PROVA DE INGLÊS – CIÊNCIAS EXATAS

CHARACTERIZATION OF FAILURE MODES IN COMPRESSION-AFTER IMPACT OF GLASS–EPOXY COMPOSITE LAMINATES USING ACOUSTIC EMISSION MONITORING

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Abstract

This paper investigates the effect of impact velocity on compression-after impact (CAI) strength, while the different failure modes arising during CAI test are characterized using the acoustic emission (AE) technique. For this purpose, CAI GFRP laminates manufactured as per ASTM D7137 were subjected to impact velocities such as 3.5, 5 and 6 m/s at room temperature. Impacted laminates were then subjected to compression tests using a specially fabricated fixture: AE activity was monitored during loading. Frequency analysis and location analysis were performed on the AE data obtained during CAI test of GFRP specimens impacted at different velocities to investigate the nature and extent of damage.

Keywords GFRP , Impact, Compression-after impact, Acoustic emission.

1 Introduction

Composite materials are widely used in the aerospace industry owing to the fact that they have relatively high strength/mass ratio compared to metals. On the other side, a limitation to the use of composite materials is that they are easily susceptible to damage that may not be visible to naked eye when subjected to accidental events, resulting in objects dropped or hitting the structure: these events are effectively simulated through the performance of lowvelocity impact tests. The chance of occurrence of low-velocity impact is high during some situations, such as aircraft maintenance, when for example a dropped tool can result in the internal structure of the laminate being damaged. The damage mechanisms in composite and metal surfaces are different; moreover, in metallic structures the damage is easily inspected. During impact, fiberreinforced resin composites undergo lesser plastic deformation when compared to metallic structures. The energy absorbed during impact is used to create internal damage in different forms, namely matrix cracking, fiber–matrix debonding, delamination and fiber failure. This damage as a whole considerably reduces the residual strength of these structures; hence, it is necessary to investigate the effect of impact on composite structures.

Compression-after impact (CAI) strength is one of the mechanical properties, which suffers the largest reduction owing to the fact that delamination present in composite laminates grows during compression and hence leads to failure. A number of papers exist dealing with the compressive residual strength of laminates subjected to impact, in which specimen global buckling is avoided by means of suitable support. Mehmet Aktas et al. investigated the effect of the impact test temperature on compression-after impact (CAI) strength. For this purpose, compressionafter impact (CAI) tests are conducted on the GFRP composite specimens subjected to different impact energy levels under normal room temperature (20 °C) and at elevated temperatures. Two stacking sequences as [0°/90°/0°/90°]S and [0°/90°/45°/45°]S were considered for investigation and the effect of the laminate orientation on CAI strength and CAI damage mechanism was studied elaborately.

The outcome of the tests indicates that temperature had effect on impact damage of the specimens tested and CAI strength. The reduction in the CAI strength with increasing impact energy is maximal at 100 °C, while it is minimal at 20 °C. Ghelli et al. [9] studied the effect of geometry using rectangular and circular quasi-isotropic specimens for CAI testing. The outcome of their investigation was that delamination produced by impact has effect on the buckling mode shapes and critical buckling loads. One of the important conclusions given by them was that damage induced by impact did not affect the compressive residual strength in all the specimens, whereas orientation and dimension of the specimen play a key role in the residual compression strength of CFRP. Similarly, Aymerich et al. [10] investigated the effect of low-velocity impact on the damage responses of stitched and unstitched graphite/epoxy laminates. It was observed that stitching provided some additional resistance in the case of low-velocity impact, but this did not result in an increased CAI strength due to the breakage of stitching wires in the impacted (delaminated) area. de Freitas and Reis [11] studied the low-energy impact and performed CAI tests on CFRP laminate composite panels, concluding that the delaminated area due to impact loading directly affects the absorbed energy and the residual strength during compression, and the delaminated area is influenced by the absorbed impact energy.

