Extended abstract
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ALTERNATIVE METHOD OF STRESS PARAMETERS DETERMINATION DURING TENSILE TESTS USING METRIC ENTROPY AND DIC

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1. Introduction

The paper proposes a combined method for the mechanical properties assessment of composite materials based on the analysis of the internal dynamics of raw data from uniaxial tensile tests. Determination of the Kolmogorov-Sinai (K-S) metric entropy from the recorded data enables to find the tensile strength of materials. A correctness of the methodology proposed was verified by the full-filed DIC measurements. The main aim of this research is to present the combination of two different research methods: classical, analytical determination of K-S entropy on the basis of measurement data captured from uniaxial tensile tests and optical full-field displacement measurements collected by means of digital image correlation technique.

2. Materials and Methods

The material tested was a glass fibres based thermoplastic Elium acrylic. Elium 150, acrylic resin was developed and provided by the chemical group ARKEMA. The glass transition temperature of Elium 150 is around 105°C ($T_g = 105°C$). The resin contains an acceleration agent (acrylic monomer) for activating the catalyst that causes a reaction of polymerization at ambient temperature. A bidirectional glass fibres fabric provided by Chomarat Textiles Industries were used as the reinforcement. The material consisted fibres intersecting themselves in the warp and weft directions. The fabric has the same properties along both these directions. The repetition period of the fabric pattern is $T = 7.8\ mm$ and its fabric mass area (surface density) is close to $ds = 600\ g/m^2$. More details of this material can be found in [1]. Since the composite containing of plain weave woven had the identical mechanical properties in the warp [0°] and weft [90°] directions, only two orientations, representing two different cases were selected in this study. The first group of rectangular-shaped specimens of 200 × 50 × 2.5 mm (Fig. 1) was cut out along the fibres direction, while the second one along direction inclined by an angle of 45° with regard to that of the fibres one.

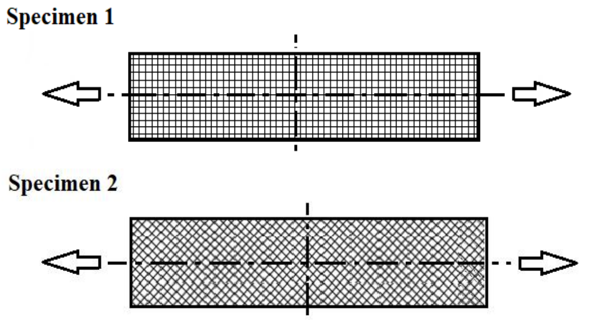

Fig. 1. Reinforcing fibres configurations in specimens tested.

A degree of physical and chemical processes' irreversibility is always expressed as a positive numerical value with the increase of entropy. According to Boltzmann, the entropy of the macroscopic state S is proportional to the thermodynamic probability. The relationship between statistical mechanics and chaos theory is reflected in the concept of the Kolmogorov-Sinai metric entropy [2, 3]. At the same time, Kolmogorov relied on the concept of statistical information proposed by Shannon [4], who describes the transmission of telecommunications signals. In this paper, the Kolmogorov-Sinai metric entropy for a discrete probability distribution is expressed by the formula:

$$S = -\sum_{i=1}^{N} p_i \ln p_i \qquad (1)$$

where: N - the number of sub-intervals into which the data set of measurement results was divided; p_i

- the probability of the results in i interval, (whereby by definition $p\ln p \equiv 0$, if p = 0).

If the sub-intervals are equal ($p_i = 1/N$ for every i), then the entropy is expressed by the formula $S = \ln N$ taking the maximum value, which represents a specific number. On the other hand, if it is known that the results fall within one particular range, then the metric entropy will take the minimum value of S = 0, because $p_i = 1$.

3. Results and Discussion

Figure 2 presents the uniaxial tensile curves for both specimen types, in conjunction with selected images obtained from the DIC optical method.

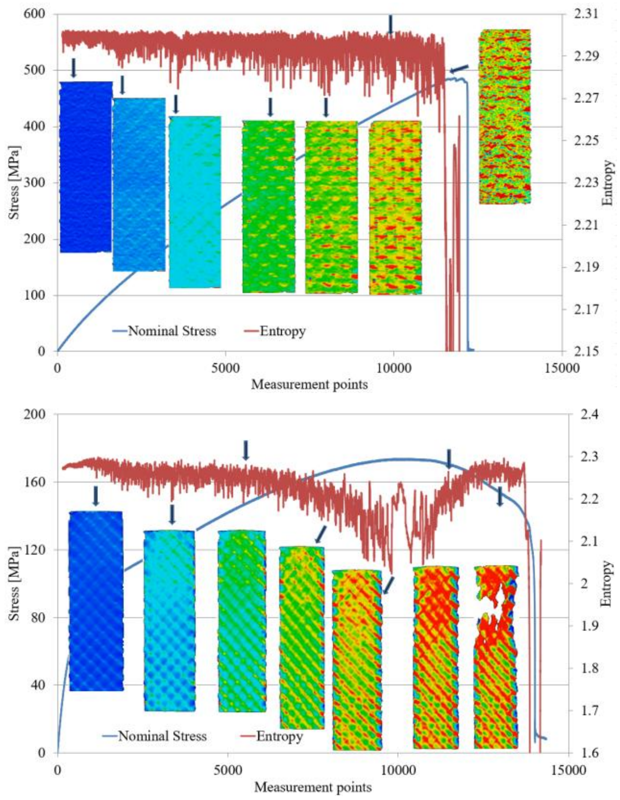

Fig. 2. Tensile curve in combination with K-S entropy diagram and DIC images as a function of measuring points for specimens 1 (top chart) and 2 (bottom chart).

The selection was made from approximately 1,000 images recorded for each specimen during the test. Stress, strain and DIC images were assigned to the successive measurement points. It was observed, that the specimen 1 is able to transfer stress more than twice as high as the specimen 2. Such behaviour of the material was related to the different location of the reinforcing phase fibres in relation to the direction of the tensile force. Deformation of the specimen 2 composite structure occurred at a much earlier deformation stage than in specimen 1. Also, the K-S entropy fluctuations of the nominal stress measurement data are more intense for this specimen. Moreover, the local minimum entropy correlates with the results elaborated on the basis of DIC images. A comparison of the ultimate tensile strength (UTS) values obtained by using different techniques was presented in Table 1.

Table 1. Comparison on ultimate tensile strength values obtained by using different techniques

	Ultimate tensile strength [MPa]	
	Specimen 1	Specimen 2
DIC	476	173
Extensometer	479	173
Entropy	476	173

The excellent agreement of these values indicates a great suitability and high accuracy of K-S entropy approach in determination of UTS. More details of this research can be find in [5].

4. Conclusions

Combination of the calculated K-S entropy and DIC measurements makes it possible to reflect basic phases of the tensile curve and objectively evaluate the selected mechanical properties of the composite material tested.

With regard to the composite in question, the proposed research methodology enabled determination of the correlation between the location of the reinforcing phase architecture in the matrix in relation to the load direction and deformation.

References

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