VIRTUAL DESIGN OF CAR COMPONENTS MANUFACTURED WITH HIGH-PERFORMANCE DISCONTINUOUS COMPOSITES

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Abstract
High Performance Discontinuous Composites (HPDCs) combine performance and manufacturability, which makes them suitable for automotive structures. However, due to the intrinsic variability in the microstructure of HPDCs, the local modulus and strength of these materials are highly heterogeneous, which raises a challenge in designing and simulating the structural response of a HPDC component. This work analyses the mechanical response of the engine bonnet of the Lamborghini Huracan PERFORMANTE, simulated using a FE Monte-Carlo framework developed specifically for HPDC structures. A significant spread of the maximum failure index and location of the critical region of the bonnet is observed, which highlights the effect of variability in HPDC materials on their structural performance.

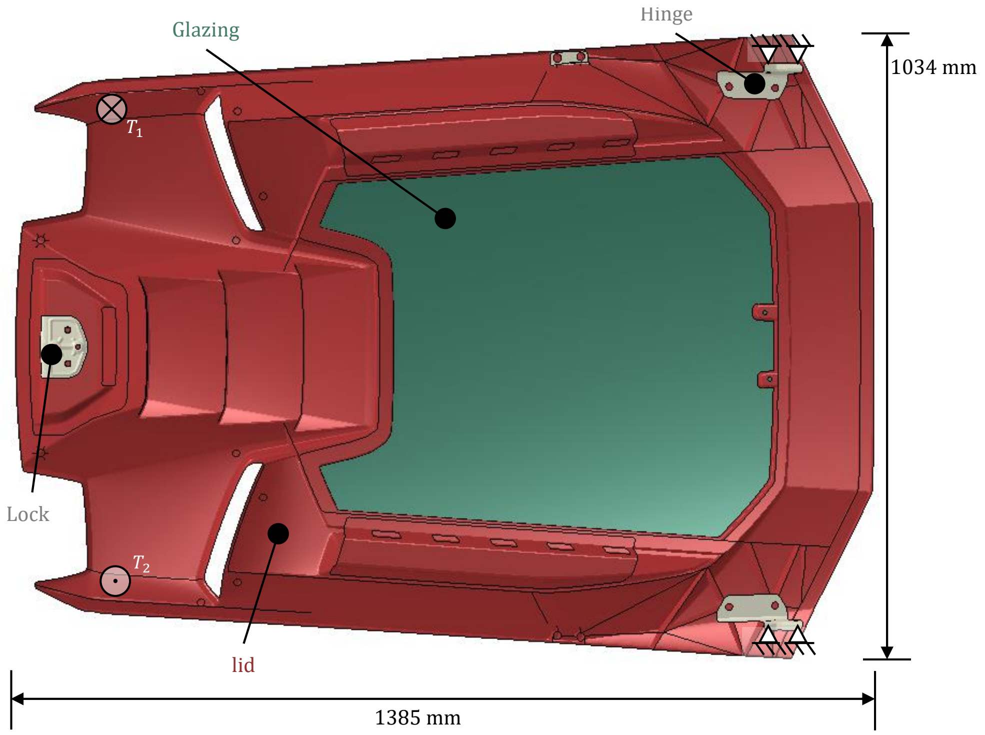
1. Introduction

High Performance Discontinuous Composites (HPDCs) are chopped tape-based discontinuous composites that combine good material properties and manufacturability, which makes them appealing for high-volume production of lightweight structural components. However, the discontinuous nature of HPDCs, with randomly distributed and orientated carbon fibre tows, leads to intrinsic variability in the microstructure of HPDCs and, consequently, highly heterogeneous local modulus and strength fields. The effect of this variability in HPDCs on a structure's mechanical response is yet to be analysed.

