An Experimental Study of Tensile and Fracture Response of PETI-5 and IM7/PETI-5 Graphite/Epoxy Composites Subjected to Quasi-Static and Dynamic Loading

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Introduction

NASA-LaRC has recently developed a material, designated PETI-5 (Phenylethynyl Terminated Imide Oligomers 5th composition) as an adhesive or a matrix material in composites for aerospace applications including supersonic aircraft structures. This material has good thermomechanical properties including superior strength, toughness, thermal stability, resistance to aircraft fluids and easy processing in an autoclave [1]. Due to the extreme conditions during a supersonic flight, it is important to investigate the response of PETI-5 at elevated rates of loading. In Hence quasi-static and dynamic tensile and fracture performances of PETI-5 are studied. Further, dynamic mode-I and mixed-mode fracture response of unidirectional IM7/PETI-5 composites is presented for two different fiber orientations.

Tensile Tests on Neat PETI-5

Several static tests (cross-head speed 0.005 mm/sec) on neat PETI-5 dog-bone samples were carried out. A combination of measurements - strain gages, extensometer, and grid pattern - was used to quantify tensile modulus (E), Poisson's ratio (ν), failure strain (ε^u) and ultimate stress (σ^u). The in-house measurements, E = 3.25 GPa, σ^u = 116.4 MPa, ε^u = 32.8%, and ν = 0.37, are in good agreement with those published [2] in the literature.

The dynamic elastic constants of PETI-5 were evaluated from ultrasonic pulse-echo measurements. Average shear and longitudinal wave speeds were found to be 1095 and 2525 m/sec, respectively. Using material density (1335 kg/m^3), dynamic E and ν were found to be 4.46 GPa and 0.384, respectively. When compared to the static values, the dynamic E is 37% higher whereas ν shows relatively negligible loading rate sensitivity.

Fracture Tests on Neat PETI-5

Under quasi-static loading conditions, 3-point symmetric bending tests were carried out on edge cracked beam samples. In these tests, 2D digital image correlation (DIC) technique [3] was used to monitor deformations in the crack tip vicinity. Decorated b/w speckles on the surface were photographed at various load levels up to crack initiation and complete fracture. The speckle patterns at each load level were then correlated with the one at no load to determine opening and sliding displacements. The stress intensity factors were then computed using displacement components in conjunction with plane stress crack tip field expressions. The resulting stress intensity factor history is shown in Fig. 1(a).

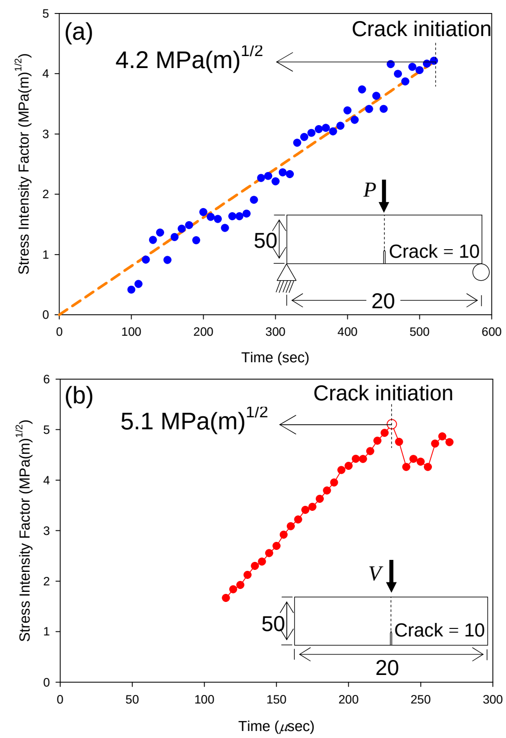

Figure 2. Measured stress intensity factor history of neat PETI-5 under (a) quasi-static loading and (b) impact loading: Inset indicates geometry of a specimen used in the respective test (units in mm).

