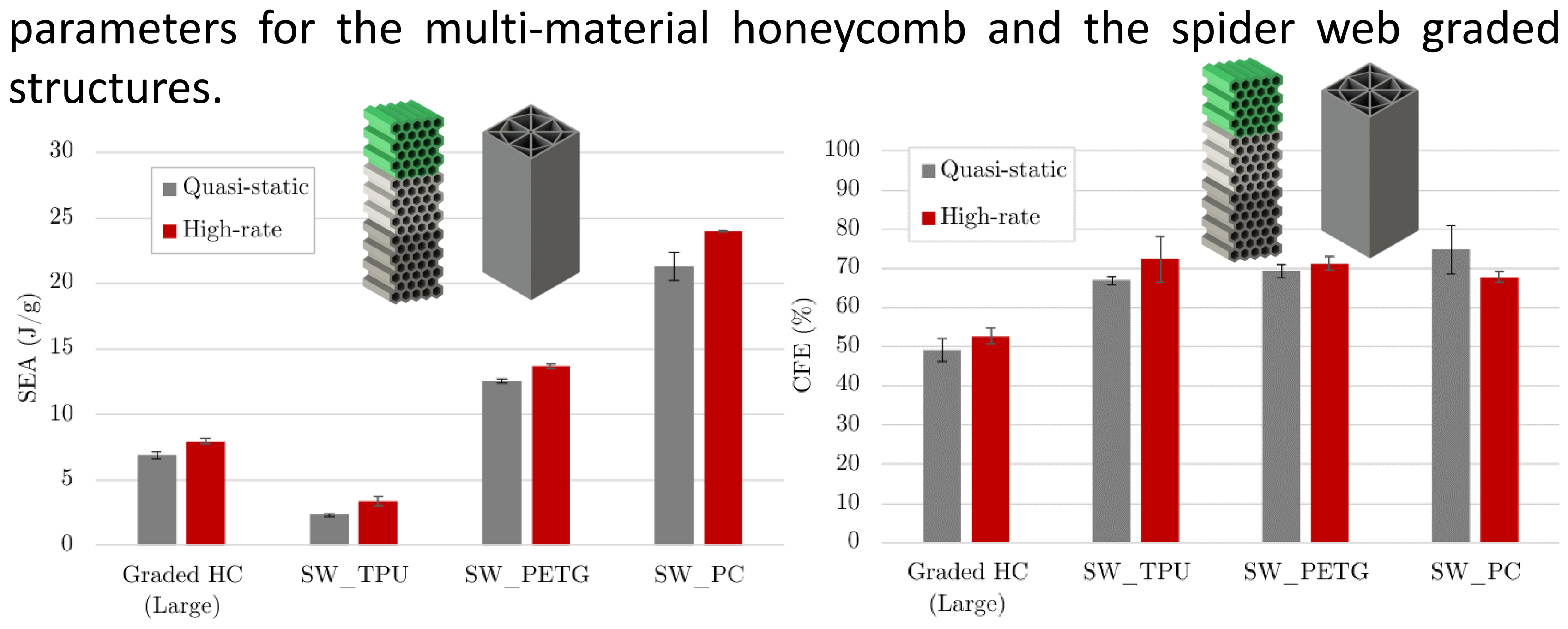

Figure 7 – Calculated SEA and CFE values for multi-material honeycomb and spider web graded structure, under quasi-static and high-rate compression.

Conclusions

The integration of multiple materials on the developed honeycomb structure led to a lower SEA when compared to the uniform honeycomb counterparts. Nevertheless, the absorption efficiency revealed to be similar for the multi-material and the PC structures. It was concluded that the energy absorption capability of a structure, under quasi-static and high-rate compression, can be determined from the compression testing of a smaller counterpart with the same configuration, since they will depend only on the material employed. Overall, the spider web configuration showed a higher crashworthiness potential than the multi-material counterparts by being able to absorb energy more efficiently. Among these, the TPU counterpart allowed a lower and more gradual energy absorption rate, when submitted to the set impact energy. Further research is needed to optimize the developed concepts.

References

[1] - Chukwuemeke William Isaac and Fabian Duddeck. Current trends in additively manufactured (3d printed) energy absorbing structures for crashworthiness application – a review. Virtual and Physical Prototyping, 17(4):1058–1101, 2022.

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