Another key aspect to be noticed in compression-after impact testing compared to other tests is the different types of specific failure modes that arise, which would not be present in other tests. Three types of failures and their combinations could be observed in composite laminates subjected to compression. They are translaminar fracture (fiber microbuckling/kinking), intralaminar fracture (fiber/matrix debonding and matrix cracking) and interlaminar fracture (delamination) [12]. Under compressive loading, interaction between all three types is critical to damage growth and catastrophic failure. Many researchers have investigated the interactions between the failure modes and were successful in modeling the failure modes [13–16]. Acoustic emission (AE) is one of the best and affordable choices of non-destructive testing method because of its extremely high sensitivity and is comparatively less costly when compared to other NDT techniques. Moreover, AE has proved its capability to detect defects of composite materials which are used extensively in application areas such as aerospace, automobile and civil structures. With AE, one is able to remotely monitor crack formation, crack growth or other local-failure mechanisms, even when such localized failures cannot be observed by any other means [17–19]. Arumugam et al. [20] used single-layer [0°] unidirectional and [90°] GFRP tensile specimens to differentiate the different ranges in peak frequency plots. While Berthelot et al. [21] used AE parameters to discriminate the failure modes from different stacking sequences (0°, crossply, 0°/45°, 90°/45°), Boominathan et al. [22] used AE to characterize the different failure modes on post-impacted CFRP specimens and the intensity of impact damage was reflected in the peak frequency plots obtained from online AE monitoring. Similarly, Arumugam et al. [23] investigated the different failure modes in CFRP specimens using both peak frequency and parametric analysis. FFT analysis was employed chiefly to discriminate the failure modes.

In this paper, the effect of impact velocity on the compressive strength and damage modes of GFRP cross-ply laminates subjected to CAI test were investigated. Previous experiments on CAI loading proved that damage does not appear to grow linearly with impact damage velocity and its effect on CAI strength may be highly variable [23]. To prove the effectiveness and accuracy of AE in characterizing damage from laminates subjected to impact loading at different velocities, which are most likely therefore to have a gradually reduced CAI strength, impact velocities quite close to each other have been selected for testing. In particular, symmetric cross-ply CFRP laminates [(0°/90°)2]6 were fabricated using hand layup with LY556 epoxy resin as a matrix medium and the specimens were cut as per ASTM D7137 (150 × 100 mm) using a water jet cutting machine. These specimens were subjected to impact at three different impact velocities, namely 3.5, 5 and 6 m/s, using a Fractovis drop-weight impact tower. Compression-after impact (CAI) tests are performed on impacted laminates using a 100 kN load cell universal testing machine with AE monitoring. Parametric and signalbased approaches were used to characterize the different failures obtained during CAI testing of zero and symmetric cross-ply laminates impacted at three different velocities.

2 Materials and testing

Laminates were fabricated by hand layup technique. This method consists of applying successively into a mold surface, a layer of resin (LY556) with hardener (HY951), and a layer of reinforcement (glass fiber) and to impregnate the reinforcement by hand with the aid of rollers. The stacking sequence consists of 24 layers. Specimens of dimension 100 × 150 mm were cut from the 6-mm-thick [0°] 24 and cross-ply [(0°/90°)2]12 laminate using water jet cutting machine, complying with the ASTM D 7137 compressionafter impact standard [...]

Com base na leitura do texto “**Characterization of failure modes in compression-after impact of glass–epoxy composite laminates using acoustic emission monitoring”,** responda às questões de 1 a 4.

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Questão 01

a) Qual o objetivo do artigo? (1,0)

b) Qual a limitação do uso de materiais compósitos? (1,0)

c) Quais são as chances de ocorrência de impacto de baixa velocidade em situação de manutenção de aeronaves? (1,0)

Questão 02

De acordo com o texto, responda às seguintes questões:

a) O que Mehmet Aktas et al investigou ? (1,0)

b) O que foi estudado na pesquisa de Gheli et al. (2011)? (1,0)

c) Qual foi a investigação de Aymerich et al.? (1,0)

Questão 03

De acordo com o texto, responda às seguintes questões:

a) Quais tipo de falhas e suas combinações podem ser observadas em laminados compósitos submetidos à compressão? (1,0)

b) Por que a emissão acústica seria uma das melhores opções de método de ensaio não destrutivo? (1,0)

Questão 04

Conforme a leitura do texto, que tipo de material foi usado e como ele foi testado na pesquisa? (2,0)

ESPELHO DAS RESPOSTAS

Com base na leitura do texto “**Characterization of failure modes in compression-after impact of glass–epoxy composite laminates using acoustic emission monitoring”**, responda às questões de 1 a 4.

