USE OF FRICTION MECHANISM FOR PSEUDO DUCTILITY IN COMPOSITES

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Abstract
A novel method of introducing pseudo-ductility in brittle materials by means of friction mechanisms has been investigated. Two model systems (the first using 3D printed polymers and the second one a machinable glass ceramic) have been explored to prove the concept prior to its application to unidirectional carbon composites. Modelling and experimental testing of the tensile behaviour of the selected configuration indicates that the ductile behaviour will not localize and that by varying key parameters a wide range of pseudo-ductile behaviours can be achieved.

1. Introduction

High performance composites are very attractive due to their high strength, high modulus, good fatigue properties and ease of manufacture. However structures made of composites tend to fail in an explosive manner without previous warning. Thus pseudo-ductile behaviour, where load redistribution can occur, is highly desirable. This paper describes an investigation of the use of friction mechanisms to achieve pseudo-ductility in composite materials.

Friction mechanisms have been used for increasing the toughness and deformations of several materials. Dyskin et al. [1] used osteomorphic (bone-like shape) blocks, assembled onto a plate, to arrest crack growing and considerably increase the maximum deflection of the indentor during an indentation test when compared to using a solid plate made of the same material. More recently Valashani and Barthelat [2] used a laser engraving technique to produce nacre-like glass increasing the toughness up to 700 times and showing failure strains as high as 20%.

This paper reports on an investigation into the potential of exploiting friction to improve the ductility of carbon fibre composites.

2. Design and investigations of interlocking configurations

The proposed mechanisms relies on the geometry shown in Figure 1. The structure is composed of jigsaw like pieces, each of which is made of bow-tie shaped elements which are connected by infill

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regions. The blue and red jigsaw blocks are separate blocks that are only connected by the interlocking jigsaw shape.

When this configuration is subjected to tension in the longitudinal direction, the blocks start to slide against each other. This sliding causes friction forces in the interlocking structure. The role of the infill region is to introduce the transverse forces thereby increasing the frictional force in the wedges and so leading to higher overall longitudinal stresses in the structure.

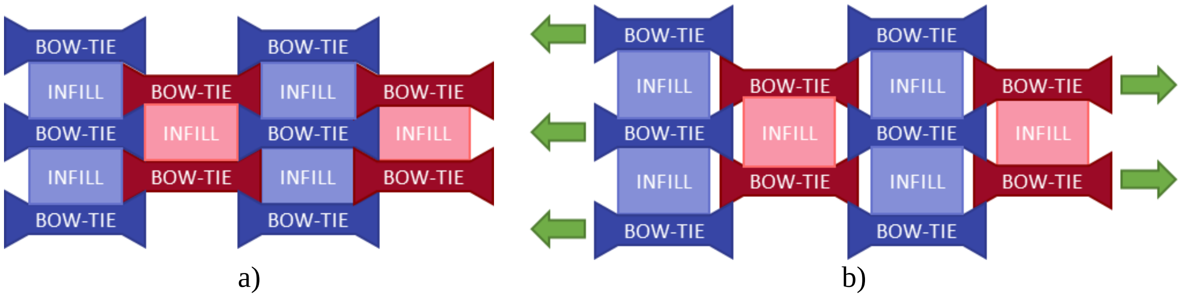

Figure 1. Geometry, a) unloaded specimen, b) loaded specimen

2.1. 3D printed plastics

A 3D printed interlocking structure was manufactured to demonstrate that relatively high stresses (in comparison to the bow-tie material strength) can be transmitted through friction only. The bow-ties were of Endur, a polypropylene-like material with an elastic modulus of 1.7 GPa and tensile strength of 40 MPa. The infill region was made of TangoBlack, a rubber-like material with a modulus of elasticity of 5 MPa and tensile strength of 2 MPa. A schematic of the interlocking zone is shown in Figure 2.

