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Characterization of the dynamic toughness of composite materials by a microscopic approach

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1 General Introduction

Organic matrix laminated composites are increasingly used in the aeronautical field. These materials are designed for certain elements such as the fuselage or wings of aircraft. These elements are subjected to impact such as bird strikes or hailstone impacts that can lead to delamination. The delamination is a significant decohesion of the resin-rich inter-laminar environment. It is a fracture mechanism that can lead to the failure of the structure. The energy release rate (G) is used to characterize inter-laminar strength. It is determined in mode I using a standardized experimental setup under quasi-static loading with a Double Cantilever Beam (DCB) sample [1]. A global analysis method with an energetic approach is applied to analyse this experiment. In the case of dynamic loading, there is no standardized experimental setup. Nevertheless, some authors have developed extensions of the global method used for quasi-static loading. However, the results show some differences between authors for the same material [2]. Others authors have used a microscopic approach at the local resin scale to determine fracture toughness with stress intensity factors (K_I et K_{II}) using local measurements with strain gauges near the crack tip [3]. Besides, some authors used non-singular terms from the Williams series for others materials. They showed the influence of the geometrical effects of the sample on the stability of the crack propagation, on the toughness and on the non-singular terms [4] [5]. The aim of this work is to determine the dynamic toughness of laminated materials in mode I. A microscopic approach on an epoxy resin is employed by adding non-singular terms of the Williams series to take into account structural effects as geometrical effects of the sample.

2 Experimental set-up and results

2.1 PMMA

An experimental investigation under quasi-static loading was carried out on an Instron 5967 electromechanical testing machine to validate this microscopic approach. As the PMMA is a well known material, it was used to verify the experimental setup. The Tapered Double Cantilevered Beam (TDCB) sample was considered during this campaign. According to literature [6] this specimen allows for stable crack propagation. Two crosshead speed 0.1 mm/min and 1 mm/min were considered. The digital image correlation technique was used with Phantom camera to evaluate displacement fields. These fields (near the crack tip) are projected onto the Williams series to evaluate K_I , T and B (respectively the first and the second mode I non-singular terms). During these experiments, the loading and displacement are recorded. The results show a stable crack propagation. Moreover, K_I values are very close for all experiments. These values evolve between $1.3 \text{ MPa}\sqrt{\text{m}}$ and $1.6 \text{ MPa}\sqrt{\text{m}}$. Non-singular terms are close to 0 as expected. This experimental set-up and the microscopic approach having been validated, they were used for epoxy resin.

2.1 Epoxy resin

Indeed, two specimen types were used to show the effect of structure on the non-singular terms. The first is a TDCB specimen and the second is a triangular specimen [7]. Three crosshead speed 0.1 mm/min , 100 mm/min and 500 mm/min were used to validate this method and to show the influence of displacement speed. The experimental set-up is represented on Fig.1. The experiments show that the

crack propagation is not stable as an unstable phenomenon appears on the load-displacement curve, which corresponds to an intermittent crack propagation. Nevertheless, K_I , T and B were obtained for quasi-static crack propagations phases. The results show that the values of K_I are very close for all specimen and for all crosshead speed. These values ranges from $0.8 \text{ MPa}\sqrt{\text{m}}$ to $1.2 \text{ MPa}\sqrt{\text{m}}$. They are close to the literature values [3]. For the TDCB specimen, the non-singular terms are close to 0 as expected. These results are similar to those for PMMA. For triangular specimens, T increases during experiments while the B decreases during experiments. The difference in B values between the TDCB specimen and the triangular specimen is significant. The drops in B for the triangular specimens are more important than for TDCB specimen. This has a significant impact on the occurrence of crack instabilities as their number and intensity vary from one geometry to the other. At these crosshead speeds, no influence of the crack propagation speed on K_I is observed.

2.1 Conclusion and perspectives

Lastly, even if stick-slip phenomenon appeared, a microscopic approach using Williams series showed good results. Furthermore, structural effects were highlighted using non-singular terms and this approach will be used for dynamic loadings. Another experimental setup was developed using a high-speed servo-hydraulic testing machine to determine the toughness and non-singular terms for dynamic loading. The digital image correlation technique was used with high-speed camera to evaluate displacement fields. Stress intensity factors and non-singular terms are calculated as in the case of quasi-static loading.

3 Figure and references

3.1 Figure

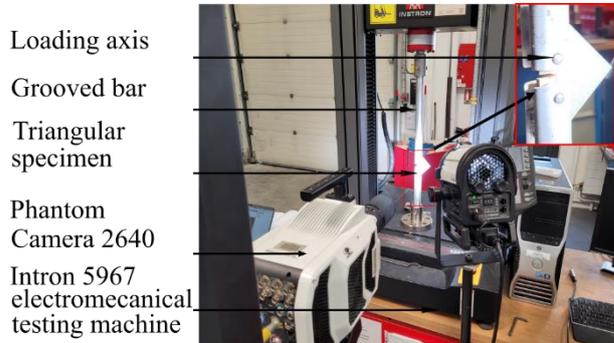


Fig. 1. Experimental set-up under quasi-static loading

3.2 References

- [1] BRK.Blackman, AJ.Kinloch, Y.Wang, and JG JG.Willims. "The failure of fibre composites and adhesively bonded fibre composites under high rates of test". *Journal of materials science*, 31(17) :4451–4466, 1996.
- [2] S. Mall, G.E. Law, and M. Katouzian. "Loading Rate Effect on interlaminar fracture toughness of a thermoplastic composite". *Journal of Composite Materials*,21(6) :569–579, June 1987. Publisher : SAGE Publications Ltd STM.
- [3] V.Joudon, G.Portemont, F.Lauro, and B.Bennani. "Experimental procedure to characterize the mode I dynamic fracture toughness of advanced epoxy resins". *Engineering Fracture Mechanics*, 126 :166–177, 2014.
- [4] M. R. Ayatollahi, M. Rashidi Moghaddam, S. M. J. Razavi, and F. Berto. "Geometry effects on fracture trajectory of PMMA samples under pure mode-I loading". *Engineering Fracture Mechanics*, 163 :449–461, September 2016.
- [5] Bhawesh Kumar, S. Chitsiriphanit, and C. T. Sun. "Significance of K-dominance zone size and nonsingular stress field in brittle fracture". *Engineering Fracture Mechanics*, 78(9) :2042–2051, June 2011.
- [6] TM.Grabois, J.Neggers, L.Ponson, F.Hild, and RD.Toledo Filho. "On the validation of integrated dic with tapered double cantilever beam tests". *Engineering FractureMechanics*, 191 :311–323, 2018.
- [7] Y.W. Mai, A. G. Atkins, and R. M. Caddell. "On the stability of cracking in tapered DCB testpieces. *International Journal of Fracture*", 11(6) :939–953, December 1975.