

## COVER SHEET

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Title: **Pseudo-Ductile Hybrid Composites with Overload Sensing Capability**

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## ABSTRACT

Fragmenting hybrid laminates create a pseudo-ductile response and a striped pattern of fractures and delaminations which can be used as a simple visual strain overload sensor. The mechanism is explained and it is shown how it may be used to detect if a specified strain threshold or a range of different strains have been exceeded. The novel hybrid composite sensor may be used as an indicator patch co-cured with composite components or retrofitted/bonded onto the surface of composite or metal components, or be incorporated as an integral load-carrying surface layer with sensing functionality.

## INTRODUCTION

Composite materials have excellent specific strength and stiffness, but a major drawback is their lack of ductility. The HiPerDuCT programme is a collaboration between the University of Bristol and Imperial College to address this challenge by developing new materials and architectures that give a more gradual failure than that of current composites [1].

One of the mechanisms that has been demonstrated to achieve pseudo-ductile response is the fragmentation of thin carbon plies in glass/carbon hybrid composites. Unidirectional carbon plies can be added to unidirectional glass, and if they are thin enough and the ratio of constituents is appropriate the carbon plies will fragment and delaminate stably without catastrophic failure [2].

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This creates a plateau on the stress-strain curve analogous to yielding in a metal as shown in Fig. 1. The response can be tailored based on the strain to failure and modulus of the carbon fibres and the absolute and relative thickness of the plies [3].

Because the glass plies are translucent, the fragmentation and associated delamination of the carbon can be seen as a striped pattern on the surface, Fig. 2. As well as providing a pseudo-ductile response, this can be used as an indicator that the damage initiation strain has been exceeded [4].

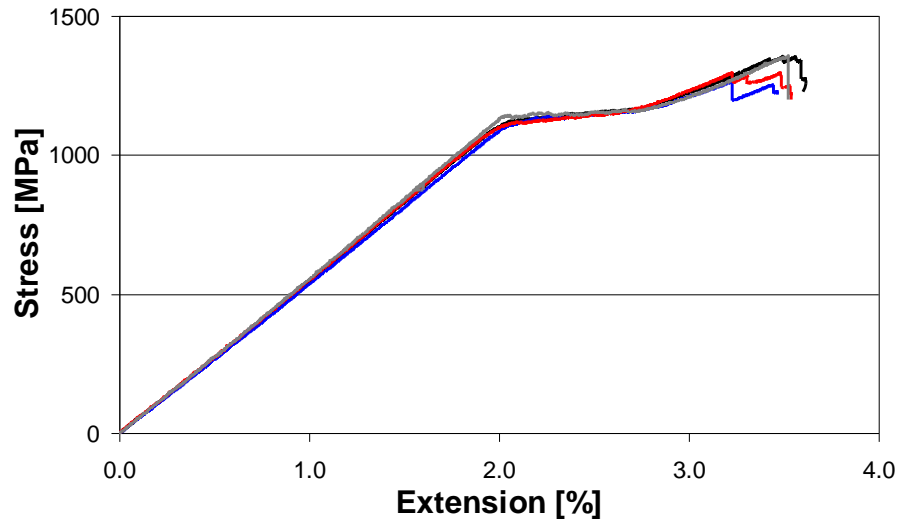


Figure 1: Pseudo-ductile response of S-glass/high strength carbon hybrid [2]

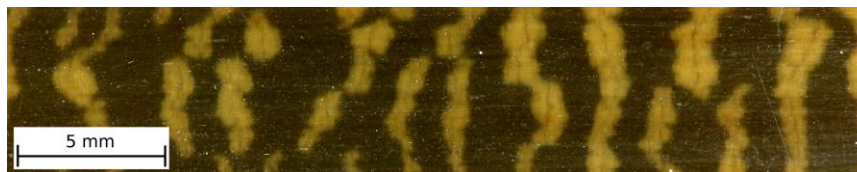


Figure 2. Striped pattern indicating carbon ply fragmentation triggered by overload in a glass/carbon hybrid specimen [5]

## USE OF UD HYBRIDCOMPOSITES AS STRAIN SENSORS

Glass/carbon hybrid composites are black if there is no damage in the hybrid since light penetrating through the glass layers is absorbed by the black carbon fibres. But, if the applied strain exceeds the failure strain of the carbon fibres, they break and local delamination at the carbon /glass layer interface produces a gap between the layers and therefore changes the optical parameters of the material. As a result, the appearance of the hybrid will change from fully black to striped black and bright. Fig. 3 shows this mechanism schematically in a glass/carbon hybrid laminate before and after fracture of the carbon layer. Fig. 4 indicates a specific

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glass/carbon hybrid before any fracture in the carbon layer where the hybrid is fully black and at increasing extensions where the carbon layer becomes more and more fragmented and the appearance of the hybrid has changed to a striped pattern. This example uses high strength carbon fibres, but there is a whole range of lower strain to failure fibres of carbon and other materials that could be used to modify the threshold strain of the sensor.