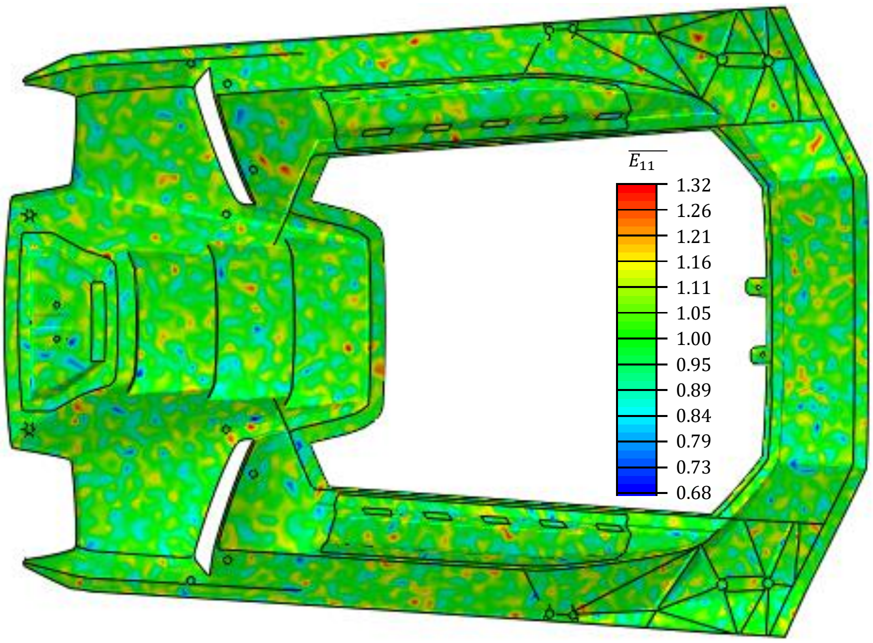
This work aims to examine the effect of variability in the microstructure of HPDCs on their structural response, by running a Monte-Carlo analysis on an automotive bonnet using an in-house developed finite element (FE) Monte-Carlo framework [1]. The set-up of the FE model is described in Section 2; the results from the Monte-Carlo analysis are presented and discussed in Section 3, and Section 4 presents the main conclusions.

2. Model set-up

The engine bonnet lid of the Lamborghini Huracan PERFORMANTE manufactured from HPDCs is simulated in the complete bonnet assembly (including the hinges, locks and glazing manufactured from other materials) under a torsional loading case (see Figure 1a). The bonnet is modelled in Abaqus [2], using shell elements.



(a) The automotive bonnet assembly with dimensions, components and boundary conditions labelled.



(b) The automotive bonnet lid with a heterogeneous modulus field assigned (values normalised against the modulus used in the homogeneous model).

Figure 1: Model set-up for the Monte-Carlo simulation.

A baseline deterministic simulation (hereafter designated as the 'homogeneous model') was run in Abaqus, using deterministic and homogeneous stiffness and strength properties for each material in the bonnet. In addition, a Monte-Carlo simulation with 100 realisations of stochastic heterogeneous stiffness and strength fields assigned to the HPDC regions (see Figure 1b) was also run in Abaqus, using our in-house FE Monte-Carlo framework [1]; each simulation run within the Monte-Carlo framework is hereafter designated as a 'heterogeneous case'. The average stiffness properties of the HPDC material in the heterogeneous cases were the same as the stiffness properties assigned to the homogeneous case; all results shown for the heterogeneous cases will be normalised with the results from the homogeneous case.

3. Results

Figure 2 compares the Cumulative Distribution Function (CDF) of the maximum failure index (F_{I}) in each of the 100 heterogeneous cases to that of the homogeneous case. A wide spread in the F_{I} value is observed, which suggests that there is a large variation in the maximum load that the bonnet can take before failure initiation occurs, which should be accounted for at the design stage.

Figure 3 shows the superposed F_{I} map in the bonnet lid, obtained by taking the maximum F_{I} amongst the 100 heterogeneous cases at each point. Moreover, the most critical region in each heterogeneous case (defined as the region with the maximum failure index of that case) is also shown; nine different critical regions were detected in the Monte-Carlo analysis. This suggests that the variability in the microstructure of HPDCs also leads to sufficiently weak spots to promote failure at unexpected regions of a structure, which would not be detected by a deterministic analysis alone.