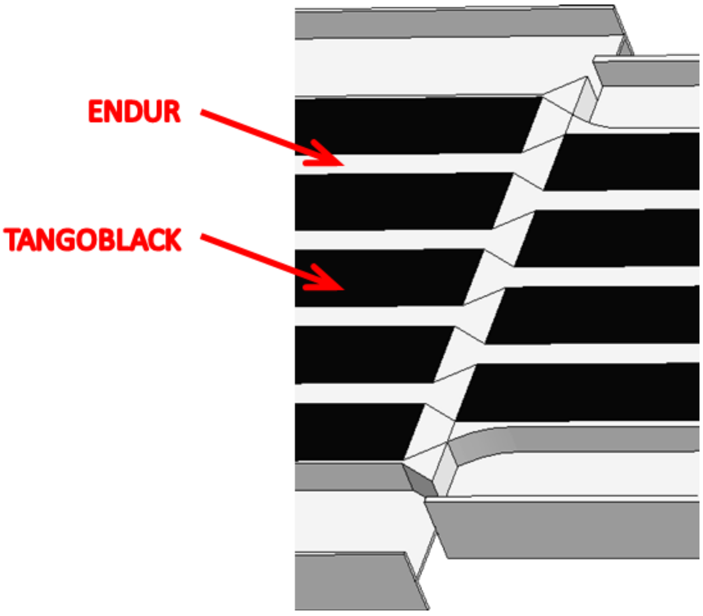

Figure 2. Interlocking zone

The structure was tested in tension under displacement control in an Instron machine, and the strains were measured using an Imetrum video gauge system. The deformed shape at different load levels is shown in Figure 3. It can be observed that no damage localization occurs, i.e. all the blocks separate

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from each other. The bulk of the deformation occurs in the interlocking regions, showing the potential to achieve large strains.

The experimentally measured stress-strain behaviour is shown in Figure 4. The stress is calculated using the gross cross-sectional area of the jigsaw block. The behaviour is nonlinear from the very beginning. At failure, the interlocking blocks suddenly separate with no failure of the constituent materials but the stress in the Endur material is close to its strength.

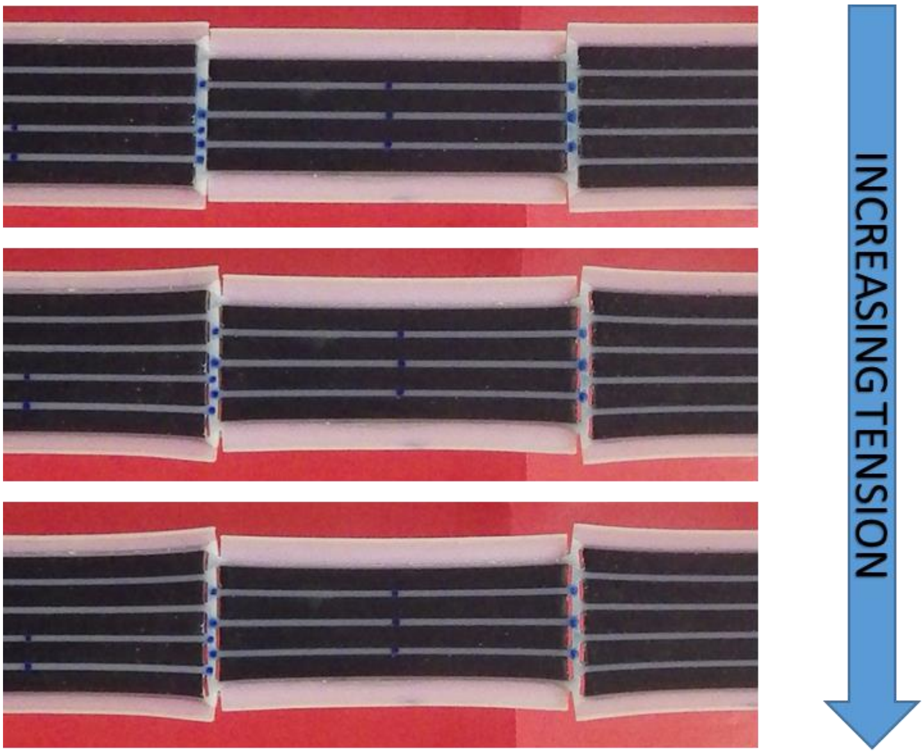

Figure 3. Deformation at increasing load levels.

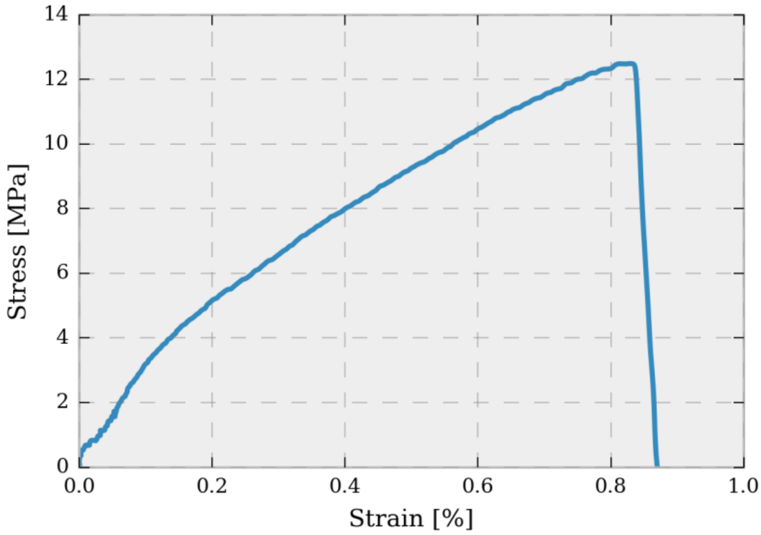

Figure 4. Experimental results of 3D printed structure

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2.2. Ceramics

The next investigation was made on MACOR, a brittle machinable glass ceramic. Its properties are summarized in Table 1.