Dynamic fracture response was also measured by subjecting specimens to 1-point impact in symmetric mode-I loading configuration (impact velocity = 4.8 m/sec). The evolution of dynamic fracture parameters during impact loading was determined using 2D DIC and high-speed photography (up to 2.5x10^5 frames/sec) by measuring displacement fields in the crack tip vicinity. Using measured displacements SIF history for PETI-5 samples was determined and a typical result is presented in Fig. 1(b). Evidently, the increase in $K_I(t)$ is linear and monotonic as in the quasi-static case.

Dynamic Fracture of IM7/PETI-5 Composites

Dynamic fracture tests were carried out to evaluate fracture parameters and compared with those for T800/3900-2 graphite/epoxy. Material properties used in this work were [4]: E_1 = 151.7 GPa, E_2 = 9.65 GPa, G_{12} = 4.14 GPa, ν_{12} = 0.33, and ρ = 1580 (kg/m^3). Subscripts 1 and 2 indicate fiber and transverse directions, respectively.

The mode-I and -II SIF histories for $\beta = 0^0$ and 45^0 unidirectional panels of IM7/PETI-5 were computed and are shown in Fig. 3(a). For comparison, the corresponding mode-I and -II SIF histories for T800/3900-2 panels are shown in Fig. 3(b) [5].

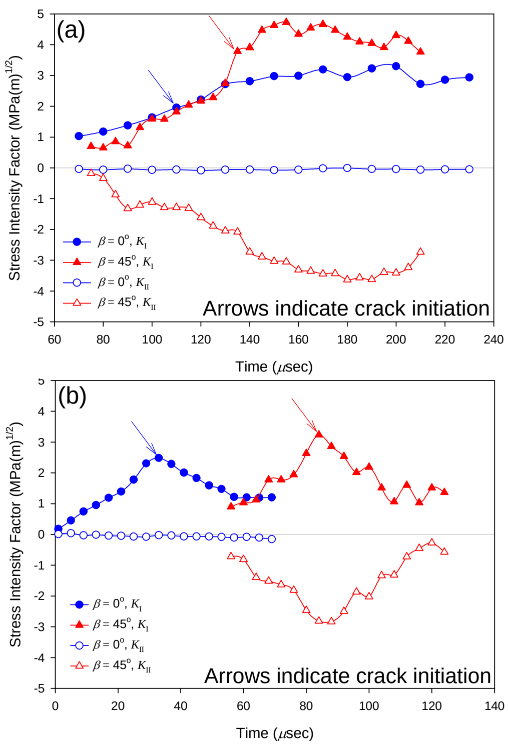

Figure 3. Mode-I and -II stress intensity factor histories for two fiber orientation angles: (a) IM7/PETI-5, (b) T800/3200-2 [5].

In Fig. 3(a), a monotonic increase in K_I values until crack initiation is evident for both cases. In the 0^0 case, the SIF values seem to reach a steady state value of approximately 2.5 MPa(m)$^{1/2}$. This value is lower than the one seen for the neat PETI-5, likely due to crack growth occurring along weaker fiber-matrix interfaces. Interestingly, K_I values for both angles show a tendency to increase even after crack initiation, unlike the ones for T800/3900-2 composites, as seen in Fig. 3(b). The magnitude of mode-I and mode-II SIFs for 45^0 is nearly equal at crack initiation and the K_I values attain nearly the same value as the one for 0^0 fiber orientation.

Conclusions

Tensile and fracture properties of neat PETI-5 and IM7/PETI-5 composites were evaluated under elevated rates of loading using high-speed photography and DIC method. PETI-5 shows strain-rate sensitivity. At two different strain rates, stress and strain at failure, SIF at crack initiation, were evaluated. The former two increased/decreased with increasing loading rate by 66%/15% and the latter increased by 21%. Regardless of the fiber orientation, IM7/PETI-5 composites exhibited higher SIFs, delayed crack initiation, and lower crack speed during dynamic growth than T800/3900-2. These point to the superiority of PETI-5 and IM7/PETI-5 composites relative to other epoxy resin systems used in aerospace applications.

Acknowledgments

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References

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