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COMPOSITES THEORY AND PRACTICE

Patryk Jakubczak*, Jarosław Bieniaś, Barbara Surowska
Lublin University of Technology, Mechanical Faculty, Materials Engineering Department, ul. Nadbystrzycka 36, 20-618 Lublin, Poland
** Corresponding author. E-mail: p.jakubczak@pollub.pl*

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IMPACT DAMAGE LIVE-TIME ANALYSIS OF MODERN COMPOSITE MATERIALS USING THERMOGRAPHY

The purpose of the study was to evaluate the possibility to use the thermography method in damage extent analysis for fibre metal laminates subjected to low–velocity impacts. On the basis of the obtained results, it has been found that the thermovision method may be used as a relatively effective method for damage identification in fibre metal laminates. It is possible to use local temperature change monitoring in FML as a diagnostic method for these elements in real time. On the basis of the studies it has been shown that depending on the impact energy, the local temperature changes. The values of this change depend on the impact energy. Moreover, the damage area in which the thermal change occurs is dependent on the impact energy. The damage areas estimated using thermography are similar to the damage areas measured by other methods known as more effective and certain. The energy absorbed by a laminate during the impact process is correlated with the process and type of laminate damage. It can be assumed that the observed thermal changes are caused by the degradation process of the structure as the results of deformation, matrix and fiber cracking, delamination initiation and propagation, friction and laminate perforation.

Keywords: FML, impact, NDT, thermography

OBSERWACJA ZNISZCZENIA W CZASIE RZECZYWISTYM NOWOCZESNYCH MATERIAŁÓW KOMPOZYTOWYCH Z WYKORZYSTANIEM TERMOGRAFII

W pracy przeprowadzono ocenę możliwości wykorzystania metody termografii w analizie stopnia zniszczenia laminatów metalowo-włóknistych poddanych uderzeniom dynamicznym z niską prędkością. Na podstawie otrzymanych wyników stwierdzono, że metoda termowizyjna może być relatywnie efektywną metodą identyfikacji uszkodzeń w laminatach metalowo-włóknistych. Monitorowanie dynamiki lokalnych zmian temperatury w laminatach FML może stanowić jedną z metod diagnostyki tych elementów w czasie rzeczywistym. Na podstawie przeprowadzonych badań wykazano, że w zależności od energii uderzenia lokalnie wartości temperatury zmieniają się. Wartość tych zmian jest zależna od energii uderzenia. Ponadto pole powierzchni, w której dochodzi do zmian cieplnych, jest zależne od energii uderzenia. Pola powierzchni zniszczenia oszacowane z wykorzystaniem termografii są zbliżone z pomiarami pola powierzchni zniszczenia laminatów innymi metodami, znanymi jako bardziej efektywne i pewne. Energia absorbowana przez laminat w procesie uderzenia związana jest zarówno z procesem, jak i stopniem zniszczenia laminatu. Można przypuszczać, że rejestrowane zmiany ciepła wywołane są na skutek procesu degradacji struktury w wyniku deformacji laminatu, procesów pękania osnowy i włókien wzmacniających, inicjacji i rozwojowi delaminacji, procesami tarcia oraz perforacją laminatu.

Słowa kluczowe: FML, uderzenie, NDT, termografia

INTRODUCTION

The dynamic loads on aircraft structures are widely described in literature [1-4]. The authors of published articles emphasize that this type of loads is of key importance for the condition of the structure and for the safety of its further operation. Impact loads may occur in the course of ground handling of airships, their take off and taxing as well as during the flight in collisions with birds, hail, falling tools, as well as collisions with loading and technical trucks, foreign bodies thrust by aircraft wheels and tyre wear [1, 5]. One of the basic issues associated with the improvement of composite materials operation safety in aviation in the scope of impact loads is their effective diagnostics by means of non-destructive methods and the application of impact resistant composite materials. Conventional composite materials reinforced with long fibres in a polymer matrix are characterized by relatively low resistance to concentrated force due to the brittle matrix and fibres [6]. The impacts, particularly low-velocity impacts (<10 m/s) may cause damages in the composite structure in the form of delaminations as well as extensive and numerous cracks in the matrix [7-10]. This type of damages leads to uncontrolled damage growth invisible on the macroscopic scale (BVID type damages) [2].

