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Numerical/Experimental Study Of The Impact and Compression After Impact On GFRP Composite For Wind/Marine Applications

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Abstract

Damage development due to impact needs to be understood to evaluate the consequences of impact on composite structures. This study concentrates on modelling low velocity impact and consequent compression after impact (CAI) test on thick industrial composites made from glass fiber epoxy produced by vacuum assisted resin infusion. Cross-plied laminates were tested with different impact energies and different numbers of interfaces (clustering). Results were compared to a 3D finite element analysis. Interfaces and their damage development were modelled with cohesive elements. Intraply properties were modelled by progressive failure analysis. The results show that the numerical model using only simple and independently measured material data was able to predict the impact and CAI behavior for the different energies and different stacking sequences.

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1. Introduction

Composite structures are extremely susceptible to impact damage [1]. The consequences of impact can results in a large reduction of the structural performance with the possibility of catastrophic failure. More importantly, the damage can easily propagate under cyclic loads, which for instance commonly occur in marine and wind turbine

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applications, producing even larger reductions in stiffness and eventually unexpected structural failure under normal design load conditions [2].

Impact is a complex interaction of an object with a structural component. It typically induces matrix cracking, fibre failure and delamination [1] that can highly decrease the stiffness of the material. Impact events have for long been investigated for thin carbon laminates produced by autoclave processes and used for high tech applications [1]. On the other hand, very few studies have been presented about impact on thicker glass fibers laminates produced by vacuum infusion or hand layup, as common practice in the marine wind energy industry [3].

González [4] performed a broad study, comparing numerical results with experimental impact and compression after impact (CAI) tests. An advanced interface model, based on the work by Turon [5], was used to model delamination. The intralaminar effects were evaluated using the LaRC04 failure theory developed by Maimi [6-8]. An advanced and innovative approach was presented by Bouvet [9], where discrete interface elements were used to simulate both the interlaminar and intralaminar damages during the impact. The same approach was used by Rivallant [10] for modelling the CAI tests. All these methods gave good agreement between theory and experiments, but they need an extensive set of input parameters requiring large and complicated test programs.

The simulation of low velocity impact event and the subsequent CAI requires: 1) definition of the impact scenario, 2) simulation of the impact event and consequent induced damage 3) assessment of the residual stiffness by in plane compression evaluation (CAI). This paper present a complete methodology capable to easily simulate the impact damage and asses the residual strength by using a simple numerical methodology based on readily available material parameters common available also for "low cost" applications.

The developed numerical model, used for both the impact and the CAI simulation, is based on 3D finite element model using cohesive elements for the interlaminar damage and a strength based failure criterion (based on Puck [11, 12] and Hashin [13]) for the intralaminar damage. This approach is fairly complicated to model and requires long computation times, but it is available to most engineers. Numerical results are compared to experimental tests on simple flat, cross-plied laminates with different stacking sequences impacted with different energies.

This is seen as a step to build up confidence in the modelling methods, eventually allowing engineers to design impact resistance of low cost composites reducing experimental testing.

Table 1: Summary of the tested material properties for the used HiPer-Tex E-Glass fibre / Momentive EPIKOTE MGS 135 resin and EPIKURE MGS 137 composite produced by vacuum infusion

Ply properties:

Properties	Value
Ply Thickness	0.86 mm
Density	1230 kg/m^3
Elastic properties	E_1= 44.87 *GPa*; E_2= E_3*= 12.13 *GPa*; G_{12}=G_{13}*=G_{23}*=3.38 *GPa;* ν_{12}=ν_{13}*=0.30; ν_{23}*=0.5
Strength *[MPa]***	X_t=1006.30; X_c=487.00; Y_t=Z_t*=45.95; Y_c= Z_c*=131.90; S_{12}= S_{13}*= S_{23}*=49.51;

Interface properties:

Properties	Value
Elastic properties	K_{nn}*= 12.13 *GPa*; K_{ss}*= K_{tt}*= 3.38 *GPa*
Strength *[MPa]*	t_n*=45.95; t_s*= t_t*=49.51;
Fracture toughness *[N/mm]*	G_{Ic}=0.98; G_{IIc}= G_{IIIc}*=3.71
Mode interaction – BK	η=1.40

**Assumed*

***Note: X is the fibre direction, Y is the matrix direction, t is for tension and c for compression; S_{12} is for shear*

2. Experimental Test

2.1. Material, Layup and geometry

The experimental tests were performed on E-Glass epoxy composite produced by vacuum assisted resin infusion, as commonly used in wind turbines, ships and offshore applications. The chosen reinforcement was a Seartex unidirectional stitch bonded mat made from 3B´s HiPer-tex W2020 E-Glass fiber with an average weight of 1150 g/m^2. Momentive Epikote MGS 135 epoxy resin with Epikure MGS 137 curing agent was used as resin. A mix ratio of 100:30 was selected with a curing time of 24h at room temperature and post curing at 80°C degrees for 15 hours.

As initial part of the work, the material properties were fully characterized. Unidirectional ply properties were measured for this material and results are summarized in Table 1 [14]. The Table also shows some assumed through