ACOUSTIC EMISSION DURING TENSILE TESTING OF COMPOSITE MATERIALS REINFORCED CARBON AND ARAMID FIBERS

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Abstract: This paper describes the prediction of material properties in composites reinforced with carbon or aramid fibres and its tensile testing. In course of tensile test the acoustic signal emission (AE) was recorded. Experimental results point to significant influence of fibre on mechanical properties of sample. AE gives the detailed overview of mechanical changes and durability thresholds in material structure in time course. With use of specialized software it is possible to interpret the AE signal to identify the current state of material integrity in real time.

Key Words: Carbon fibre, aramid fibre, acoustic emission, composite material, matrix

INTRODUCTION

Composite materials are fabrics manufactured from two or more phases, which are mutually different in their mechanical, physical and chemical properties. Usually one phase of composite is coherent, this is called matrix. Discrete phase is called reinforcement. Compared to matrix the support has usually significantly better mechanical properties (flexibility module, firmness, hardness, etc.) and its particular purpose is enhancement of said characteristics in the composite (Morgan 2005). Most notable advantage of composites with organic matrix is the synergic combination of easily formable fluid resin with firmness and toughness of supporting fibres (Jancar 1988). Synergism also means that characteristics of composite materials are better accordingly proportional summary characteristics of individual components.

Synergic performance of composite materials is characteristic with dampening the fissure break on matrix – support interface. The spreading fissure is diverted to different direction and also strong friction occurs between matrix and stretching fibres. Quality of matrix – support interface is of vital importance for resulting material properties. Composite materials are manufactured in manner to maximize the synergic effect (Cernohorsky 2006).

Acoustic emission is a physical phenomenon caused by plastic deformation in material accompanied by acoustic crackling or noise emitted inside the material structure. According to terminology coined in National technical standard (CSN EN 1330-9), the acoustic emission means elastic tension waves generated by dynamic release of mechanical tension inside the material or process causing the emergence of tension waves on the material surface (Pazdera et al. 2004). Acoustic emission method is term describing detection of acoustic emission, subsequent electronic processing of recorded signal and finally analysis of characteristics of detected AE signal (Dostal et al. 2011). Entire process of emergence and detection of AE consists of several steps: AE event, spread of tensile waves from source to detector, recording the AE with sensor, translating it to electric signal and finally assessment of electric AE signal with measuring system (Legendre 2001).

Advantage of AE is continuous observation of tested object and time saving factor ‘in comparison with subsequent multiple testing by other defectoscopic methods. Disadvantage could be seen in fact that cause of acoustic wave emission is still unclear, because emitted energy is influenced with a broad spectrum of factors including object shape and surface properties, trajectory path of wave conditioned by material homogeneity and structure, etc. (Kreidl, Smid 2006).

MATERIALS AND METHODS

For tested set of samples we proposed the shape and size according to National technical standard (CSN EN ISO 527–4), which defines the conditions and dimensions of objects subjected to tensile testing.

Samples have a rectangular profile measuring 250×25 mm. Material used in sample fabrication consists of carbon fibre, which has high firmness, flexibility module, heat resistance and fatigue resistance together with low specific mass. Aramid fibres have great capacity for energy absorption and are preferred for their low density, high sturdiness and firmness of fibre, which is caused by almost perfect orientation of strict linear macromolecules in longitudinal dispersion. These two materials combined with epoxide resin show best adhesion of fibres.

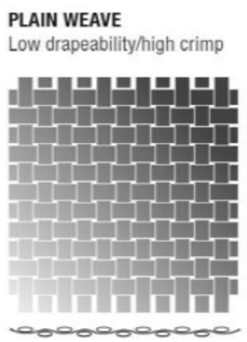
Used epoxy resin LG 700 allows the formation of very low weight laminates. Used hardener was HG 700 F with mixing ratio of 100:30. The fibres were procured from Carbonstar s.r.o. Composite characteristics are described in Table 1.

Table 1 Used material fibres for sample

Item	Weight (g/sqm)	Style	Material/Linear density		Thickness (mm)
			Wrap	Weft	
Style 624	65	Plain weave	carbon 67 tex	aramid 42 tex	0.14

Selected samples were constructed with use of plain weave. This is the basic type of weave. Bundles of fibre are regularly interwoven in perpendicular direction and have the fibre ratio 50% to 50%.

