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Mechanical Behaviour of Normal Modulus Carbon Fibre Reinforced Polymer (CFRP) and Epoxy under Impact Tensile Loads

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Abstract

This paper is concerned with experimental investigations of the mechanical properties of unidirectional normal modulus carbon fibre reinforced polymer (CFRP) sheet and Araldite 420 epoxy under quasi-static and medium impact tensile loads. It is found that both the CFRP sheet and Araldite resin were strain rate dependent. For CFRP the increase in tensile stress is about 20 to 40% whereas the increase in modulus of elasticity and strain at failure is about 20%. For Araldite the increase in tensile stress and modulus of elasticity is about 220% and 100% respectively, whereas a 50% reduction in strain at failure was observed.

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Keywords: Mechanical properties; normal modulus CFRP; epoxy; impact tensile loading

1. Introduction

Carbon fibre reinforced polymer sheet (CFRP) has great potential in retrofitting civil infrastructure [1]. These structures are possibly subjected to high strain loadings. Although the unidirectional normal modulus CFRP (CF130) and Araldite 420 are commonly used to strengthen concrete and steel structures. There is a lack of understanding of the mechanical properties of CF130 and Araldite 420 under dynamic tensile loads. Extensive research has been conducted to investigate the mechanical behaviour of different

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types of composites materials under various strain rates using several techniques, as summarised by Jacob et al. [2] where tensile, shear, compressive and fractural properties of composite materials were presented.

Impact tensile tests on different kinds of carbon/epoxy and glass /epoxy composites at quasi-static and different high strain rates have also been performed by many researchers [3, 4, 5, 6, 7]. However the FRP and epoxy used in the existing research are different from CFRP (CF130) and Araldite 420. This paper reports the investigation of the mechanical properties of CF130 and Araldite 420 epoxy at intermediate impact loads. The tensile stress, modulus of elasticity and strain at failure obtained at 3 strain rates (54.2, 67.2 and 87.4 s^{-1}) are compared with those obtained from quasi-static tests to demonstrate the influence of strain rate on mechanical properties.

2. Experimental Program

2.1 Materials and preparation of test specimens

Unidirectional normal modulus carbon fibre reinforced polymer sheet (CF130) and Araldite 420 epoxy resin were tested in this program. In the static testing of CFRP sheet, a series of carbon/epoxy specimens were used and these samples were prepared in accordance with ASTM: D3039/D 3039M-07 specifications. Fig.1 shows a CFRP testing specimen .A wet-lay-up process was used to manufacture a test panel (thin laminate carbon/epoxy) which was later cut into several coupons. Steel tabs were bonded on both sides at the ends of specimens to avoid damage on gripping CFRP sheets. These tabs were sandblasted and cleaned with acetone prior to bonding to ensure their surfaces were free from contaminates. Specimens used for static tests were similar in dimensions to those utilised for impact testing but the gauge length differed to achieve the desired strain rate, being 138mm for the former and 50mm for the latter. Five specimens were tested in quasi-static tests while five samples were examined for each strain rate in impact tests. Concerning epoxy specimens, the special dog-bone mould which was used to prepare epoxy specimens according to the ASTM: D 638-01 is illustrated in Fig.2.

2.2 Equipments and test procedure

As reported in the research literature, impact tensile tests can be performed using several methods which each have different advantages and limitations, as summarised by Barré*, et al* [5] and Fernie and Warrior [8].

The drop mass rig at Monash which was modified to carry out the impact tensile tests [9] was utilised for testing CF130 whereas the impact Instron testing machine at Swinburne University of Technology was used to test Araldite 420. The strain rate for the quasi-static tests was 2.42 x 10^{-4} s^{-1} and 6.66 x 10^{-4} s^{-1} for C130 and Araldite 420 respectively. The strain rates for the impact tests were 54.2, 67.2 and 87.4 s^{-1}. The different strain rates were generated by dropping a mass of 156kg from various heights (0.375m, 0.575m and 0.975m).

