FINITE ELEMENT ANALYSIS OF STRESS TRANSFER IN CARBON NANOTUBE REINFORCED MAGNESIUM MATRIX COMPOSITES

KONEČNĚ-PRVKOVÁ ANALÝZA PŘENOSU TLAKU V MAGNEZIOVÝCH KOMPOZITECH VYZTUŽENÝCH UHLÍKOVÝMI NANOTRUBICEMI

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Abstract

A simplified finite element model was established to simulate deformation of carbon nanotubes (CNTs) reinforcing magnesium matrix composites during the tensile test. The stress and strain of matrix and reinforcement agent and the effect of interface on mechanical behaviour of composites were specially studied. The simulation results showed that for uniformly distributed CNTs a stress concentration occurs from the fibre axis towards the interface. The simulations proved that the destruction of the composites starts at the interface; what well coincides with the experimental results.

Abstrakt

V příspěvku je podán zjednodušený konečně-prvkový model deformace karbonových nanotrubic vyztužujících hořčíkovou matrici při tahové zkoušce. Speciálně jsou studovány napětí a přetvoření v matrici i ve zpevňujících komponentech, jakož i mechanické chování rozhraní. Simulační výsledky ukazují, že koncentrace tlaku působí od osy vlákna směrem k rozhraní. Destrukce kompozitu začíná na rozhraní s matricí, což je ve shodě s experimentálními výsledky.

Key words: CNTs, Mg matrix composites, Finite element method, ANSYS

1 INTRODUCTION

In short fibre composites, the loading does not affect on a fibre directly, but in the whole structure, because the matrix can transfer the loading from fibres to close ambient of fibres interfaces. Therefore, the coupling between the matrix and interface has a significant effect on the stress transfer. In order to better understand the influence of the interface on mechanical properties of materials, many researches on interface have been done [1-4].

At present, the metal matrix composites are considered to improve the sub-critical damage, which influences fibre breakage under the external forces. The critical phenomena depend on the mechanical bonding inside the matrix and between the fibres. If the interaction between fibres and their ambient was very tight, the reinforcement of fibres would significantly increase. Therefore, the requirements for the reinforced fibres are as follows:

1. Fibre with high strength and good toughness.
2. Good bonding between fibre and metal matrix.

The first premise means that mechanical properties of materials can ensure a sufficiently intensive transfer of external loads, the second one allows an enhancement of coupling between components in the whole structure. If these conditions are satisfied, the fibres act as an improving material of reinforcement.

The CNTs exhibit no changes for temperatures less than 937 K what indicates that CNTs are more stable than carbon fibres. The tensile strength of CNTs can reach 50 – 200 GPa, what is over 10 times higher than the one of graphite and 100 times higher than the one of steel. Moreover, their elastic modulus can reach 1000 GPa and bending rigidity 14.2 GPa [5-7]. Thus, we can assume the carbon nanotube as a kind of short fibre with a high strength (in accordance with the first condition; the problem is, whether it satisfies the second one).

Generally, the interfacial microstructures of composites are different in various composite systems depending on the method of preparation. They are not clearly understood until now, nevertheless there are seldom studies on the short fibre reinforced metal matrix composites.

2 FINITE ELEMENT MODEL

In this paper, a unit cell model is adopted to analyze the mechanical coupling between CNTs and matrix, when the metal material induces a macroscopic deformation. We suppose that reinforcing CNTs are randomly distributed in the matrix with a certain volume ratio. The CNTs are assumed as an elastic material, however, the matrix as an elasto-plastic one.

As the deformation of CNTs under the external force is far less than the one of the matrix, CNTs are considered as basic components during the finite element calculation. If the ratio of the radius of nanotube to the radius of matrix is 1:4, then the deformation around CNTs has a small effect on the far-field stress. Considering the sample under uniaxial stress, we use a simplified model of cylindrical volume element containing a section of CNTs (see Fig. 1), for which the 3D problem can be transformed into two-dimensional axis-symmetric one.

