EXPERIMENTAL AND NUMERICAL INVESTIGATIONS OF LOW-VELOCITY IMPACT BEHAVIOR OF SELECTED FIBRE METAL LAMINATES

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Abstract
The paper presents a numerical analysis of impact response of aluminium hybrid laminates with glass fibres reinforced polymer matrix. Verification of numerical analyses was conducted with experimental methods. The low-velocity impact test were performed using a drop-weight impact tester, while ABAQUS/Explicit was used to develop numerical simulations of the FMLs. Delaminations between composite layers and at the interface of metal/composite, transverse cracks of composite layers and crack of bottom metal layer are the dominant mechanism of degradation as a result of low-velocity impact. The conducted verification of the results of numerical calculations demonstrated high conformity of the simulation with experimental results.

1. Introduction

Impact damage resistance is a one of the important issue for composite structures, particularly in aerospace. It is well known that fibre reinforced polymer composites (FRP) are very susceptible to low-velocity transverse impact. The relationships between damages and impact responses, identification of damage types and the understanding of damage propagation mechanisms is an essential issue for laminates resistance to dynamic impacts. Low-velocity impact may significantly affect the durability, strength and stiffness of composite structure. Frequently barely visible impact damage (BVID) is associated with internal damaged area of the laminated composites, with numerous delaminations, matrix cracking, transverse cracks and fibre fracture [1-5].

An interesting material solution is represented by Fibre Metal Laminates (FML). FML are hybrid materials, consisting of alternating thin layers of metal sheets and fibre reinforced composite material. FML laminates possess superior properties of both metals and fibrous composite materials. There are characterized by excellent damage tolerance: fatigue and impact characteristics, low density, high mechanical properties, corrosion and fire resistance [2,6-8].

The understanding of impact behaviour is particularly important in the selecting of materials and their designing, in damage tolerance philosophy aspect as well as in the searching of the methods of forecasting of FML hybrid materials resistance to dynamic impacts [1,3,5,10-12].

Numerical simulations based on application of the finite element method (FEM) form a tool supporting the formation process and analysis of composite materials. These methods allow for simulation, optimization of composite structures as well as analysis of damage taking resistance criteria into account [4,13-16].

This work presents a numerical analysis of impact response of aluminium hybrid laminates with glass fibres reinforced polymer matrix. Verification of numerical analyses was conducted with experimental methods.

2. Experimental procedure

2.1. Material

The subject of examination was FML composed of thin aluminum layers with glass fibers reinforced polymer (Al/GFRP). The 2024-T3 aluminum alloy sheets with 0.5 mm thickness were used. The composite layers consists of unidirectional prepreg (Hexcel, USA) based on R-type high-strength glass fibers with epoxy matrix resin (thickness of 0.255 mm). The nominal fibre content was about 60 vol.%. Before laminating, the surface of aluminum alloy sheets were anodized in chromic acid (CAA) and next, adhesive primer (EC3924B, 3M USA) to improve bonding with fibre reinforced polymers was applied. The lay-up scheme of the FML laminates was 2/1, two outer aluminium layers and one interlayer made of glass/epoxy prepreg with (0/90) stacking sequence.

The hybrid laminates were produced in the Department of Materials Engineering - Lublin University of Technology by autoclave method (Scholz Maschinenbau, Germany). The cure cycle was carried out at a heating rate of 2 °C/min up to 135 °C and held at this temperature for 2 h. The pressure and the vacuum used were 0.5 and 0.080 MPa, respectively. The laminates were cut to the final size of 150 mm x 100 mm for impact tests.

2.2. Impact testing

The low-velocity impact test were performed using a drop-weight impact tester (InstronDynatup 9340). Impact tests were carried out according to ASTM D7136 standard. A hemispherical impactor tip with a diameter of 12.7 mm was used. The impact was realized with energy of 20J (impactor mass 3.93 kg, velocity 3.19 m/s). The specimens after impact were examined by macroscopic and microscopic observations (cross-sections) in order to visualize the impacted region and internal damage.

2.3. Finite element modelling

ABAQUS/Explicit was used to develop numerical simulations of the FMLs under low-velocity impact. 8-node solid element (C3D8R) was applied for the hybrid laminate. In the finite element model, the aluminium and the glass fibre reinforced layers were bonded together by the *TIE* interaction. The finite element model of the impact system is illustrated in Fig. 1. In the case of composite material used *VUMAT* model, whereas for aluminium *Damage for Ductile Metals - Ductile Damage* was applied. Selected mechanical properties of composite used in numerical analysis are listed in Table 1.