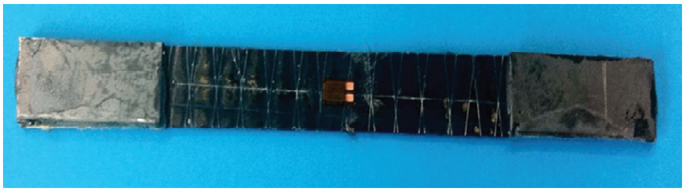

Fig.1 Coupons for testing the properties of CFRP

Fig.2 Mould for preparing epoxy specimens

3. Experimental Results and Discussion

A total of 30 impact tensile tests for both CFRP and adhesive resin were tested in the fabricated impact tensile rig and the impact Instron testing machine at three strain rates (54.2, 67.2 and 87.4 s^{-1}), and 10 static tests were conducted in an Instron testing machine to serve as reference tests. The measured properties include tensile stress, modulus of elasticity and strain at failure.

3.1 Unidirectional carbon fibre reinforced polymer (CFRP) sheet

3.1.1 Stress-strain relation

The influence of axial strain rate on the stress-strain curve of carbon/epoxy specimens is illustrated in Fig. 4. These quasi-static and dynamic tensile tests were conducted at four strain rates of 2.42×10^{-4}, 54.2, 67.2 and 87.4 s^{-1} on the tested specimens. As it is well known that carbon fibre is an elastic brittle material, its brittle behaviour was obvious from the rapid drop in stress after reaching the maximum stress for all the tested strain rates as shown in Fig. 4. It can be seen from Fig. 4 that the stress-strain behaviour is similar for all the strain rates. This is consistent with observations [3, 4] for other types of FRP and adhesives.

3.1.2 The effect of strain rate on tensile stress

The tensile stress against the strain rate is presented in Fig. 5 for all the aforementioned strain rates. It is clear that there is a general trend of increase in tensile stress as the strain rate increases. The increase in tensile stress varies from 20% to 43% when compared with that under quasi-static load. It is interesting to observe that such increases are more than the 5 to 9 % and 8% obtained for other types of FRP reported by Adams and Adams [3] and Harding and Welsh [4].

3.1.3 The effect of strain rate on tensile stiffness

The tensile modulus of elasticity of normal modulus carbon fibre sheet was also influenced by increased strain rate, as shown in Fig. 6.