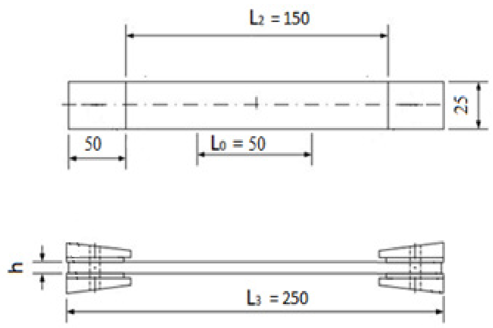
Figure 1 The most common version of bidirectional weave (plain weave)



Assessment of tensile characteristics according to ČSN EN ISO 527-4

Testing principle:
-Shear tensile load is transferred to object with terminal fittings
-Load is applied axially
-Test provides information on quality of fibre – resin connection

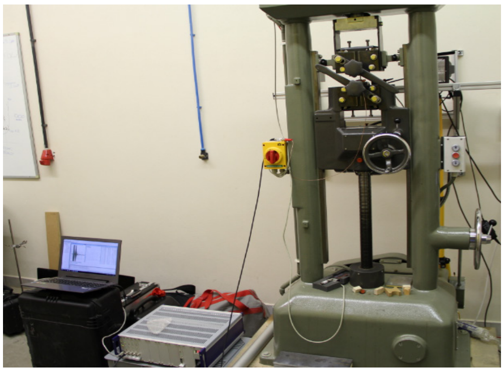
Figure 2: Normalized testing sample

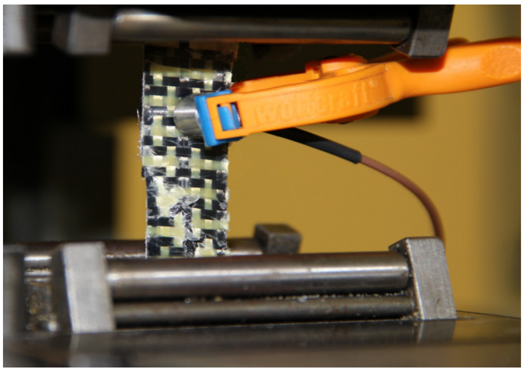


Legend: L_0 – measured length, L_2 – distance between the ends straps, L_3 – total length, h – thickness

For tensile testing of model composite sample we employed the Universal testing device ZDM 5/51. From previously conducted experiments we set the optimum speed to 5 mm.min^{-1}. Tested sample was fixed into clamps of testing device. After final check of proper settings of testing machine the tensile test commenced.

Figure 3 Testing device ZDM 5/51 for tensile testing (left, photo Author)
Figure 4 Fixation of AE pickup during the tensile testing (right, photo Author)





AE signals were captured in the test with one piezoelectric sensor (Dakel), fixed in upper sample part with clamp. Ultrasonic gel was applied on contact surface. Measuring of AE was conducted using Dakel XEDO measuring apparatus. Parameters are logged in Table 2.

Table 2 Configuration measuring apparatus XEDO

Parametr AE	Value
Sampling frequency	2 MHz
Gain sensor	30 dB
Gain (preamplifier)	30 dB
Value interval reach	± 2000 mV

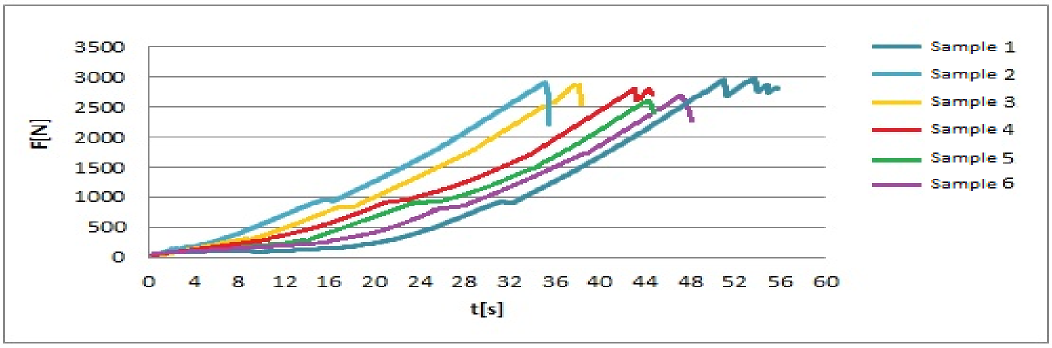
Root mean square (RMS) of acoustic emission was observed. This parameter describes the signal effective value. For alternating current the RMS equals to the value of direct current, which would show the same performance when subjected to resistance load. Units of RMS are mV. This value describes the quantitative characteristics of measured AE event.

RESULTS AND DISCUSSION

Tested samples showed differences in their performance, however insignificant. Figure 5 depicts values of firmness measurement. From graph it is obvious that shearing threshold occurs between 0.8–1.0 kN, which points to fact, that material shows lesser elasticity.

This decrease is relatively stable for all samples and occurs at certain force interval. Therefore we concluded that this phenomenon isn't caused by mechanical influence of testing device, e.g. deformation of sample by fixing jaws of testing apparatus in course of force load. Ends of samples show relatively mild indentures of self-clamping jaws. The curves report quite steep increase and don't show structures typical for soft material.

Figure 5 Tested samples - sturdiness of representative samples



Legend: F – force, t – time

Figure 6 shows the results of AE measurement in loaded samples. Parameters are assessed with median quadratic level of detected signal - RMS.

Figure 6 Record of AE test course.

