Mechanical characterisation of bio-based epoxy resin using Shear Compression Specimen

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Abstract

This research investigates the mechanical behaviour of bio-based epoxy resin over a wide strain range using a Shear Compression Specimen (SCS). This geometry features a cylinder with two semi-circular slots fabricated at a slot angle of 45^0. Digital Image Correlation (DIC) enables non-contact strain measurement, while Infrared thermography (IR) is also applicable to this test setup. The shear properties of the resin can be evaluated using this geometry.

Introduction

Matrix materials play a crucial role in positioning and alignment of fibre architecture while also distributing operational stresses between them. Fibre instability and kink-band formation are generated when compressive loads are applied on fibre-reinforced polymers due to the effect of combined compression-shear on the matrix. Traditional resin systems, primarily sourced from fossil fuels, pose environmental challenges due to their limited renewability and high carbon emissions linked to their production. In contrast, biobased resin systems originate from renewable resources, providing significant sustainability advantages for structural composites [1].

Therefore, understanding the mechanical behaviour and shear response of the matrix materials under combined shear and compression is crucial for determining the failure mechanism. Gaining deeper insight into matrix shear properties aids in identifying potential failure modes and contributes to the development of new matrix strategies to delay or reduce tensile and compressive failures in composite structures [2]. This study aims to establish an alternate method to determine shear properties of the epoxy resin systems using SCS geometry while integrating DIC and IR for enhanced analysis.

Geometry & Experimental setup

SCS geometry is shown in Fig. 1(a) and it is made up of a solid cylinder with two semi-circular slots at 45^0 angle. When subjected to compressive loading, parallel displacement is induced on either side of the slot leading to shear damage. The dimensions of the sample are height (H) = 20mm, diameter (D) = 10mm, radius of the circular slot (r) = 1.5mm, width of the slot (W) = 2r = 3mm, t = 1.6mm, height of the gauge (h) = $2\sqrt{2}r$ = 4.24mm [3]. The gauge section is longer in length compared to its width and thickness. Thus, by assuming the existence of plane stress in the gauge section and using Drucker-Prager yield criterion, the equivalent von Mises stress and strain are determined [4].

In this study, SR Infugreen 810 bio-epoxy with 38% biobased carbon content, supplied by Sicomin, paired with 8824 hardener was used. A 10mm diameter stainless steel rod was procured from RS Components (UK) and machined into SCS geometry, featuring 45^0 slot angle, with six samples prepared. These were placed in a plastic container, and a silicone mould was made using CS25 condensation cure silicone rubber, supplied by Easy Composites (UK). Bio-epoxy resin samples were prepared by mixing, de-gassing, and casting the resin into the silicone mould.

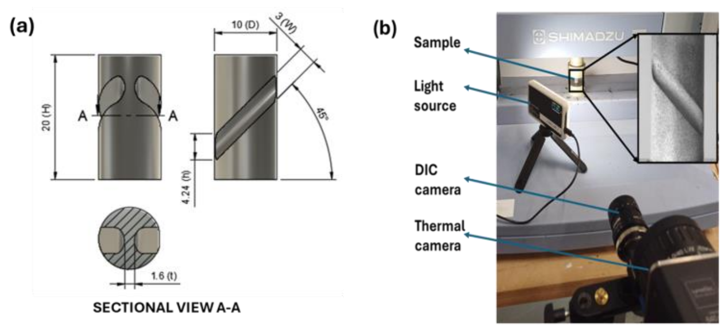

Fig. 1 (a) SCS geometry with side view and sectional view A-A (b) Experimental setup

The experimental setup includes a Shimadzu test machine equipped with 10kN load cell, a light source, a FLIR Blackfly optical camera for capturing images used in DIC and InfraTec VarioCAM as shown in Fig. 1(b). The samples were initially coated with a white paint background, followed by the application of fine black speckles using an airbrush to assist with DIC. DIC was utilized to capture displacement and strain field along the slot as the load was applied until failure. Additionally, a thermal camera recorded energy dissipation throughout the loading process. Scanning Electron Microscopy (SEM) was used to examine the fracture surface.