Therefore, effective diagnosis of their condition is essential for this group of materials. From the literature review, it was noted that non-destructive tests are relatively well known for conventional composite materials. Particularly ultrasonic and thermography methods ensure effective imaging of structural discontinuities, i.a. after impact [11-13]. Among others, fibre metal laminates characterized by relatively high resistance to impact due to significant impact energy absorption by metal layers belong to the state-of-the-art material solutions responding to the need to improve impact resistance [3, 5, 14]. However, it has been demonstrated that in FMLs, the structure is also characterized by damage propagating in the form of delaminations, composite matrix cracks and even perforations as a result of impact. The size and nature of the defect depends i.a. on impact energy [14]. Therefore, there is the need for effective diagnosis for fibre metal laminates. In contrast to conventional composite materials, non-destructive tests of FMLs are troublesome and often not effective enough to evaluate their condition after impacts [15-17]. Bisle et al. [18] described the issues associated with fibre metal laminates, concluding that this type of structures impede NDT diagnostic effectiveness owing to their hybrid nature. Components with different physical properties disturb the possibility to identify the signals received in the course of the test. However, it is assumed that ultrasonic and thermography methods are the most appropriate methods of non-destructive tests for the condition of FMLs [17, 18].

The purpose of the study was to evaluate the possibility to use the thermography method in the damage extent analysis for fibre metal laminates subjected to low-velocity impacts.

MATERIALS AND METHODS

The object of the research was the fibre metal laminates with R glass fibres (Al/GFRP) and high strength AS7 (Al/CFRP) carbon fibres in a matrix made of thermosetting resin. The metal component was made of 2024-T3 aluminium alloy, 0.5 mm thick. The laminates were produced in a 2/1 configuration (with two outer layers of metal filled with a composite with fibre configuration [0/90]). Al/composite adhesion was assured by chromic anodizing and next primer deposition. The laminates were manufactured in the Department of Materials Engineering - Lublin University of Technology by using the autoclave method [19].

The plates with dimensions of 100x150 mm were subjected to single dynamic impacts at a velocity within 2÷5 m/s by means of a spherical impactor with the diameter of 0.5” (12.7 mm).

The impacts were carried out at room temperature in accordance with the guideline included in ASTM D7136 [20] by means of a trip hammer (INSTRON DynaTup 9340) with impact energies of 5, 10 and 25 J.

The compactor penetration process into the material in real time was recorded by means of a thermovision camera (OPTPI450T900, Optris). The stand layout is illustrated in Figure 1.

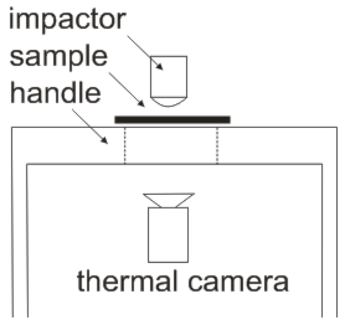

Fig. 1. Stand for low-velocity impact recording by using thermal camera

Rys. 1. Stanowisko do rejestracji uderzeń z niską prędkością z wykorzystaniem kamery termowizyjnej

The surface area of the damage was estimated on the basis of individual frames from thermovision recordings by means of image analysis software (Image ProPlus). The results were compared with the damage area determined by means of ultrasonic methods (MAUS System, Boeing) by the Air Force Technical Institute and by means of macroscopic observations of the external damage after impact.

RESULTS AND DISCUSSION

The nature of impact damage of modern fibre metal laminates is complex and it depends on the impact energy. Impact energy and force cause particular stages of damage growth. The stage of damage growth determines the failure mechanism [21-23].

The use of thermography techniques in diagnosing the composite material structure condition e.g. after impacts, is the subject of numerous studies being currently conducted [24-26]. From the literature, it was noted that the thermography method makes it possible to ensure the identification of inner damages in composite materials including FMLs. However, by using thermovision observations in real time, it is possible to gather additional information on material damage and to supplement the data with the local temperature change parameter (ΔT). The combination of the ΔT value with impact energy may be used to estimate the size and even to determine the type of FML damage. Examples of thermography images at the moment of impact and temperature distributions are illustrated in Figure 2.

The increase in local temperature of FMLs in the impact area were observed in both kind of laminates. In the case of the impact energies of 5 and 10 J on laminates with carbon fibres, the temperature increased by a few degrees which may indicate local damage in the laminates (mainly composite matrix cracks [2, 9, 10]). The temperature increased by 24°C in the case of the impact energy of 25 J which may indicate significant structure degradation [14, 27].