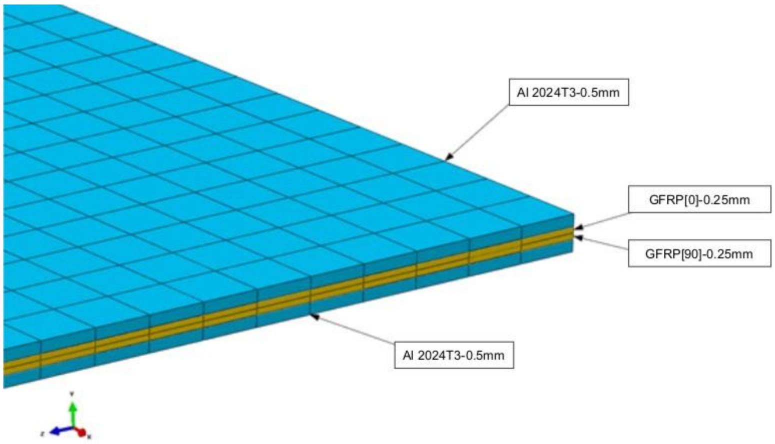

Figure 1. Numerical model of aluminium/GFRP laminate.

Composite									
Tensile strength [MPa]		Tensile modulus [GPa]		Poisson's ratio ν		Compression strength [MPa]	Compression modulus [GPa]	Tensile ultimate strain [%]	
0°	90°	0°	90°	0°	90°	0°	0°	0°	90°
1534	74.5	46.4	14.9	0.27	0.09	1046	21.4	4.6	0.55
Aluminium 2024T3 from [8]									
Tensile strength [MPa]		Tensile modulus [GPa]		0.2% Tensile yield strength [MPa]				Tensile ultimate strain [%]	
450		72		340				19	

Table 1. Selected mechanical properties of GFRP and 2024T3 aluminium alloy.

3. Results and discussion

The conducted numerical calculations considering modelling techniques enabling analysis of the investigated damage of aluminium/glass hybrid laminates for identification and evaluation of damage of the sample subject to impact load. Fig. 2 and Fig. 3 presents a general view of the deformed metal layers on the top and back impacted side and numerical model model in conditions of damaging load.

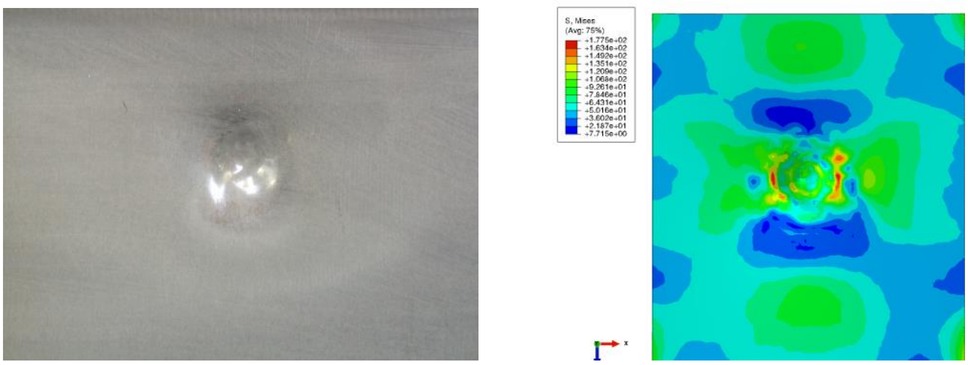

Figure 2. Deformations of top metal layers under low-velocity impact: experimantal (left), simulation (right).

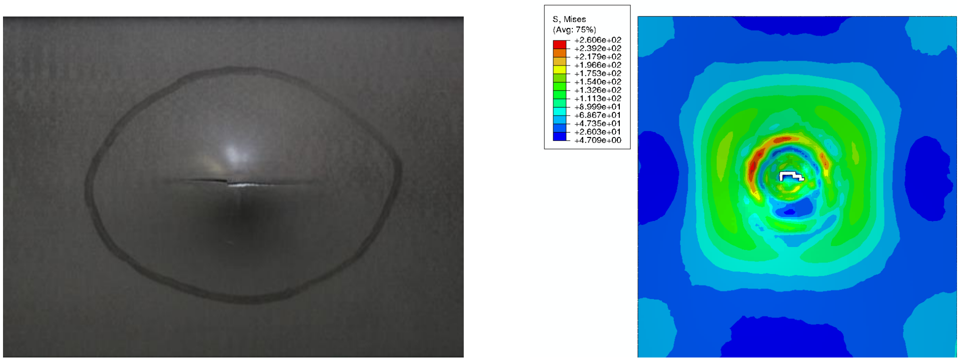

Figure 3. Deformations of back-side metal layers under low-velocity impact: experimantal (left), simulation (right).