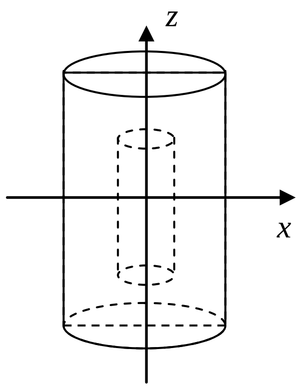

Fig. 1 Axis-symmetrical volume element scheme

In order to keep the grid symmetry in the case of oblique uniform far-field tensile stress, the loading of the representative volume element is transformed to the form as shown in Fig. 2 by relations [8-12]

$$\sigma'_{\mathrm{L}} = \sigma_C \cos^2\alpha, \qquad \sigma'_{\mathrm{T}} = \sigma_C \sin^2\alpha, \qquad \tau'_{\mathrm{LT}} = \sigma_C \cos\alpha \sin\alpha \,.$$

Due to the described symmetry of the problem, it suffices to consider only one eighth of the element. The axial and radial displacements u_z, u_r as well as axial and radial shears T_r, T_z satisfy the following boundary conditions:

$$u_z = 0, \quad z = 0, \quad ; \quad T_z = 0, \quad z = H_m / 2,$$
$$u_r = 0, \quad r = 0, z = 0 \quad ; \quad T_r = 0, \quad r = R_m .$$

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Here, H_m, R_m denote the axial length and radius of the modelled element, respectively. The prescribed tension applied at the top surface of the model along the direction *z* excites an uniaxial deformation.

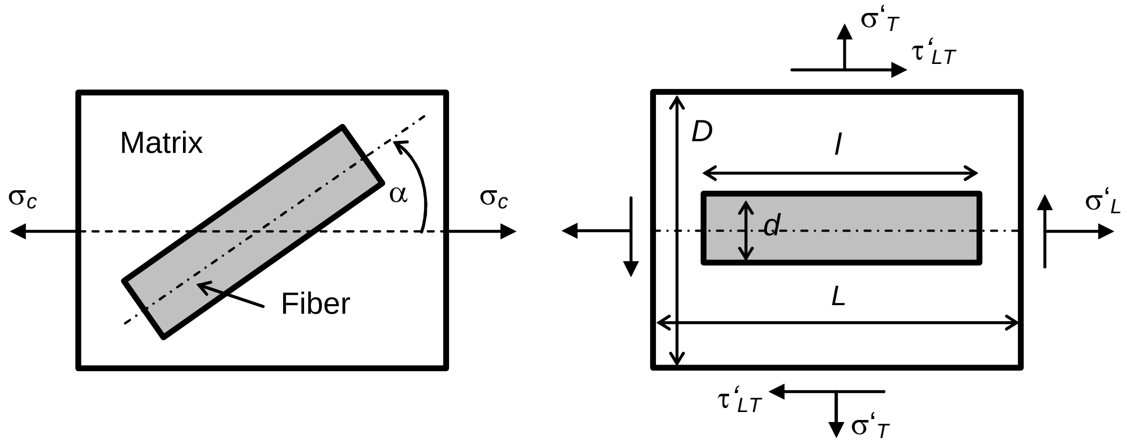

Fig. 2 The diagram of load transformation ($L = H_m$, $D = 2R_m$)

3 ANALYSIS AND DISCUSSION

3.1 Stress in CNTs

The computer simulation based on the finite element method was oriented to the deformation during the tensile test, thereby the ANSYS software was applied for a detailed analysis. In Fig. 3, the finite element discretization and diagram of deformation are shown, the dashed line represents the position after deformation.

