Digital image correlation approach for improving low-velocity impact tests on UHMWPE panels with nanofillers

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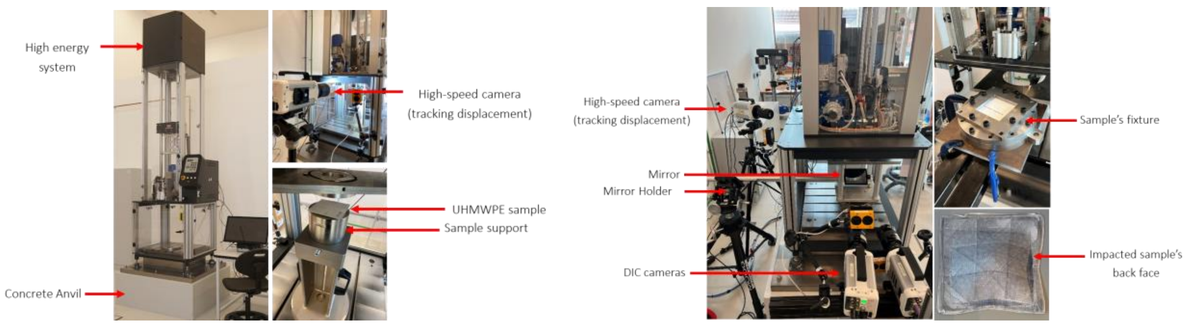
Abstract. Advanced measurement methods are necessary to accurately assess material behavior under extreme loading conditions. This study aims to develop a reliable low-velocity impact testing methodology to evaluate the dynamic behavior of UHMWPE composite panels containing nanoparticles. Two alternative drop-weight impact testing methods were conducted on the composite panels. Approach (1) used a single, side-on, high-speed camera to track the central displacement of an impacted panel with simple supports. Approach (2) added a clamped boundary and employed two cameras, a 3D digital image correlation (DIC) system to obtain full-field rear face displacement measurements. The inclusion of nanoparticles appeared positive in approach (1), but this was reversed when the clamped boundary was used. The clamped boundary and increased panel thickness increased the peak forces by approximately 100%, but led to extensive delamination initiated along the clamped edges. The 3D DIC measurement approach worked well, enhancing the dataset obtained from the simple impact test set-up.

Introduction

Fiber-reinforced polymer composites have attracted much study attention due to their outstanding specific strength-to-weight ratio. For instance, ultra-high molecular weight polyethylene (UHMWPE) composites are a lightweight, high-performance material class recognized for their exceptional impact resistance [2]. Researchers have recently attempted to use nanotechnology to increase its strength by incorporating nanofillers with outstanding mechanical characteristics into the composite material [3-4]. This paper describes an approach to impact testing that involves imaging and digital image correlation in measuring the transient displacement of UHMWPE composite panels.

Methodology

Approach 1. UHMWPE fiber-reinforced composite sheets with polyurethane matrix were cut into square layers of 70 mm x 70 mm. Five layers were stacked and hot pressed following the supplier's recommended cycle, producing nominally 0.73 mm thick UHMWPE panels. Three panels were manufactured without nanoparticles, while three more had nanoparticles sprayed between the layers. The composite samples were subjected to low-velocity impact testing using an Instron 9450 drop tower rig with a high-energy system. The samples were mounted on a 80 mm rigid circular ring and secured with a pneumatic clamp. The panels were impacted by a 2.05 kg impactor, with a 5mm diameter hemispherical tip, at an impact velocity of 5 m/s. A high-speed Photron camera operating at 25000 fps was employed to track the displacement (side-on) during the impact. It is clear from the machine configuration in Fig. 1, a) that the drop-weight machine is mounted on a sturdy concrete anvil to eliminate any vibrations that might occur during the test.



a) b)

Fig. 1: Machine setup for the a) first testing approach, b) second testing approach

Approach 2. New square UHMWPE panels with 10 layers and a longer side length of 160 mm were manufactured using the same hot pressing technique as approach 1. The impactor diameter was increased to 10 mm. The panels were mounted in a 120 x 120 mm clamp frame to provide additional restraint. The experimental arrangement was upgraded with a 3D digital image correlation system to capture the rear face panel deformation using two high-speed cameras and a mirror. As illustrated in Fig. 1, b), the mirror was mounted at a 45-degree angle to reflect the impacted area to the cameras. The rear face of the panel was given a suitable speckle pattern to enable accurate DIC recording.

Results and discussion

Approach 1. The force-displacement histories from the impact tests conducted using approach 1 are shown in Fig. 2a. The average impact force on the panels suspended with nanofillers was 6.4% higher than those without nanoparticles. Given the impact energy was kept constant, this means the maximum displacement was lowered for the panels with nanoparticles. This could translate into significant gains because minimizing back displacement is crucial in many applications, such as defense protection.

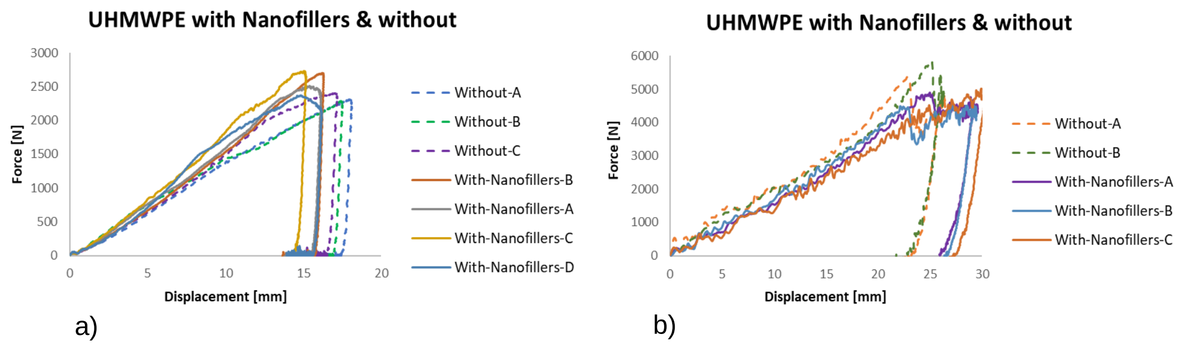


Fig. 2: Force- Displacement histories (a) from the first approach (b) from the second approach

Approach 2. Fig. 2b shows force displacement histories obtained from approach 2. Noticeably, the peak forces are much higher in these tests, approximately double that measured in approach 1. Interestingly, however, this increase is attributed to the presence of nanoparticles in the samples caused higher displacements and lower peak forces than the equivalently impacted samples without nanoparticles (reversing the trend in approach 1). The change in boundary conditions and indentor diameter appear more influential than the presence of nanoparticles. The addition of (larger) rigid particles has been studied elsewhere (see Langdon et al. [1] for a brief introduction) without any definitive answer regarding their performance improvement, so this remains an open area of research.

The back face displacements obtained by the 3D DIC system were compared to the side-image track procedure used in approach 1 and to the permanent diaplacements measure post-test. The results confirm the suitability of both methods, with 3D DIC offering the apparent advantages of capturing the response across the entire exposed area and ascertaining an asymmetrical behavior. The post-impact deformation revealed that the increased boundary restraint initiated in-plane slippage at the boundary and severe delamination along the clamped edges, as might be expected.

Conclusion

In summary, the introduction of stereo-imaging and the 3D-DIC method into a basic drop-mass impact test procedure is helpful in capturing the peak displacement and transient deformation profile across the panel. The panel response was influenced by its boundary conditions, thickness, impactor geometry and the presence of nanoparticles.

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