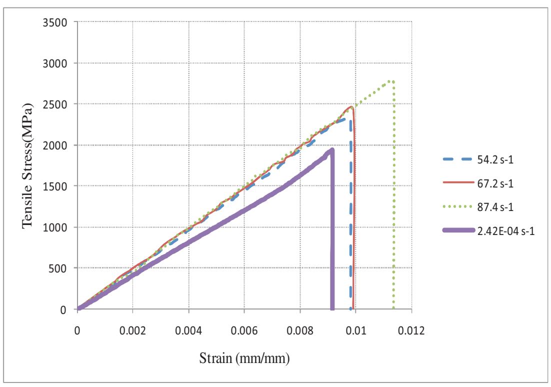

Fig. 4 Stress-strain curves of CFRP for various strain rates

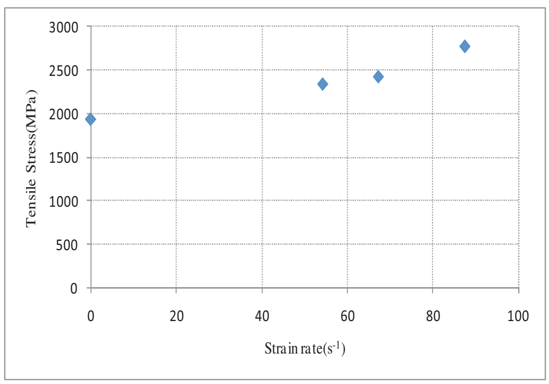

Fig 5 The effect of strain rate on the tensile stress of CFRP

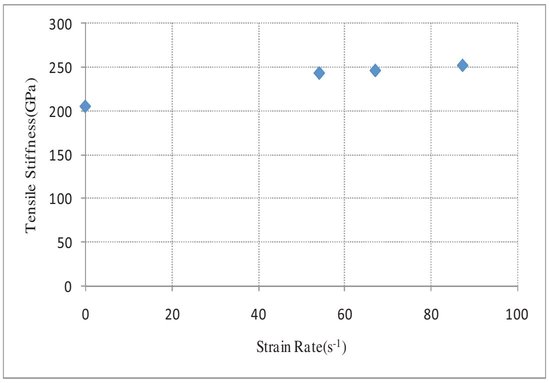

Fig.6 The effect of strain rate on the modulus of elasticity of CFRP

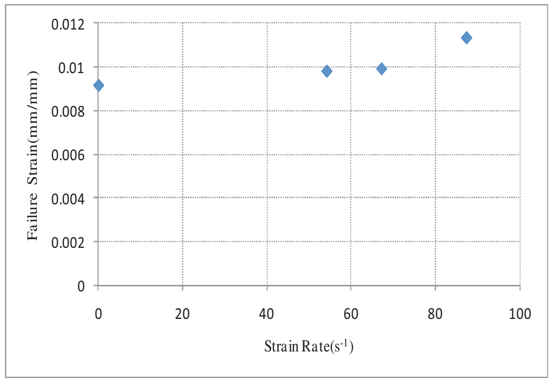

Fig.7 The effect of strain rate on the strain to failure of CFRP

The increase in modulus of elasticity was about 20% when the strain rate was above 52.4 s^{-1}. Less increase (4%) in modulus of elasticity was found by Harding and Welsh [4], whereas Adams and Adams [3] found a slight reduction (6%) for the FRP they tested. It seems that the influence of strain rate on modulus of elasticity depends on the type of FRP.

3.1.4 The effect of strain rate on failure strain

Fig. 7 illustrates the influence of strain rate on the strain at failure for CF130. Again there is a general trend of increasing strain at failure as the strain rate increases. For strain rate of 54.2 and 67.2 s^{-1} the increase is about 9%. A greater increase (24%) was found when the strain rate reached 87.4 s^{-1}. The increased stain at failure matches the improved energy absorption found in previous studies on CFRP CF130 strengthened steel tubes under impact loading [10].

3.2 Araldite 420 epoxy tests

3.2.1 Stress-strain relation

Typical tensile stress-strain curves of neat (pure) Araldite 420 epoxy at different strain rates are presented in Fig. 8. Araldite 420 shows less ductile behaviour under high strain rate loading especially beyond 54.2 s^{-1}. This could be attributed to the fact that with increased strain rate the material does not have enough time to show its nonlinearity behaviour. It is also obvious that the behaviour of the stress-strain curve for strain rates of 67.4 and 87.4 s^{-1} is nearly identical, which implies no further increase in tensile stress after a certain strain rate.

3.2.2 The effect of strain rate on tensile stress

The variation of dynamic tensile stress against the strain rate is plotted in Fig. 9. It is apparent from this graph that the tensile stress of Araldite 420 exhibited a high degree of sensitivity when the strain rate increased from quasi-static to 54.2 s^{-1}. There is little increase in the tensile stress after the strain rate reaches 54.2 s^{-1}. The impact tensile stress increased by about 219%, 222% and 231% compared to the static value for the three high strain rates tested. Adams and Adams [3] found only a 20% increase in tensile stress for the epoxy they tested in a similar range of strain rates.