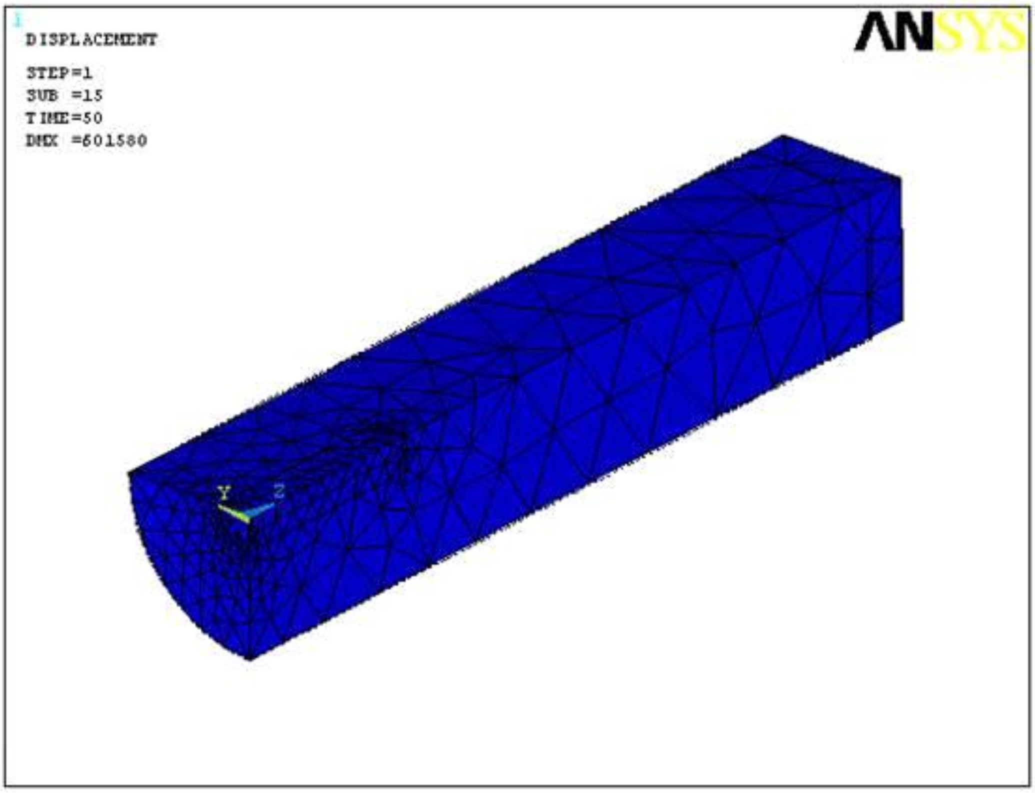

Fig. 3 Mesh diagram of elements and tensile deformation

When the elasto-plastic deformation of matrix occurs, the internal stress gradients are not remarkable, because they change in the same order as in axial direction. It suggests that CNTs are uniformly forced and no obvious stress concentration appears. The typical stress concentration can be observed only at the peripheral position of CNTs at the contact with the matrix. In other words, the magnitude of stress decreases from the centre in the axial direction, and, also decreases from the edge to the axis (Fig. 4a,b).

