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RESIDUAL TENSILE STRENGTH OF MULTI-IMPACTED WOVEN GLASS FIBRE-REINFORCED POLYMER COMPOSITES

Luis Miguel Ferreira[1(*)], Carlos Campos Coelho[2], Paulo Reis[3]

[1]Dep. Mecánica de Medios Continuos y Teoría de Estructuras. Universidad de Sevilla, Sevilla. España
[2]Unidade Departamental de Engenharias. Instituto Politécnico de Tomar, Abrantes. Portugal
[3]Dep. Engenharia Mecânica. CEMMPRE. Universidade de Coimbra, Coimbra. Portugal
[(*)]*Email:* lmarques@us.es

ABSTRACT

The effect of multiple low-velocity impacts on the tensile strength of E-glass/epoxy woven fabric composite laminates was studied. For this purpose, specimens with a lay-up sequence of $[0,90]_{10}$ were considered, which were subjected to multiple impacts with an energy of 4 J. For a better understanding of the phenomenon, the impact tests were analysed in terms of maximum load and displacement, contact time and energy absorbed. Finally, the residual tensile strength of the specimens was evaluated after each series of impacts, and the results were compared with those obtained in the control specimens (without impacts). It was possible to conclude that the residual tensile strength is strongly affected after the 1st impact, while the damage introduced in the following impacts is not so expressive and, consequently, affects the residual strength less.

Keywords: multi-impacts, residual tensile strength, woven fabric composites.

INTRODUCTION

The post-impact mechanical response of composite materials is an important property that needs to be considered early in the design phase (European Aviation Safety Agency, 2010). Most of the research available in the literature is essentially dedicated to studying the influence of several parameters, such as the impactor's energy and geometry, the stacking sequence and thickness of the laminates, as well as the fabric architecture and matrix stiffness on compression after impact (CAI) strength (Davies and Olsson, 2004). For example, impact damage is considered the primary cause of in-service delamination in composites giving reductions of the compressive residual strength by up to 60% (Moura and Marques, 2002). In fact, the compressive strength of composites is already lower than their tensile strength, which significantly reduces the advantage of these materials, and this property further limits their application when composites have defects. In terms of tensile strength, a similar trend is observed, although it is much less affected when compared to compressive loading. However, the available literature on tensile after impact (TAI) strength is still scarce. In this context, the present study aims to understand and complement the available literature on this subject.

RESULTS AND CONCLUSIONS

Laminated composites manufactured from 10 layers of bi-directional E-glass fabric (EC9 68x2) and an epoxy resin (SR 1500) with a hardener (SD 2503) were subjected to multiple low-velocity impacts with an energy of 4 J. From these tests, Table 1 presents the values of maximum impact load, maximum displacement, absorbed energy and contact time to characterize the impact parameters.

Table 1 – Multi-impact results for the composite laminates.

Number of impacts	$F_{max.}$ [kN]	$D_{max.}$ [mm]	$E_{abs.}$ [J]	$T_{contact}$ [ms]
1	2.63±0.123	2.95±0.095	3.16±0.054	5.63±0.123
2	2.43±0.053	3.56±0.050	3.41±0.056	6.53±0.247
3	1.84±0.051	4.17±0.124	3.54±0.051	8.15±0.347
4	1.51±0.018	5.35±0.071	3.82±0.057	12.62±0.403
5	-	-	-	-

It is possible to observe a gradual decrease in load with the number of impacts, and an opposite trend can be noted for displacement. This is due to the accumulation of damage and consequent lower stiffness of the laminates. After the laminates have been subjected to different numbers of impacts, the specimens were subsequently subjected to tensile tests in order to obtain the residual tensile strength. It should be noted that the total perforation occurred on the 5th impact. Full perforation is defined when the impactor completely moves through the samples. Table 2 presents the results obtained for each condition tested.

Table 2 – Residual tensile strength.

Number of impacts	$F_{max.}$ [kN]
0	13.947±1.310
1	6.570±0.621
2	6.085±0.351
3	4.688±0.862
5	4.158±1.122

Regarding the residual strength, it is possible to notice that it drops abruptly after the 1st impact. Compared to control specimens, this decrease is about 51%. The damage introduced by subsequent impacts is less severe, revealing a decrease between the 2nd and 5th impact of only 39.7%. After the introduction of significant damage by the first impact, their progression occurs more slowly until saturation occurs, from which the final collapse (perforation) is imminent. Literature indicates that the nature of damage in impacted laminates is quite complex, involving multiple delaminations, but there is a consensus that the first damage mode to appear is matrix cracking. Subsequently, these cracks evolve into inter- and intra-yarn cracking and, finally, into inter- and intra-ply delaminations, evidencing, all this interaction, a very complex damage mechanism. At a later stage, the fibres begin to fail at the impact/indentation point, and the final failure culminates in perforation when the remaining fibres can no longer withstand the impact.

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