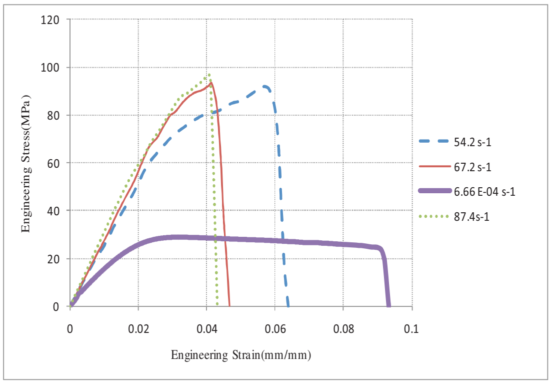

Fig.8 Stress-strain curves of epoxy for various strain rates

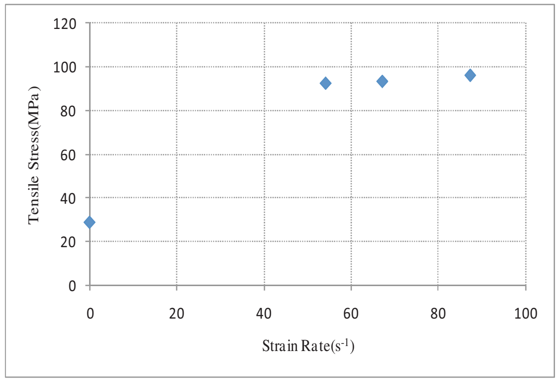

Fig.9 Strain rate effect on the tensile stress of epoxy

3.2.3 The effect of strain rate on tensile stiffness

The effect of strain rate on the dynamic modulus of elasticity of Araldite 420 is depicted in Fig. 10 for the four different strain rates. It is obvious that the dynamic modulus of elasticity of Araldite 420 increases as the strain rate increases. For the strain rate of 54.2, 67.2 and 87.4 s^{-1} the increase is 85%, 98% and 106%. Only 12% increase was found by Adams and Adams [3] for the epoxy they tested in a similar range of strain rate.

3.2.4 The effect of strain rate on strain at failure

The strain rate affects not only the tensile stress and modulus of elasticity but also the strain at failure. Fig. 11 clearly shows a significant reduction in the strain at failure when the strain rate increases. The reduction is very sharp when the strain rate is less than 67.2 s^{-1}. It becomes much flatter (about 55%) for very high strain rate. More tests are needed in the range of strain rates between static and 67.2 s^{-1}. It is interesting to observe the opposite trend in strain at failure for C130 and for Araldite 420. This may be related to the fact that a much larger increase in modulus of elasticity was found for Araldite 420 (100%) than for CFRP C130 (20%).

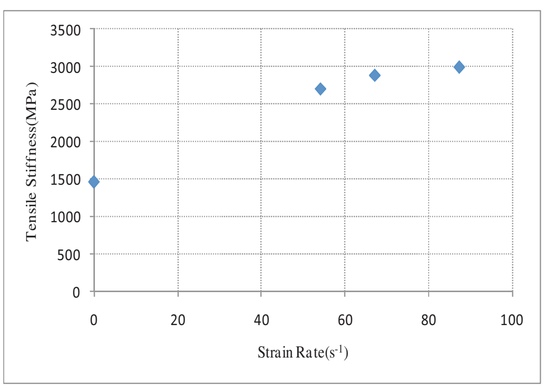

Fig.10 The effect of strain rate on the stiffness of epoxy

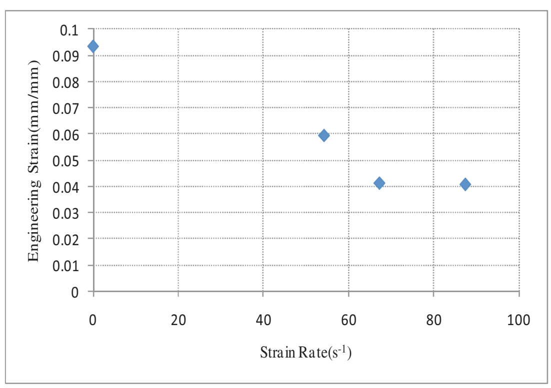

Fig.11 The effect of strain rate on the strain to failure of epoxy

4. Conclusions

This paper reported a study of strain rate influence on the mechanical properties of normal modulus CFRP sheet and neat Araldite 420 epoxy resin over a range of strain rates from quasi-static up to 87.2 s^{-1}. The following observations and conclusions are based on the limited tests conducted.

- More influence of strain rate on material properties was found for Araldite 420 than for CFRP C130.
- For CFRP C130, the increase in tensile stress is about 20 to 40%. The increase in modulus of elasticity and strain at failure is about 20%.
- For Araldite 420, the increase in tensile stress is about 220% and the increase in modulus of elasticity is about 100%. However, a reduction (up to 55%) in strain at failure was observed. More tests are needed in the strain rate range between the quasi-static to 67.2 s^{-1}.

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