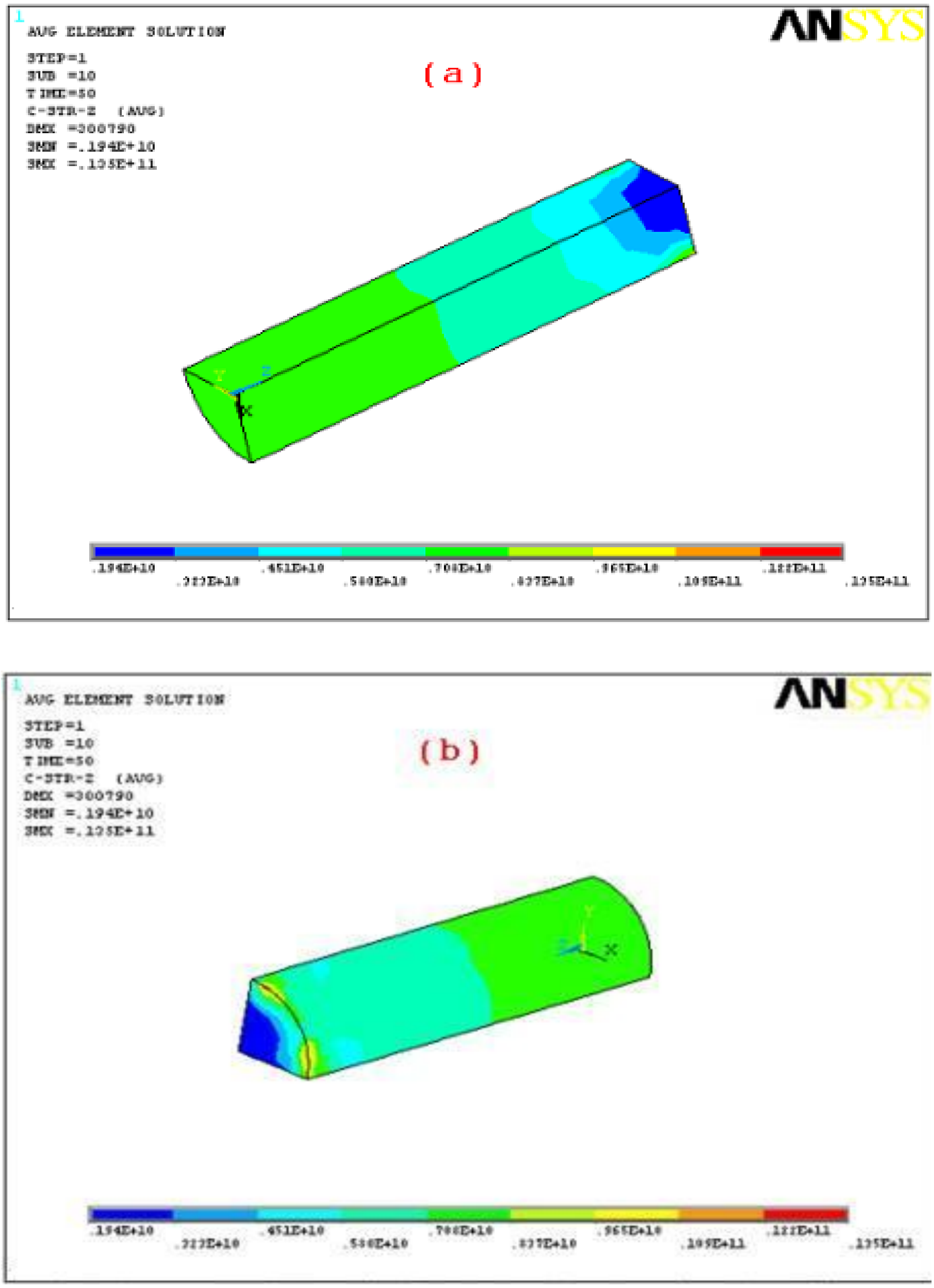

Fig. 4 Contours of effective stress in CNT

The effective stress dependence in Fig. 5 is computed for the front and back faces.

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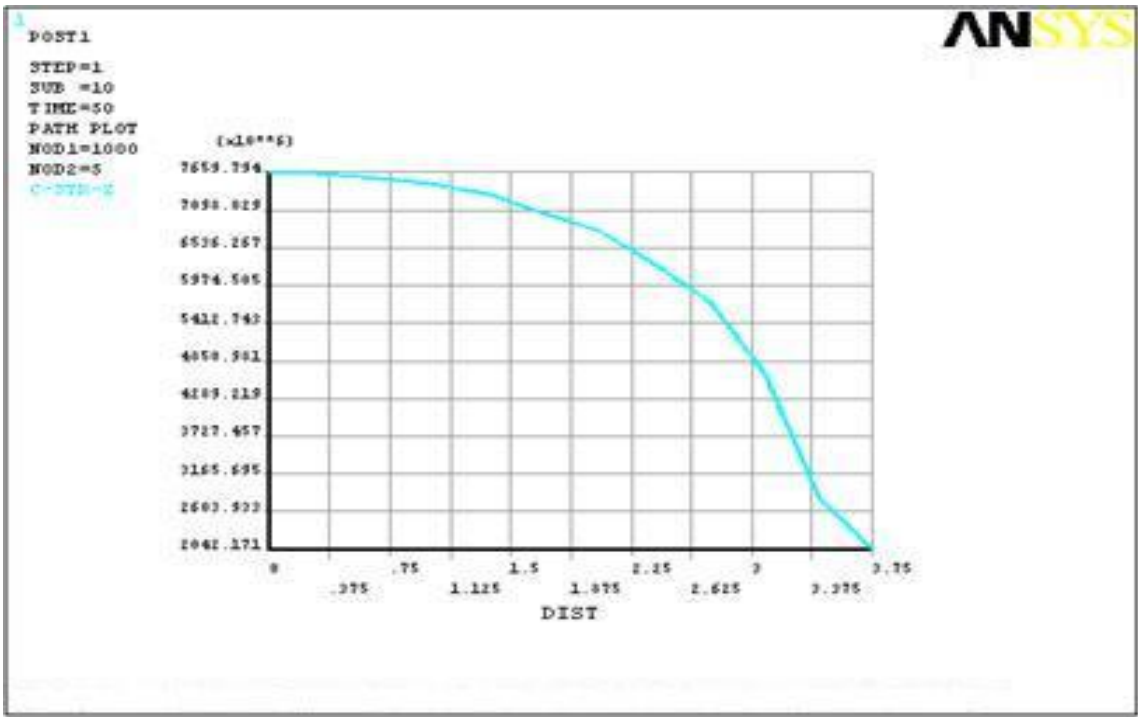