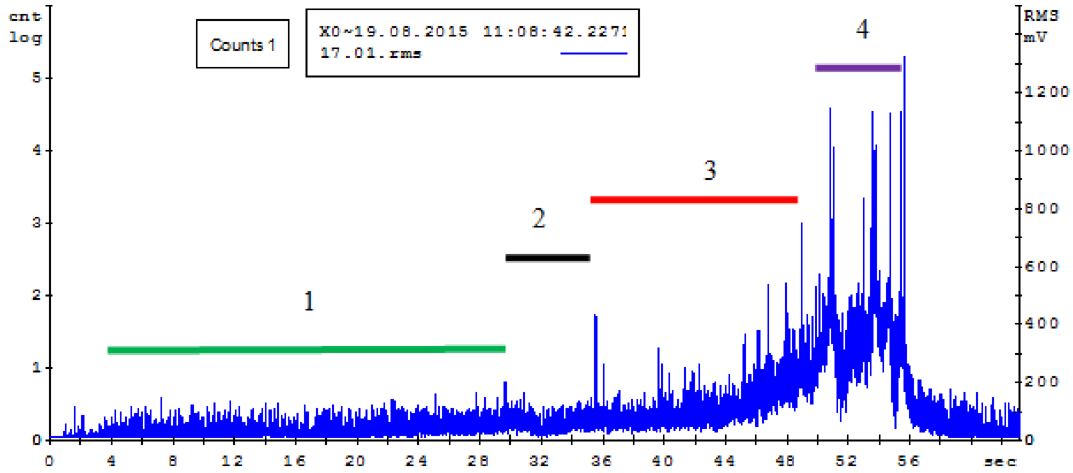


Figure 6 depicts the representative log of AE for sample no. 1, which shows four phases of AE signal.

1) The continuous destruction of matrix is observable - micro fissures emerge in matrix - mostly local disturbances, which are hard to detect. Fissures in matrix don't necessarily lead to serious reduction of mechanic characteristics of composite; however, they could precede the delamination, which is the serious structural damage.

2) Separation of matrix from reinforcement: the breaking suspense of the fibres is significantly higher than in matrix. When subjected to low load, small fissure emerges in matrix at point of highest load concentration. This fissure is either stopped by reinforcement, or surpasses the reinforcement without disturbance in weave. With increasing load the reinforcement and matrix start do deform divergently and their surface is subjected to high levels of shear force. When the force exceeds the critical level, the interphase separation of fibre from matrix occurs, possibly advancing for certain distance along the fibre.

3) Extraction of the fibre from matrix occurs most likely when advancing fissure in matrix is unable to cross the reinforcement fibre, meanwhile fissure occurring after breaking the fibre which is unable to spread further through the tough matrix. Direction of fissure is diverted and intensive friction occurs between matrix and extracted fibres. Process of fibre extraction is often accompanied with transformation of matrix.

4) Breaking of fibres in composite occurs for numerous reasons, every time after reaching their threshold reformation. In course of fissure spreading in direction perpendicular to reinforcement (under sufficient mechanical load) the fibres finally break, which significantly contributes to final breakdown of composite structure.

Other phenomenon deserving attention is the course of RMS in tensile testing. In one spot we can observe the local RMS level decrease, which indicates the change in otherwise gradually ascending trend of AE activity. It is possible that in this moment a change of adhesion quality occurred among carbon and aramid fibres and epoxy resin. When subjecting the composites to mechanical strain, extensive damage occurs in entire sample. These mechanical mechanisms of structural breakdown include plastic deformation of matrix, damage of reinforcement (tearing of fibres) and separation of individual layers (delamination).

Failure of sample structure is according to the endpoint of RMS curve, which indicates the stop of measuring apparatus after reaching the maximum load.

Pilot experiment conclusively showed suitability of proposed method, which is employable in future research on greater number of samples. AE pickup was fixed in simple and effective way. Configuration of measuring sequence was set correctly considering the expected characteristics of AE signal. Possible external sources disruptive AE signal were eliminated (testing device, sample fixating device). All samples reported reliable AE signal originating from structural changes in stressed samples. As confirmed in other AE applications, we conclude that non-destructive AE measurement provides priceless information of structural changes in stressed material.

CONCLUSION

Prediction of final composite product characteristics on basis of entry component parameters allows economical research and fabrication of composite materials in target applications (Dadourek 2007).

Regarding that every composite material is completed in product manufacturing, real material characteristics are strongly determined by used compounds, their composition and fabrication process. These characteristics are observable and measurable ex–post, on finalized product. This primary uncertainty brings difficulties into designing any structural and firmness calculations. For construction of quality products from composite materials it is necessary to comprehend the anisotropy of composite structures, including all possibilities of its organization, accounting for environmental influence on composite characteristics and strain of entire construction.

Mastering the technique for reliable prediction of material structure and characteristics of complicated composite materials enables the preparation of individually designed materials tailored exactly for specific purpose.

Final product is exactly fitted to demand. Selection of suitable materials for individual components, together with skilled dimensioning and shaping of construction parts enables fabrication of components with wide spectrum of improved mechanical, physical and other final characteristics.

ACKNOWLEDGEMENT

The research has been supported by the project IP 21/2015. "Monitoring of quality of composite materials in agricultural environment" financed by IGA AF, Mendel University in Brno.

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