MECHANICAL PERFORMANCE OF CARBON NANOTUBE FILM SUBJECTED TO IMPACT LOADING

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Abstract.
Carbon nanotube (CNT) is continuously attracting attention from both academic research and industry fields due to its excellent performance in multiple aspects, including density, mechanical properties, and electric & thermodynamic properties, but there is a lack of understanding of the impact behaviours of CNT and CNT-based composites. This research focuses on the performance of CNT film and CNT composites under high-velocity impact (40-70 m/s) and quasi-static (1 mm/min) indentation. Impact tests under different velocities were conducted. Results show that CNT film has a higher impact resistance than CNT-epoxy composites due to higher fracture toughness. Finite element models with different constitutive laws were presented to predict the impact behaviours of CNT film and CNT composites. The models were able to predict the stress contours and capture the wrinkling deformation observed in the experiment.
Keywords: *Carbon nanotube, Composite, High-velocity impact, Finite element analysis*

Possible Sessions

8. Fatigue & Fracture and 9. Impact, Blast and High Strain Rate.

Introduction

Carbon nanotube (CNT), as shown in Fig.1, received significant attention due to extraordinary electrical and mechanical properties [1], including Young's modulus of 1 TPa, a tensile strength of approximately 100 GPa [2] and high fracture toughness, whilst isolated CNTs possess electrical conductivities of 2×107 s/m [3], and thermal conductivity of 3500 W/mK [4]. As a newly developed 2D film material, it shows extreme potential in applications ranging from flexible electronics and photonic devices to barrier films and paints to sensors and biomedical applications. With large advantages in engineering applications, CNT composites can be used in many industry fields, some of which may be subjected high-velocity impact, such as transportation, airplane, or space exploration. Thus, the impact resistance of CNT film and its mechanism in high-velocity impact need to be observed and analysed. This study aims to understand the mechanical behaviours of CNT mat and CNT-polymer composites under impact loadings in different velocities via experimental and computational methods.

Fig.1 CNT mat provided by Tortech Ltd

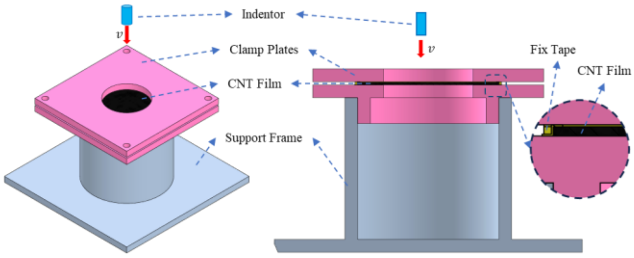

Fig.2 Quasi-static indentation

2. Research Methods

2.1 Low-velocity Impact Test Method
In the indentation test shown in Fig.2, a slow but constant load will be applied to the specimens by the indentor to observe the behaviour of the material during low-velocity impact. Two clamp boards with holes in their centre fixed the CNT film, and tapes are used on the film edges to prevent the film from slipping during the test. An indentor with a round head (d= 4 mm) will apply a constant impact of 1 mm/s to the film in the centre of the hole on the clamp board.

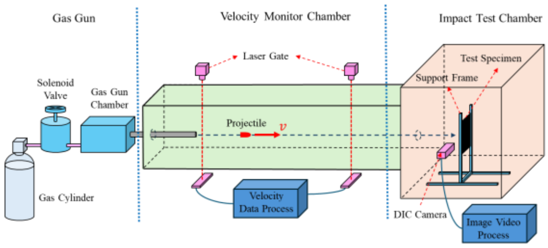

Fig.3 Low-velocity Impact Test System

2.2 High-velocity Impact Test Method

Figure 3 shows the structure and components of high-speed impact test system. A projectile is accelerated by compressed air in the gun barrel. The high-velocity projectile will impact on the CNT film. The high-speed camera records the film deformation and penetration in the impact process. The impactor is made of stainless steel, and the diameter of the impactor is 7 mm. The CNT film, as the target to impact, is fixed by a steel support with a hole of 30 mm diameter in the centre and a magnetic ring attached to the support.

