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FAILURE ANALYSIS OF HYBRID GLASS/CARBON THIN PLY LAMINATES SUBJECTED TO TENSILE LOADING

Alens Šņepsts and Andrejs Pupurs

Laboratory of Experimental Mechanics of Materials
Riga Technical University, Ķīpsalas 6A, LV-1048 Riga, Latvia
Email: andrejs.pupurs@rtu.lv, web page: www.rtu.lv

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ABSTRACT

Micro-damage such as fiber/matrix interface debonds, matrix cracks, delaminations and fiber breaks forming during the service life of composites is a significant limiting factor in many applications. Matrix cracks in off-axis layers are typically the first damage mode to occur in laminates due to weak properties in the transverse direction to the fibers and it is the main cause for the appearance of subsequent damage modes – delaminations and fiber breaks. Hence, it is highly desirable to suppress the initiation and development of transverse matrix cracks. In this context, laminates with thin plies, introduced in the composites industry during the last 15 years [1], has been a promising new development for composite materials. Compared to conventional composite laminates a superior damage resistance is expected in thin-ply laminates due to higher in-situ transverse strength. More specifically, carbon fiber thin-ply laminates manufactured from spread tow fabrics from Oxeon (Sweden), Chomarat (France), NTPT (Switzerland) and other manufacturers have been studied, for example, in [2,3]. While occurrence of matrix cracks is delayed, the overall brittleness of composite ultimate failure is increased in thin-ply laminates, which is seen as a limiting factor in many applications. Hence use of carbon/glass hybrid thin-ply laminates can be proposed as a potential solution to combine thin-ply induced suppression of micro-damage with increased ductility due to glass fibers. Combining thin plies of carbon and glass fibers in hybrid laminates may lead to an improvement of 20% in the failure strain according to [4]. It has also been shown that unstable delamination is suppressed in such laminates [5]. In the present work, a thorough parametric analysis is performed to study the effect of ply thickness and ply clustering on the ultimate tensile strength of carbon/glass hybrid thin-ply laminates. The work consists of experimental testing, analysis of polished specimen edges and fracture surfaces, and numerical modelling of the micro-damage propagation.

In the present work, thin-ply laminates were manufactured using Textreme carbon fiber thin-ply plain weave fabrics from Oxeon (Sweden) with areal weight of 100g/m^2 and glass fiber plain weave fabrics from Interglas (Germany) with an areal weight of 80g/m^2. Hybrid carbon/glass laminates with various combinations of single, double and quadruple carbon and glass fiber layers were manufactured. All plates consisted of 16 layers. Symmetric laminates with alternating single carbon and glass fiber layers were denoted as TH1 and TH3 with carbon and glass fiber external layers respectively. Similarly, laminates with alternating double carbon and glass layers were denoted ad TH2 and TH4 and finally, laminates with alternating quadruple carbon and glass layers were denoted as TH5 (carbon external layers) and TH6 (glass external layers). Reference laminates consisting of 16 carbon fiber layers (denoted as CR1) and glass fiber layers (GR1) were also included in the parametric study. Standard size tensile test specimens (according to ASTM D3039) were prepared to perform experimental tests for determination of elastic tensile modulus, maximum tensile strength and ultimate strain to failure of reference and hybrid thin-ply laminates. Mechanical tests were performed on Zwick/Roell Z150 universal testing machine equipped with 150 kN capacity load cell. Tensile strain was measured using non-contact video-extensometer from Messphysik with gage length of 50 mm which allowed accurate measurement of the ultimate failure strain. At least 3 specimens were tested for each configuration. Specimen edges were polished for performing inspection of damage with optical microscopy.

The results summarized in Fig.1a demonstrate a trend that laminates with single alternating carbon and glass fiber layers (TH1 and TH3) exhibit higher ultimate tensile strength compared to laminates with double (TH2, TH4) and quadruple (TH5, TH6) carbon and glass/epoxy layers. A similar trend was observed regarding the maximum tensile strain to failure. The obtained values of elastic modulus for hybrid composites (TH1 – TH6) were consistent with predictions based on the measured stiffness of reference materials CR1 and GR1.