Results and discussion

Compressive load was applied at a strain rate of 1mm/min. Fig 2(a) shows the average equivalent stress vs strain with error bars as shaded region. The average equivalent yield stress is 87.17 ± 0.87 MPa. The elastic region persists up to the yield point, where the equivalent stress exhibits an almost linear response with increase in the equivalent strain. The plastic region begins at approximately an equivalent strain of 0.15, where the equivalent stress increases non-linearly. Fig. 2(b) presents the equivalent stress-strain curve for sample 3 with various sections labelled by numbers. The corresponding DIC and IR images are shown in Fig. 2(c) & Fig. 2(d), respectively. Images in Fig. 2(c) illustrates the increase in strain rate from image 3, similar to the image 3 shown in IR image (Fig. 2(d)), which represents the yield point. As the load further increases, both strain and temperature dissipation from the fracture surface also increase. Fracture surface of the sample after loading to failure is shown in Fig. 2(e). The pattern in the image indicates that the damage resulted from shear failure.

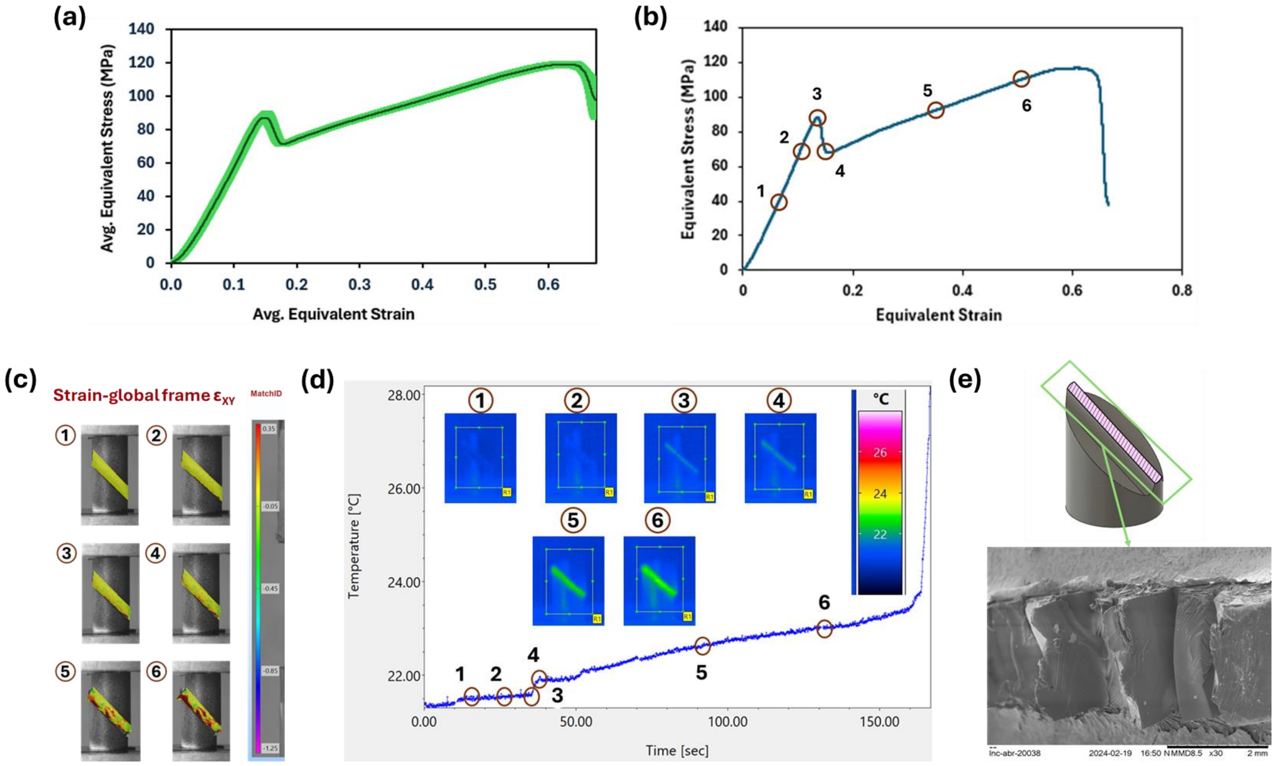

Fig. 2 (a) Avg. eq. stress vs. strain curve with shaded error bar (b) Eq. Stress – Strain curve with (c) DIC images (d) IR images and (e) SEM image of the fracture surface.

Conclusion and Future work

This study effectively introduces an alternative method for determining the shear properties of a bio-based epoxy resin. The integration of DIC & IR imaging proves effective for capturing critical failure related data in this setup. Future work will explore comparison with combined compression-shear test on thin-walled cylinders and the hierarchical hybridization of epoxy resins with thermoplastics.

References

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