Questão 01

a) Qual o objetivo do artigo? (1,0)

Espera-se que o (a) candidato (a) consiga entender que o objetivo da pesquisa era investigar o efeito do impacto da velocidade na força de compressão após impacto (CAI), enquanto os diferentes modos de falha que surgem durante o teste CAI são caracterizados usando a técnica de emissão acústica (AE).

b) Qual a limitação do uso de materiais compósitos? (1,0)

Espera-se que o (a) candidato (a) entenda que a limitação ao uso de materiais compósitos ocorre porque são facilmente suscetíveis a danos que podem não ser visíveis a olho nu quando submetidos a eventos acidentais, resultando em queda de objetos ou colisão com a estrutura: esses eventos são efetivamente simulados através da realização de testes de impacto de baixa velocidade.

c) Quais são as chances de ocorrência de impacto de baixa velocidade em situação de manutenção de aeronaves? (1,0)

Espera-se que o (a) candidato (a) compreenda que as chances são altas, quando, por exemplo, uma ferramenta derrubada pode resultar em danos na estrutura interna do laminado.

Questão 02

De acordo com o texto, responda às seguintes questões:

a) O que Mehmet Aktas et al investigou ? (1,0)

Espera-se que o (a) candidato (a) fale que Mehmet Aktas et al. investigou o efeito da temperatura do teste de impacto na compressão após força de impacto (CAI) . Para este propósito, testes de compressão após impacto (CAI) são conduzidos nos corpos de prova compostos de GFRP submetidos a diferentes níveis de energia de impacto sob temperatura ambiente normal (20 °C) e em temperaturas.

b) O que foi estudado na pesquisa de Gheli et al. (2011)? (1,0)

Espera-se que o (a) candidato (a) infira Gheli et al. (2011) estudaram o efeito da geometria usando espécimes retangulares e circulares quase isotrópicos para CAI teste. O resultado de sua investigação foi que a delaminação produzida pelo impacto tem efeito sobre o modo de flambagem formas e cargas críticas de flambagem. Um dos importantes conclusões dadas por eles foi que os danos induzidos por impacto não afetou a resistência à compressão residual em todos os espécimes, considerando que a orientação e dimensão de a amostra desempenha um papel fundamental na compressão residual.

c) Qual foi a investigação de Aymerich et al.? (1,0)

Espera-se que o (a) candidato (a) compreenda que Aymerich et al. investigaram o efeito do impacto de baixa velocidade nos danos respostas de laminados de grafite/epóxi costurados e não costurados. Observou-se que a costura forneceu alguma resistência adicional no caso de impacto de baixa velocidade, mas isso não resultou em aumento da resistência do CAI devido à quebra dos fios de sutura na área impactada (delaminada).

Questão 03

De acordo com o texto, responda às seguintes questões:

a) Quais tipo de falhas e suas combinações podem ser observadas em laminados compósitos submetidos à compressão? (1,0)

Espera-se que o (a) candidato (a) entenda que há três tipos de falhas e suas combinações podem ser observadas em laminados compósitos submetidos à compressão. São fraturas translaminares (fibra microflambagem/torção), fratura intralaminar (fibra/matriz descolamento e trincas da matriz) e fratura interlaminar (delaminação).

b) Por que a emissão acústica seria uma das melhores opções de método de ensaio não destrutivo? (1,0)

Espera-se que o (a) candidato (a) compreenda que a emissão acústica é uma das melhores opções de método de ensaio não destrutivo porque de sua sensibilidade extremamente alta e é comparativamente menos cara quando comparada a outras técnicas de END. Além disso, AE provou sua capacidade de detectar defeitos de compósitos materiais que são amplamente utilizados em áreas de aplicaçãocomo aeroespacial, automobilística e estruturas civis.

Questão 04

Conforme a leitura do texto, que tipo de material foi usado e como ele foi testado na pesquisa? (2,0)

Espera-se que o (a) candidato (a) compreenda que os laminados foram fabricados pela técnica de laminação manual. Este consiste em aplicar sucessivamente na superfície do molde, uma camada de resina (LY556) com endurecedor (HY951), e uma camada de reforço (fibra de vidro) e para impregnar o reforço manual com o auxílio de rolos. A sequência de empilhamento consiste em 24 camadas. Amostras de dimensão 100 × 150 mm foram cortadas do [0°] de 6 mm de espessura 24 e laminado cruzado [(0°/90°)2]12 usando corte a jato de água máquina, em conformidade com o padrão ASTM D 7137 compressão após impacto