No visible damage evolution was found in hybrid laminates using optical microscopy inspection of polished edges which can be explained by very thin layers and closure of micro-cracks in unloaded specimens. On the other hand, fracture surface analysis performed using scanning electron microscopy demonstrated a clear qualitative difference between laminates with thin plies such as TH1 (Fig.1b) and laminates with ply clusters, such as TH6 (Fig.1c). FEM calculations of energy release rate were performed to validate the observed differences in fracture surfaces. Cohesive elements were applied in FEM to perform simulations of delamination growth prior to ultimate failure.

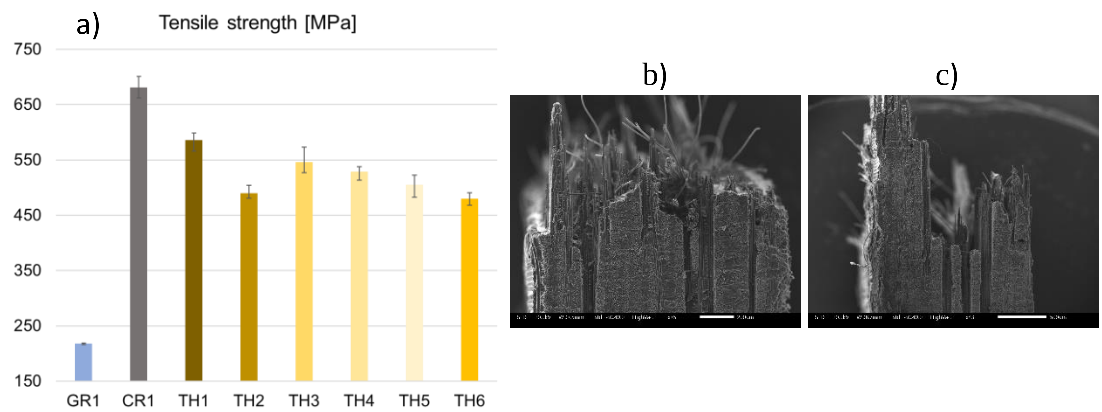

Figure 1: a) Ultimate tensile strength of hybrid thin-ply laminates; b) typical fracture surface of TH1 laminate; c) typical fracture surface of TH6 laminate.

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REFERENCES

[1] Sihn, S., Kim, R.Y., Kawabe, K., Tsai, S.W., *Experimental studies of thin-ply laminated composites*, Composites Science and Technology, **67(6)**, 2007, p. 996-1008.

[2] Guillamet, G., Turon, A., Costa, J., Renart, J., Linde, P., Mayugo, J.A., *Damage occurrence at edges of non-crimp-fabric thin-ply laminates under off-axis uniaxial loading*, Composites Science and Technology, **98**, 2014, p. 44-50.

[3] Cugnoni, J., Amacher, R., Kohler, S., Brunner, J., Kramer, E., Dransfeld, C., Smith, W., Scobbie, K., Sorensen, L., Botsis, J., *Towards aerospace grade thin-ply composites: Effect of ply thickness, fibre, matrix and interlayer toughening on strength and damage tolerance*, Composites Science and Technology, **168**, 2018, p. 467-477.

[4] Wisnom, M.R., Czél, G., Swolfs, Y., Jalalvand, M., Gorbatikh, L., Verpoest, I., *Hybrid effects in thin ply carbon/glass unidirectional laminates: Accurate experimental determination and prediction*, Composites Part A: Applied Science and Manufacturing, **88**, 2016, p. 131-139.

[5] Swolfs, Y., Meerten, Y., Hine, P., Ward, I., Verpoest, I., Gorbatikh, L., *Introducing ductility in hybrid carbon fibre/self-reinforced composites through control of the damage mechanisms,* Composite Structures, **131**, 2015, p. 259-265.