Effect of waviness defects on impact damage in composite materials

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Abstract. In this study, a technique was used to monitor damage creation in carbon fibre reinforced polymer (CFRP) during impact testing. This reduces the amount of time required for processing experimental data to reveal how damage forms in complex materials. High-speed digital image correlation (DIC) was used to measure full-field strains as specimens were impacted. The measured strain data was then fed into an algorithm, the outputs of which provide a better understanding on the damage mechanics of CFRP. Different severities of waviness defects were introduced to CFRP specimens before they were impacted to identify how the defects affected impact damage. Locations with higher fibre misorientation angles were found to stop delamination growth during impact.

Introduction

Waviness defects are often unavoidable during the manufacturing process of carbon fibre reinforced polymer (CFRP); degrading component strength. In addition to this, structures are likely to experience impact within their lifespan. This can further reduce the strength of structures and put lives at risk. Waviness defects can occur with different severities and thus their effect on other damage mechanisms can be complex. Therefore, experiments must be carried out to further understand the effect of waviness defects in CFRP specimens during impact. The digital image correlation (DIC) technique can be employed to track changes in surface strains during impacts. However, this creates a large amount of data that often stretches into gigabytes. This presents a bottleneck during analysis as researchers have to spend a lot of time interpreting the data. This study introduces a data processing technique that gives a better understanding of damage formation in defective CFRP specimens during impact.

Experimental Methodology

21 CFRP specimens containing varying levels of fibre waviness were impacted using a drop weight impact machine (CEAST 9340, Instron, USA) combined with a high-speed DIC system (Q-450, Dantec Dynamics, Germany). The DIC system monitored the bottom surface of the CFRP specimens during impacts at a rate of 10kHz; resulting in more than 300 strain fields. These strain fields contain substantial amounts of data, orthogonal decomposition [1] was used to reduce the dimensionality of each strain field into feature vectors. Feature vectors are a group of coefficients that represent the surface strain on the specimen in a dimensionally reduced way.

From these vectors, the rate of change of the strain field was calculated. This rate has three elements: measurement noise, elastic deformation due to loading, and the creation of permanent damage in specimen [2]. Damage creation was the main interest of this study, thus the contribution of elastic deformation and measurement noise to the rate of change were removed by calculating a baseline value of rate of change based on the speed of the impactor. A one-sided 95% prediction interval above the baseline was calculated, acting as a threshold to detect damage. Any rate of change that is above the threshold was identified as damage. As damaged regions have higher strain values than undamaged, a measure of damage severity was calculated based on the rate of change showing when damage was being created.

Damage-time maps [2] were created by comparing feature vectors from just before and after damage events. Pulse-echo ultrasound was employed to accurately measure the size of damage in the damaged specimen. The ultrasound data was then used to verify the estimated morphology given by the damage-time maps.

Discussion

A high rate of change relative to the baseline was found between 1 ms and 3 ms after the impact started, as shown on the left of Fig 1. When the rate of change was converted to indicated damage severity it was found that for both non-waviness and waviness specimens the values reached a peak of 6000 με and 4000 με respectively within 3 ms and then plateaued. This indicates that the specimens were permanently damaged during the first 3 ms of the impact. The time showing when damage occurred is comparable to the times indicated on the damage-time map shown in Fig 2. Damage-time maps shown damage occurrence and shape at different time steps. The damage initiated at 1.3 ms from the centre of the specimen, where the impactor contacted. Damage grew towards the waviness defects location at y = -30 mm and then stopped growing further. Damage then started to propagate in the x-direction with growth detected at 1.7 ms and 2.1 ms, causing the impact damage to become wider. Damage shape and size for damage-time maps were found to be comparable to damage measured using ultrasound, see Fig 2 middle. The damage shape for the specimen containing 30% waviness was found to be very different compared to the non-waviness specimen, shown on the right of Fig 2.