4. Conclusions

By conducting a FE Monte-Carlo analysis which considers the variability in the microstructure and local properties of HPDCs on an automotive bonnet, it was found that:

1. The variability in HPDCs leads to a wide spread of the maximum failure index of the bonnet under a given loading case;

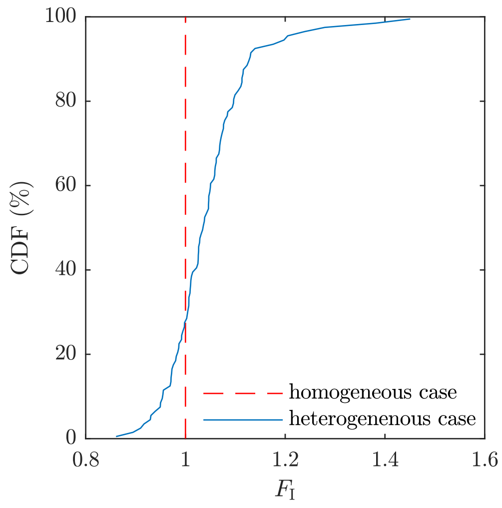


Figure 2: Cumulative Distribution Function (CDF) of the maximum failure index in the bonnet lid.

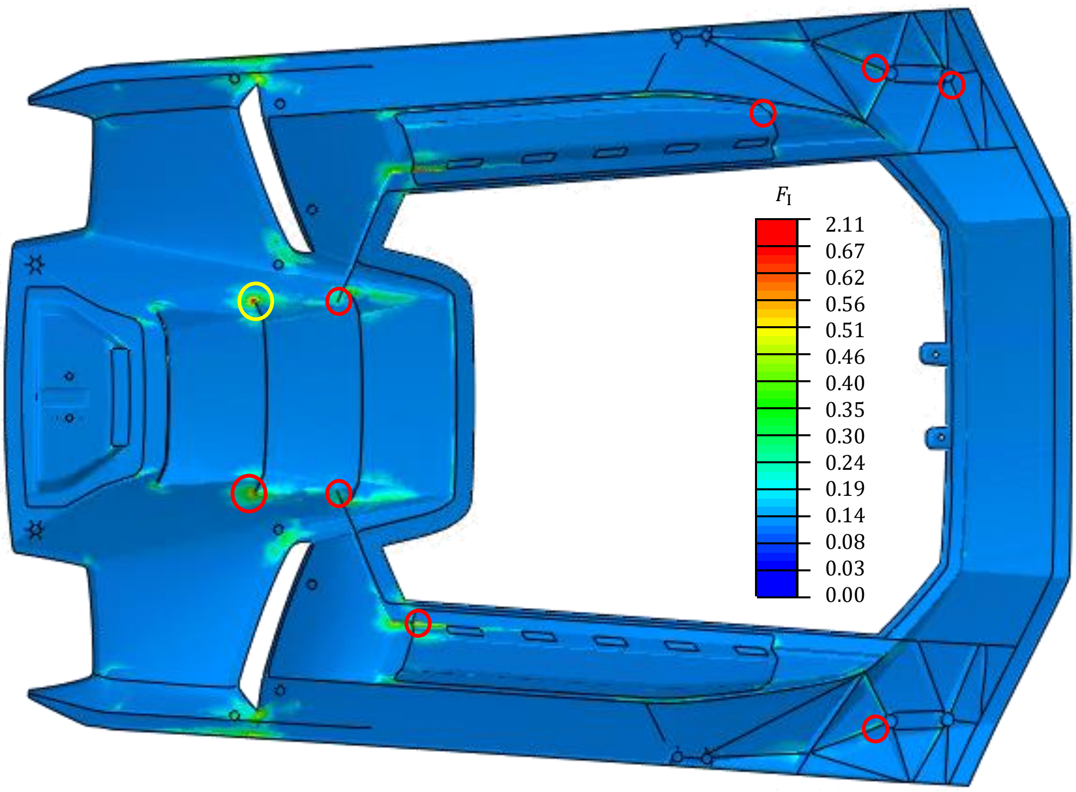


Figure 3: Failure index field of the bonnet, superposed from the 100 heterogeneous cases. The failure index (ratio between applied stress and ultimate strength) is normalised against the maximum failure index in the homogeneous case. The region highlighted by the yellow circle is the most critical region identified in the homogeneous model, and it coincides with the critical regions for 44 heterogeneous cases; the regions highlighted by the red circles are the other critical regions identified in the remaining 56 heterogeneous cases.

2. Due to the variability in HPDCs, failure may initiate at unexpected locations of a structure, which would not be detected by a deterministic simulation;

3. The in-house FE Monte-Carlo framework developed [1] is suitable to design large real-life structures manufactured with HPDCs or other classes of heterogeneous materials.

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