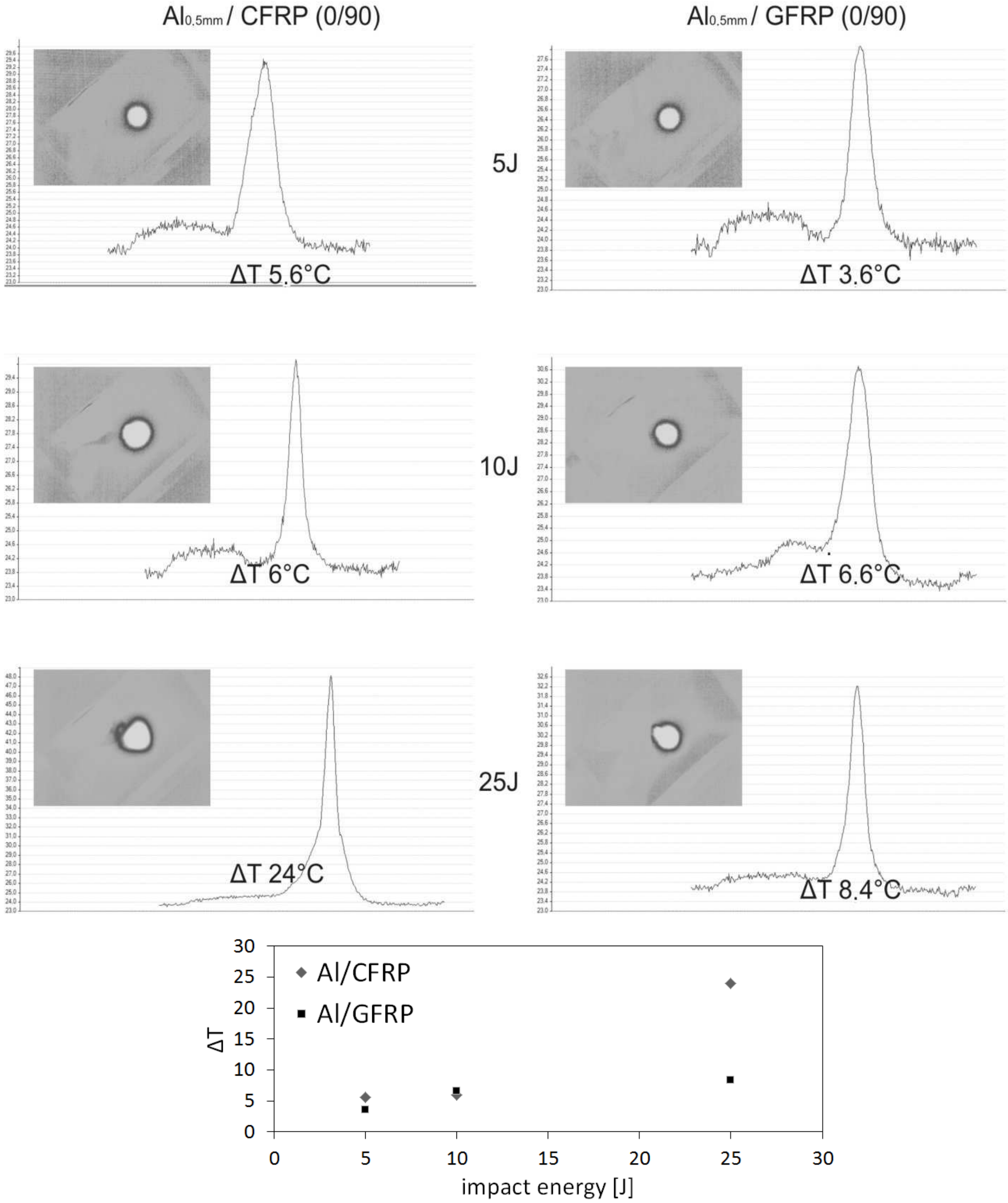

Fig. 2. Profile and growth value of temperature in impact area of FML depending on impact energy

Rys. 2. Profil i wartość przyrostu temperatury w obszarze uderzenia laminatów FML w zależności od energii uderzenia

The absorption of heat energy by the carbon laminate may be the symptom of aluminium cracks on the side which was not subjected to impact [14, 27]. An intensive and sudden temperature increase is accompanied by laminate perforation. An insignificant temperature increase in the Al/GFRP laminates depending on the impact energy indicates insignificant damage growth. In this case, insignificant heat growth is generated by insignificant damage progression. Additionally, this phenomenon can be associated with the lower thermal conductivity coefficient of glass fibres in comparison to carbon fibres. The observed temperature differences depending on impact energy may correspond to degradation phenomena occurring in the composite materials in the course of impacts.