2.3 Impact Simulation Method

In the indentation test, the CNT film was fixed by tapes on the edge and clamped by two boards with a hole in the centre. Thus, the film model was divided into 3 parts: fix zone, restrict zone and hit zone (Fig.4). The edges of the film, known as the fix zone, were completely constrained in both displacement and rotation. The restricted zone (clamped area of CNT film) restrained the displacement in the direction of indentation and rotation around the other two directions. The Hit zone (indentation area) was set in the centre of the film model as a round area with no constraint.

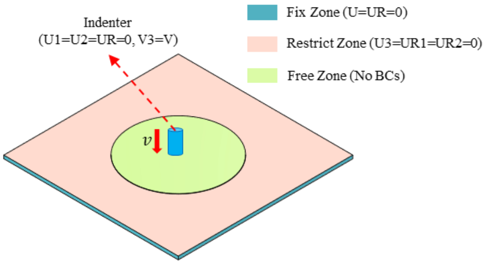

Fig.4 Low-velocity Impact Simulation Model

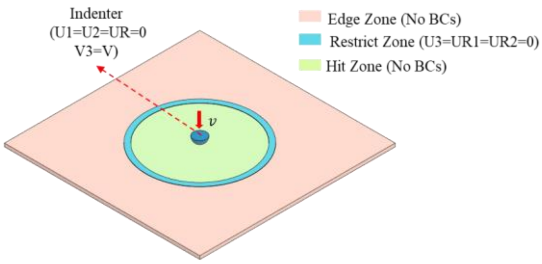

Fig.5 Low-velocity Impact Simulation Model – Film Part

In the high velocity impact simulation (Fig.5), a model consists of a target support with CNT film and an indentor was created to simulate the impact process after the contact instance between CNT film and indentor. the fixing ring and support board was fully fixed. The indentor was given an initial velocity of 40-60 m/s and set to touch the film as the initial location.

Result

The test and FE model show the performance of CNT-polymer composites in the impact and penetration process. Fig.6 shows the stress distribution of CNT film in the high-velocity impact process and after penetration. Fig.7 shows the simulated change of reaction load-displacement and strain energy during the high velocity impact process.

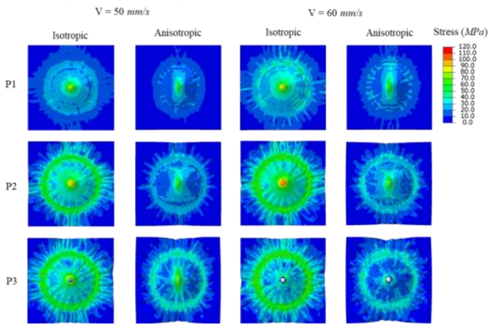

Fig.6 Stress Distribution in HV - Impact

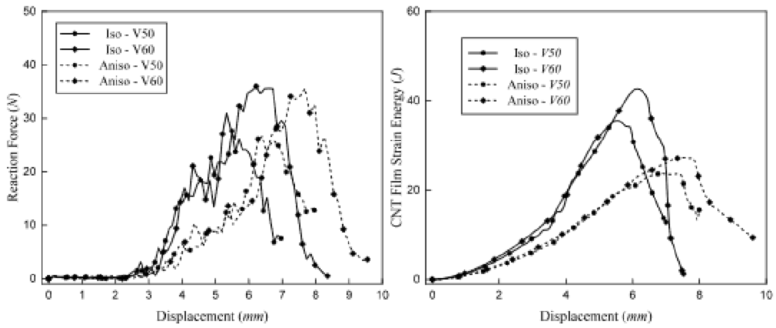

Fig.7 Force – Displacement and Strain Energy Curve

Conclusion

The CNT film shows impressive impact resistance from the impact tests. The simulation results capture the deformation of materials and energy-time history. The current simulation results, however, are influenced by both the dynamic impact loading and the friction between contact surfaces. The friction is believed to cause the oscillation in reaction force data, especially in the contact and penetration periods. Future work will focus on the role of CNT fracture toughness on impact resistance.

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