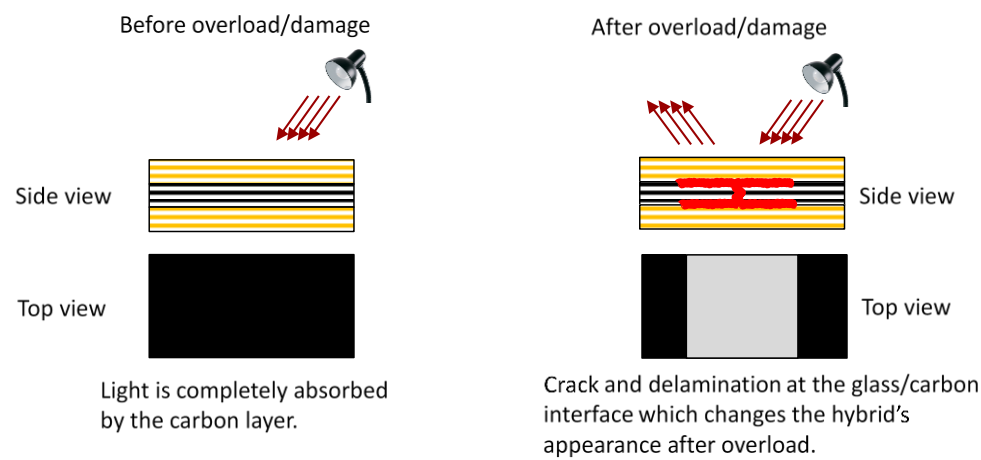


Figure 3. Overload sensor mechanism based on failure of carbon fibres embedded in translucent glass layers

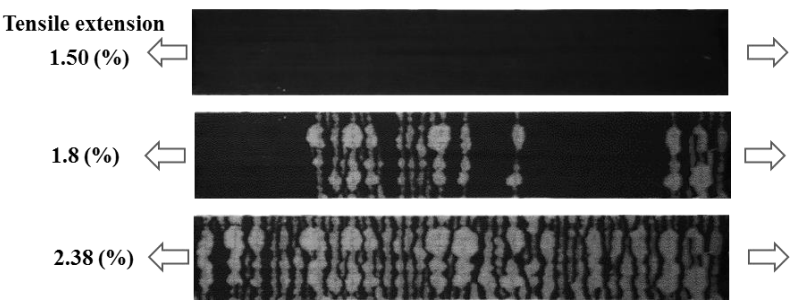


Figure 4. Greyscale optical camera images of a glass/carbon hybrid laminate at three different extensions of 1.5% (before carbon layer failure) and 1.8% and 2.38% (beyond carbon failure strain).

The described change of appearance can easily be spotted visually, indicating that the applied strain has exceeded the known value of the carbon fibre failure strain. The type of fibre used can be selected to match the desired level of strain to be detected.

### ALTERNATIVE CONFIGURATIONS

The sensor can be based on fragmentation of the hybrids, as described, or alternatively it can be based on a single ply fracture followed by delamination. The

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latter approach provides a clear single event when the threshold strain has been