Fig. 5 Diagram of effective stress of CNT

3.2 Stress in matrix

At the contact positions between CNTs and matrix, the stress concentration is largest in the fibre centre and decreases towards the periphery. For the rest part of the matrix, the stress is extremely low (Fig. 6). In particular radial, at the contact positions between matrix and the CNT (2 mm from the centre), the stress sharply decreases in one half (Fig. 7).

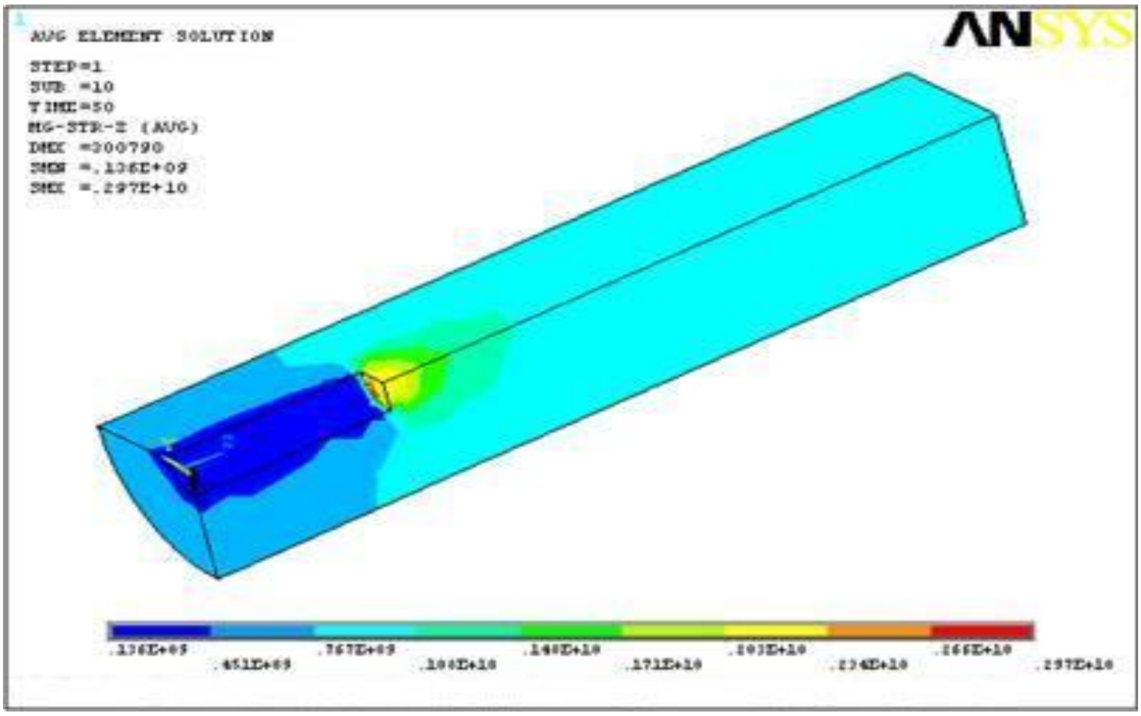

Fig. 6 Contour of effective stress of magnesium matrix

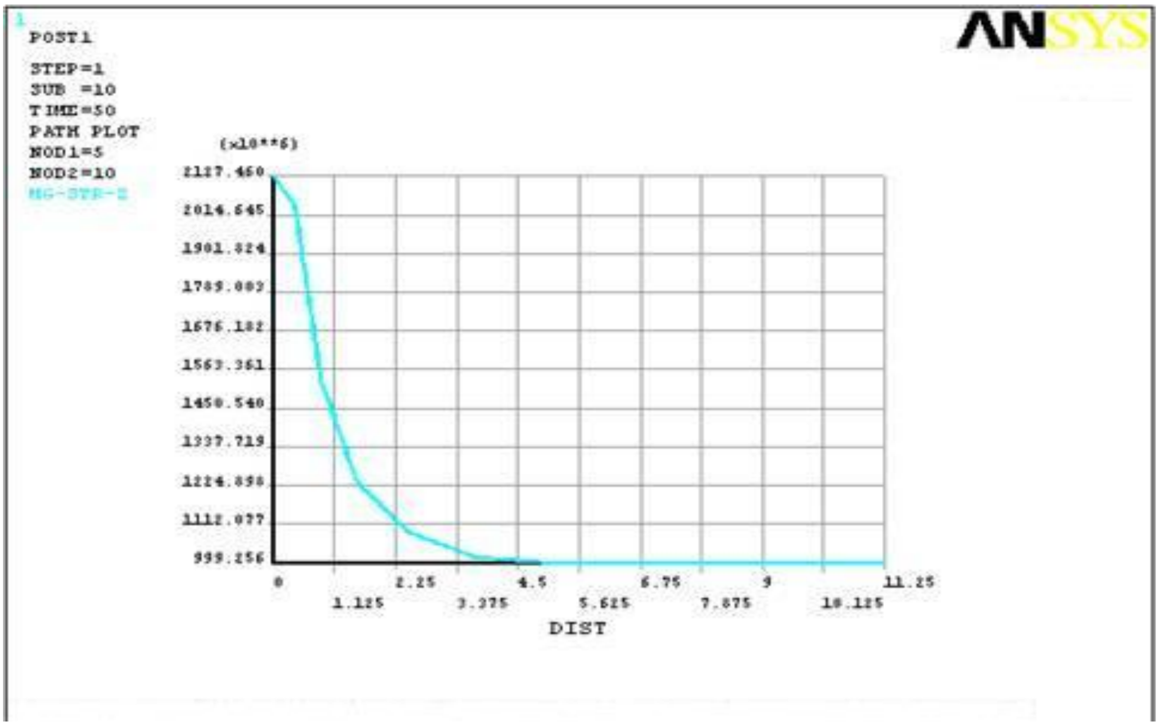

Fig. 7 Diagram of effective stress in magnesium matrix

4 CONCLUSIONS

The computer simulations of the CNT/Mg composite deformation within the tensile test were performed by the finite element method. For an axis-symmetrical model, the stress of matrix and reinforcement were specifically discussed. The simulation results showed that for equally forced CNTs the stress concentration occurred in the axial direction. It was estimated that the stress magnitudes are the largest in the centre with a successive decrease towards the periphery. The results proved that the composite destruction will start at the interfaces, and, the failure mechanism leads to the boundary separation.

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RESUMÉ

V příspěvku jsou prezentovány výsledky počítačové simulace deformace kompozitu tvořeného karbonovými trubicemi v hořčíkové matrici. Pro osově symetrický model jsou diskutovány tlak a napětí ve zpevňujících elementech kompozitu. Je ukázáno, že jsou-li všechny karbonové elementy namáhány stejnoměrně, koncentrace tlaku převažuje v axiálním směru. Přitom je největší v ose karbonové trubice a postupně klesá směrem k okraji. Z výsledků vyplývá, že případná destrukce kompozitu začíná na koncích vláken a mechanismus porušení spočívá v separaci rozhraní.

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