The extensive delaminations, transverse cracks of composite layers, crack of bottom metal layer are the prevailing type of damages in Al/GFRP laminate (Fig. 4). Delaminations in composite between layer with different orientations and at the interface of metal/polymer composite were noted. Apart from the component kind and characteristics, the interfaces is the main factor determining the properties of laminate. It directly influences the quality of connection of the reinforcing phase with matrix, the composite cracking mechanism and cracking of the individual components.

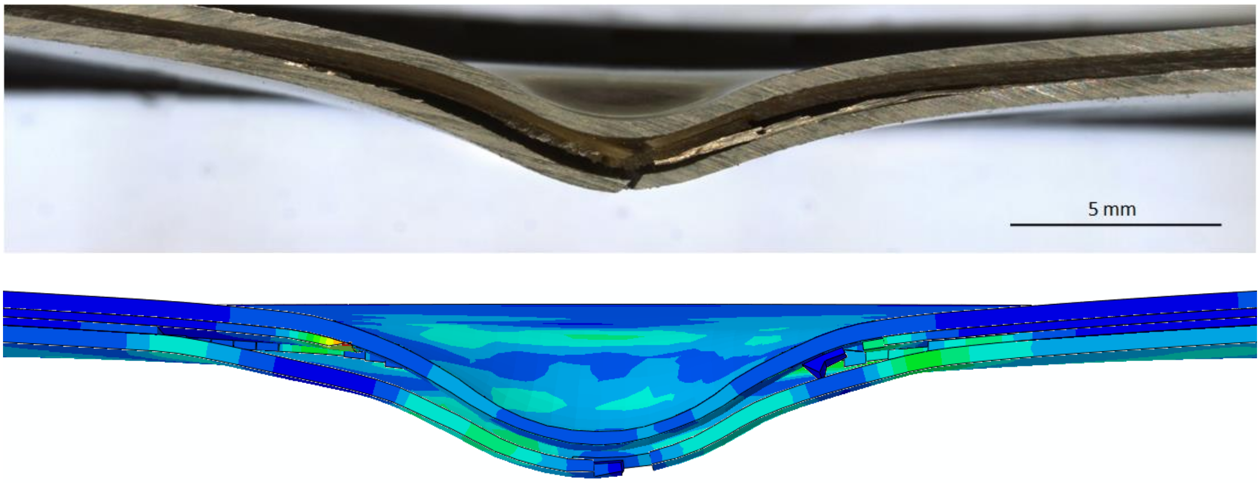

Figure. 4. Typical failure of laminate after low-velocity impact (cross-section): experimental test (top), numerical simulation (bottom).

From the observations it appears that the principal damage is located in the lower part of laminates structure. Moreover, it was observed that the cracks propagating in the bottom aluminum layer in Al/GFRP are consistent with the direction of the lower composite layer orientation.

It is known that the dynamic impact in metals is absorbed and converted into plastic deformation, but the impact energy in composites is associated with the occurrence of damage. In case of hybrid laminates under test, part of impact energy is absorbed by metal layers and the other part is associated with the occurrence of damage in the laminate.

4. Summary

Describing damage of composite materials is a complex problem, necessitating thorough and detailed research and application of modern tools and research methods.

Microstructural analysis and numerical simulations – FEM, allowed for identification of the damage mechanism of the investigated composite material.

Delaminations between composite layers and at the interface of metal/composite, transverse cracks of composite layers and crack of bottom metal layer are the dominant mechanism of degradation in polymer composite materials and fibre metal laminates as a result of low-velocity impact. The conducted verification of the results of numerical calculations demonstrated high conformity of the simulation with experimental results.

Impact phenomena has been known as an important property in assessing the damage tolerance of a composite materials. Thanks to the understanding and the possibility of predicting of impact resistance of hybrid laminates and their degradation it could be possible in the future to extend the range of composite materials and to increase their service life in aircraft components.

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