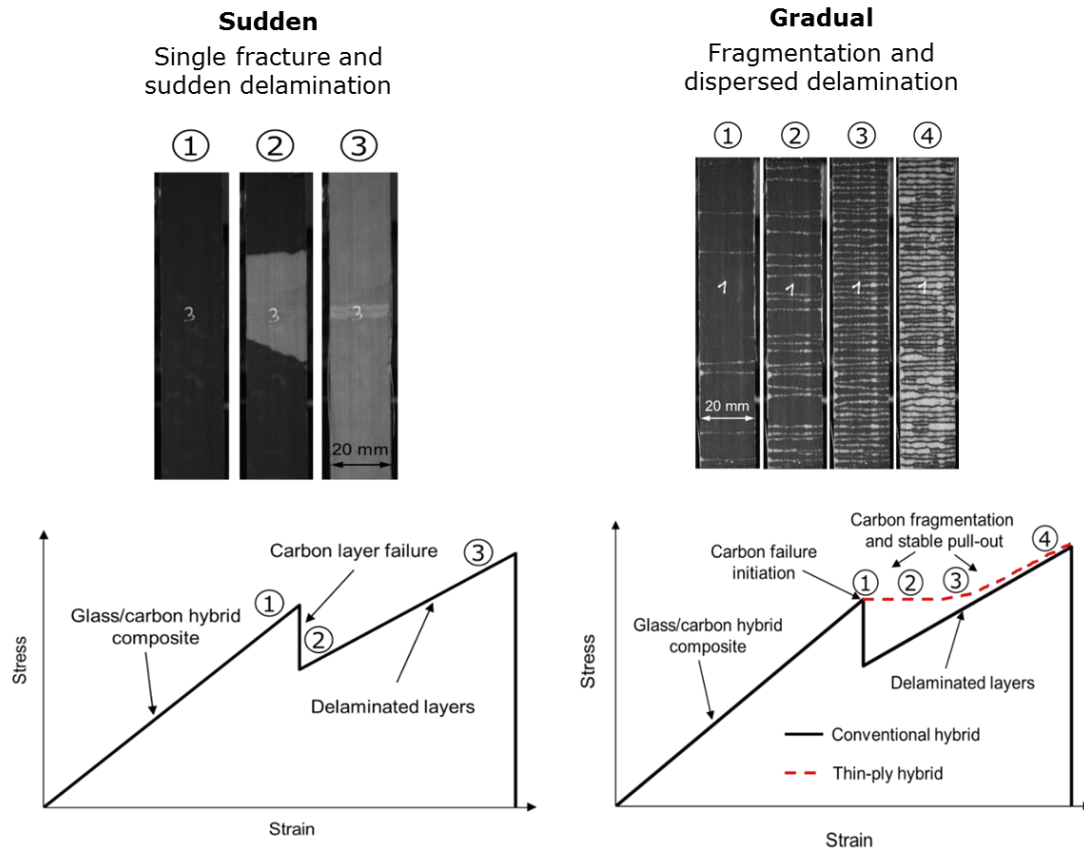


Figure 5. Alternative forms of sensor by changing the thickness of the layer

exceeded rather than the progressively increasing fragmentation shown before. These two approaches are contrasted in Fig. 5.

The difference in response is controlled by the thickness of the low failure strain layer, which determines the energy release rate and hence the propensity to delaminate. It is also possible to combine strips of different types of fibres placed side by side in order to create sensors that monitor a number of different strain overload thresholds. By introducing dye into the glass layer it is possible to colour code the strips depending on the strain experienced, as illustrated in Fig. 6.

The sensor can be a discrete patch that is bonded on the surface of a composite or metal structure, as shown in Fig. 6. It can also cover whole components in the form of a sensing outer layer, which carries load and contributes to structural performance. Example applications could for instance include wrapping a gas pressure cylinder so that in case of an overload, the appearance of the sensor wrap changes, revealing that the specified strain has been exceeded and that the cylinder should be withdrawn from service or repaired/refurbished.

The sensor concept has been developed primarily for tension dominated applications, and most of the work so far has focussed on this type of loading. However it has also been demonstrated that a similar fragmentation mechanism occurs in compression [6], indicating the potential to extend the concept for compressive as well as tensile loading applications.

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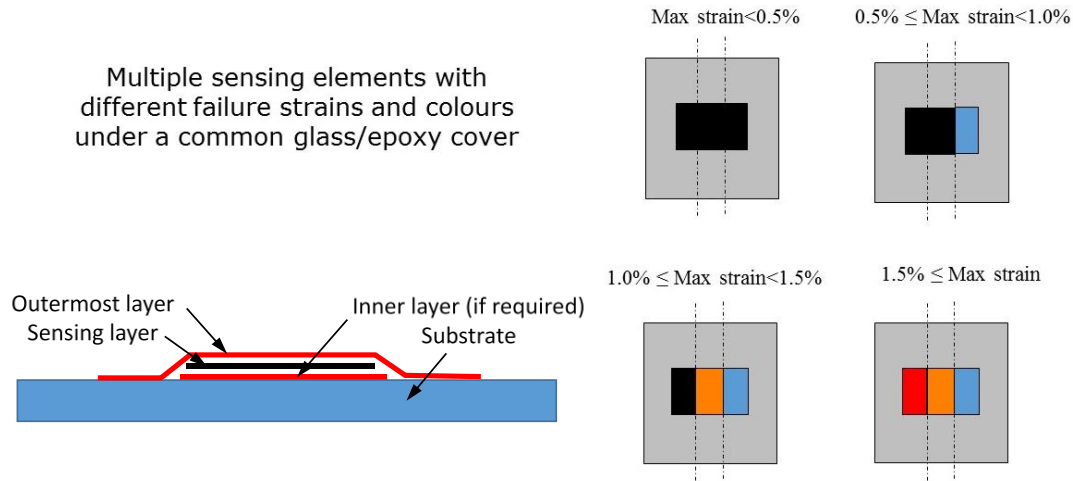


Figure 6. Multiple sensors bonded to the surface of component

This overload sensing concept provides a robust and low-cost tool for warning end users that excessive strain has been applied to a component or structure. It does not need any electric power, electronics, wiring, data acquisition or processing device, and can be checked by a very simple visual inspection. There is no need for special training and it can be applied in a broad range of applications and situations. The mechanism relies only on the failure strain of the carbon layers which stays unchanged in a wide range of environmental conditions.

## CONCLUSION

It has been demonstrated how pseudo-ductile hybrid composites can be used to detect when specified strain thresholds have been exceeded. The concept can be applied in the form of patches bonded to the surface of composite or metallic components or as a load carrying surface sensing layer, and offers a simple, robust and low-cost method for structural health monitoring.

## ACKNOWLEDGEMENTS

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Supporting data can be requested from the corresponding author.

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