QUASI-STATIC AND IMPACT DAMAGE OF THERMOPLASTIC COMPOSITES: MICRO-MACRO EXPERIMENTAL APPROACH

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ABSTRACT

We developed a micro-macro experimental approach to understand the damage and fracture behaviour of cross-ply thermoplastic composites subjected to out-of-plane loading. Firstly, cross-ply laminates were subjected to quasi-static loading in order to evaluate the damage pattern. Next, we performed low-velocity impact at various impact energies, and observed the damage due to impact. Since it is difficult to track the damage behaviour at plate level, we developed a micro-scale test device (micro-3-point-bending or micro-3PB) to capture the principal damage mode (transverse crack and delamination) through the use of unsymmetrical-unbalanced cross-ply laminate. We found that the physics of degradation (damage mechanism) at macro-scale can be qualitatively captured with our micro-3PB setup.

1 INTRODUCTION

Continuous fiber reinforced thermoplastic composites are promising materials for automotive structures and portable electronic enclosures. Short production cycle (culminating in a high volume of production), excellent mechanical properties, and improved impact performance are the main reasons for the use of thermoplastic composites. Unlike the behaviour of thermoset composites which are greatly understood, the understanding of impact performance in thermoplastic composites is not yet at the same level. Furthermore, evaluation of impact performance always requires advanced experimental equipment and a large number of specimens. An efficient approach to capture the fracture behaviour of thermoplastic composites under out-of-plane loading is still required.

In this work, we explore the capabilities of a micro-mechanical testing device, i.e., in-situ, micro-three-point-bending (micro-3PB), for studying the principal damage modes in thermoplastic composites [1]. At micro-scale, we particularly studied the propagation of intra-ply damage via transverse cracking and its ‘migration’ to inter-ply damage via delamination as well as delamination growth. This covers the physics of degradation in composites under out-of-plane loading ranging from quasi-static indentation (QSI) [2] to impact [3]. At macro-scale, we performed quasi-static indentation and low-velocity impact on thermoplastic composites. Hence, we developed a micro-macro experimental approach to capture the initiation and progression of intra-ply and inter-ply damage modes. The thermoplastic composite of interest is continuous glass fiber reinforced polypropylene (GFPP). Since PP may have several variants, we studied the effect of using two different PP matrices, namely homopolymer PP (non-reinforced PP) and copolymer PP (homopolymer PP added with rubbers).

In this paper, our objectives are (i) to study the influence of loading speed on damage in GFPP at macro-scale (we compared QSI and low velocity impact), (ii) to examine if damage in GFPP at macro-scale (QSI) can be qualitatively captured by micro-scale test device. Future works include the development of high-speed micro-scale device which may capture the physics of degradation in thermoplastic composites under impact.
2 EXPERIMENTS

We employed continuous E-glass fiber reinforced polypropylene (GFPP) thermoplastic composites. Two PP matrices were employed, i.e. homopolymer (non-reinforced) PP and copolymer (rubber-reinforced) PP. We manufactured the GFPP laminates by using metallic mold under static press (pressure was 7.5 bar). The processing cycle is as follows:

- A stack of dry tapes with certain orientation was inserted into the metallic mold
- The mold was compressed with specified pressure, while the temperature was simultaneously increased from 25 °C to 210 °C.
- The temperature was held at 210 °C for 20 minutes, while the pressure was constantly kept at 7.5 bar.
- The temperature was then reduced to 25 °C with the cooling rate of 40 °C/min.

To avoid leakage from the plate during manufacturing process, we bound the edges of dry tapes with Kapton tapes. The resulting plate was 275 mm x 110 mm. The processing condition in our study has also been reported elsewhere, where we inserted fiber Bragg gratings into the laminate during the static pressing [4].

The stacking sequence used for micro-3PB is \([0/90]_8\) where an initial crack of 1 mm was made with high precision cutter. Fig. 1 shows the schematic of micro-3PB specimens. Fig. 2 shows that at the micro-scale, we employed our custom-made, micro-3-point-bending device inserted within scanning electron microscope (SEM) in which the intra-ply and inter-ply damage in cross-ply GFPP laminates was captured at fiber-matrix scale. At the macro-scale, we employed QSI test setup with backlight method to capture the damage progression in GFPP in real-time (Fig. 3). We also conducted low-velocity impact test utilizing Instron CEAST 9350 at various energy levels ranging from 12-30 Joule. The lay-up for QSI and impact test was \([0/90]_8\). The specimen size for QSI and impact was 110 x 110 mm. Thickness of plate was 2 mm. Fig. 4 shows the low-velocity impact test setup. The applied energies were 12, 18, 24 and 30 Joules.

![Figure 1: Schematic of micro-3-point-bending specimen.](image-url)
Figure 2: Micro-3-point-bending setup.

Figure 3: Quasi-static indentation setup for thermoplastic composites with backlight method to capture the damage in real time.
3 RESULTS AND DISCUSSION

At macro-scale, our preliminary results show that damage in GFPP under quasi-static indentation and low-velocity impact is greatly dependent on the PP type (see Fig. 5). For GFPP copolymer, damage between QSI and impact is similar, and it is characterized by transverse cracks (fiber splitting) and extensive delamination. For GFPP homopolymer, we observed that the damage in QSI and impact is completely different. Damage in GFPP homopolymer under QSI is localized while that under impact is extensive.

Figure 5: Damage in GFPP copolymer and GFPP homopolymer under QSI and impact.
Fig. 6 shows the path of transverse crack and delamination progression in GFPP copolymer and GFPP homopolymer captured at micro-scale using micro-3PB with scanning electron microscope (SEM). We observed that the progression rate of transverse crack in GFPP is the same regardless the PP type. However, the delamination length in GFPP is greatly modified due to the ductility of PP. We found that GFPP homopolymer experienced shorter delamination than GFPP copolymer. A more ductile matrix like homopolymer PP may dissipate more energy through plasticity in comparison to a less-ductile matrix like copolymer PP. This is consistent with the damage that we observed in GFPP under QSI where shorter delamination in micro-3PB may be equivalent to a more localized damage in QSI test. Here, the physics of degradation in GFPP with two different PP types at macro-scale could be captured qualitatively at micro-scale by micro-3PB.

**Figure 6:** Damage progression in GFPP copolymer and GFPP homopolymer under micro-3PB.

4 CONCLUSIONS

Our preliminary results show that damage in GFPP copolymer is similar between QSI and impact. Thereby, we could use QSI to study the damage phenomenon in GFPP under impact. However, a more ductile GFPP homopolymer exhibits different damage phenomenon when it was subjected QSI and impact. Damage in GFPP homopolymer under QSI showed localized damage, while the one under impact showed extensive damage. In other words, QSI may fail to reveal the damage phenomenon in GFPP homopolymer under impact since a more ductile PP could be strongly rate-sensitive. We also found that the micro-3PB was capable in capturing the damage process, which is representative for understanding the damage at macroscopic scale under QSI. It is also able to capture the effect of the two different matrices in terms of their damage responses.

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REFERENCES