On the basis of the analysis of thermal changes in the material and based on knowledge about FML damage after impact, it may be concluded that the thermal phenomena observed in real time can be associated among others with (1) material cracking energy (mainly in the composite matrix) transformed into thermal energy, (2) friction in the intermediate layers as a result of bending at impact and displacement of individual layers in relation to each other, (3) material plastic deformation with a determined velocity and (4) friction between the compactor and plate surface (less detectable on bottom side of the sample). The factors specified above (1-3) perform the principal role in the FML degradation process caused by impact and constitute a quantitative description of changes occurring in these materials in the course of impacts.

Therefore, it is possible to use local temperature change monitoring in critical elements as a diagnostic method for these elements in real time. In Figure 3, a comparison of damage surface areas measured using different methods is presented.

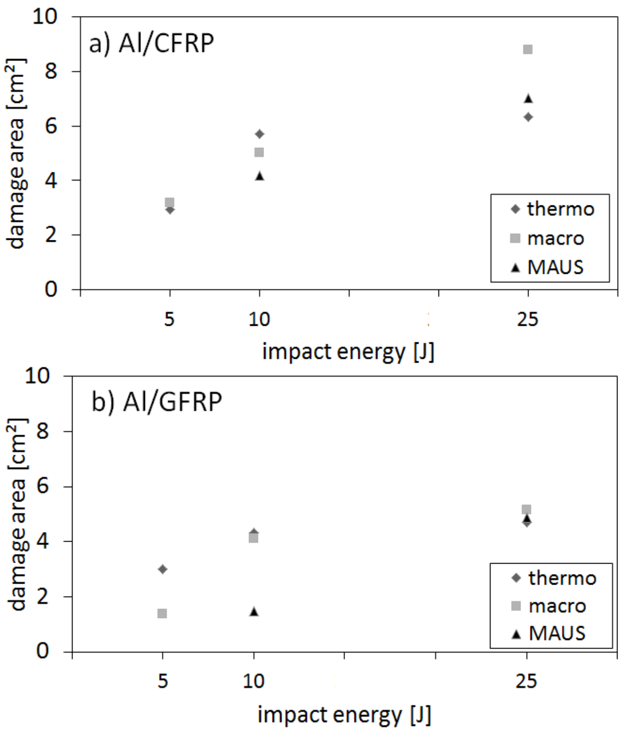

Fig. 3. FML damage area (a - Al/CFRP, b - Al/GFRP) measured with: thermography, ultrasonic and visual methods

Rys. 3. Powierzchnia uszkodzenia struktury laminatów FML (a - Al/CFRP, b - Al/GFRP) mierzona metodami: termografii w czasie rzeczywistym, ultradźwiękową oraz wizualną

On the basis of the presented results (Fig. 3), it may be concluded that the impact damage areas (measurements by means of three methods) of the laminates are relatively coincident, especially in the laminates with carbon fibre. The coincidence is the highest at lower impact energies. This fact may be caused by the increasing plastic deformation of the bottom laminate layer which disturbs discontinuities imaging in the ultrasonic and macroscopic methods. In the case of laminates with glass fibre, the coincidence is the highest in the macroscopic and thermographic methods. However, the coincidence is lower than in the case of the laminates with carbon fibre. This fact may be caused e.g. by the lack of perforations, extensive delaminations and relatively large plastic deformation area characterizing the impacts in GLARE laminates, in this energy range [27].

CONCLUSIONS

1. The thermography method may be used as a relatively effective method of damage identification in aluminium-carbon and aluminium-glass fibre laminates. It is possible to use local temperature change dynamics monitoring in FMLs as a diagnostic method for these elements in real time. With an increasing impact energy, the observed local temperature and damage area of the laminates also grow.
2. On the basis of the observation, it was found that in the aluminium-carbon fiber laminates, major thermal changes due to low-velocity impact in comparison to the aluminium-glass fiber laminates occur. This may indicate a lower impact resistance of aluminium-carbon fiber laminates and their greater susceptibility to degradation.
3. The energy absorbed by a laminate during the impact process is correlated with the process and type of laminate damage. It can be assumed that the observed thermal changes are caused by the degradation process of the structure as the results of deformation, matrix and fiber cracking, delamination initiation and propagation, friction and laminate perforation.

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