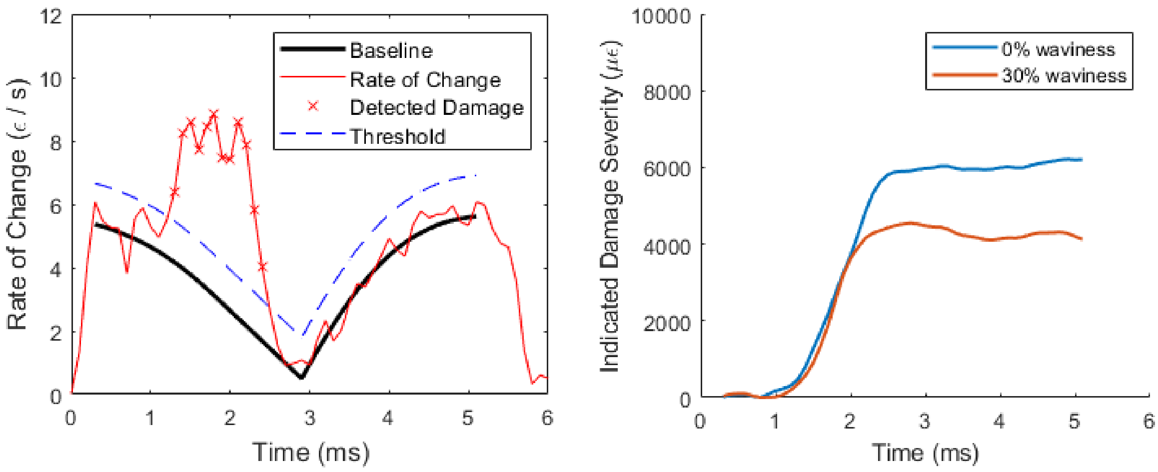

Fig 1: Rate of change graph for a 0% waviness cross-ply CFRP specimen impacted at 30 J (left) and the indicated damage severity for both the 0% waviness and 30% waviness specimens (right).

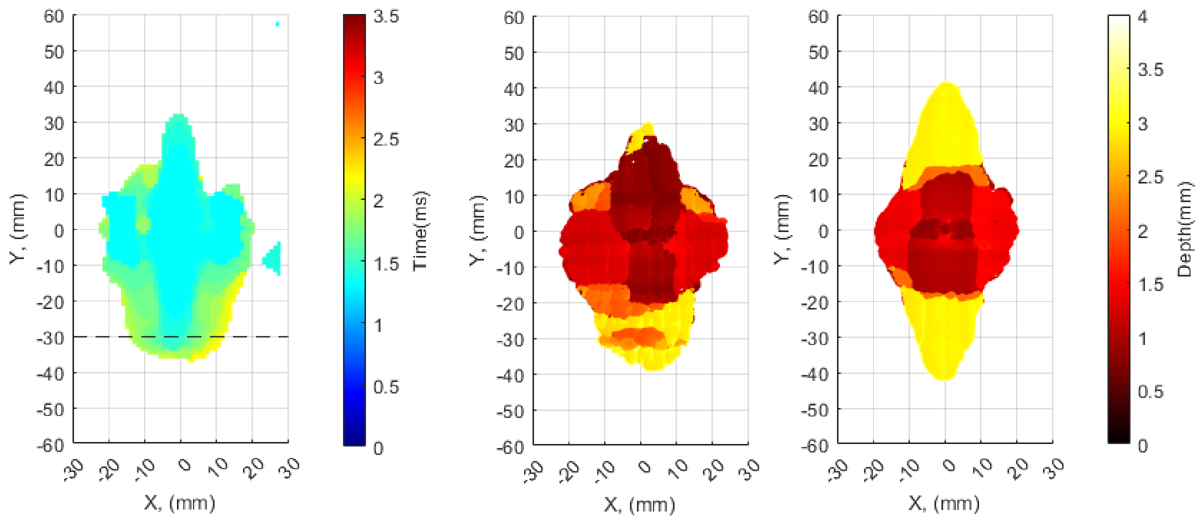

Fig 2: Damage-time map for a CFRP specimen impacted at 30 J and dashed line showing the location of the 30% waviness defect (left). The corresponding ultrasound scan (middle) and ultrasound scan for a non-waviness specimen (right).

Conclusion

The introduced algorithm has the ability to identify the location of damage when it was formed and estimate its severity during impact events that last just 5ms, whereas ultrasound can only provide information about damage after an impact. The presence of waviness in a specimen was found to stop delamination growth, resulting in a unique damage shape in comparison to specimens that did not contain fibre waviness.

References

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