Table 1. MACOR material properties

Symbol	Value	Description
E	67 GPa	Elastic Modulus
σ_0^C	345 MPa	Compressive strength
σ_0^T	34.5 MPa	Tensile strength
G_f	0.35 N/mm	Fracture toughness
ε_f	5.15e-4	Failure strain

A multi-objective optimization was performed to obtain optimal geometries of the interlocking configuration. Genetic algorithms were used during the optimization where the elastic modulus, the failure strain and the strength of the interlocking structure were the competing objectives. Different finite element models were generated parametrically during the optimization, and a damaged plasticity material model was used to capture the behaviour of the ceramic.

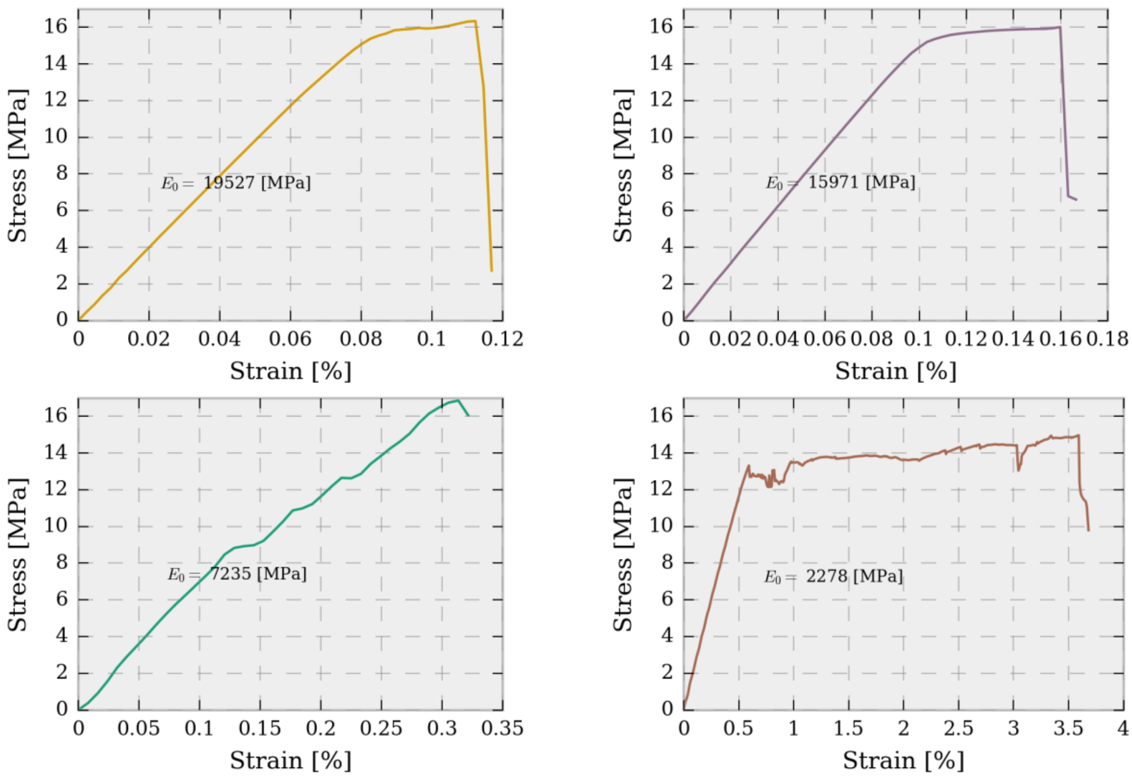

Figure 5. Different behaviour achieved in interlocking ceramic designs

Figure 5 shows some of the different behaviours that can be obtained by changing the geometry. It can be seen that models with high moduli of around 20 GPa can be obtained while doubling the failure strain of the constituent material.

The interlocking structure can behave in a pseudo-ductile manner showing large plateaus and even hardening. The best strain to failure obtained was almost 3.6% which is almost 70 times higher than the

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one for MACOR, although the modulus then drops to 3.4% of the original one.

The strength of the interlocking structure is also affected, but most of the designs fail at stresses between 15 and 16 MPa.

3. Conclusions

This paper has shown the possibility of exploiting friction in an interlocking configuration as means to produce pseudo-ductile behaviour in brittle materials. Finite element models indicate tha pseudo-ductility with hardening behaviours can be obtained in ceramics by optimizing the interlocking structure of the jigsaw blocks. Using this mechanism for UD CFRP is currently being explored.

Acknowledgments

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