Identification of complex modulus using of the Hopkinson Split Pressure Bar.

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Abstract: A split Hopkinson pressure bar procedure was used for non-parametric identificon of complex modulus under conditions of non-equilibrium and axially non-uniform stress Tests were carried out with aluminium bars and with specimens of composite materials (Low viscosity epoxy resin and Baytube multi-walled carbon nanotubes) and having diameter 15 mm and length 7 mm. The influence of the nanotubes concentration on the dynamic response of given composites was evaluated.

Keywords: viscoelasticity; complex modulus; Hopkinson bar;

1 Introduction

Viscoelastic components employed for vibration isolation or shock absorption in automobiles, machines and buildings are often subject to a dynamic loading. From the dynamic design point of view, it is essential to be able to predict complex stiffness of the viscoelastic components accurately and efficiently, which requires, first of all, information about the complex modulus of the viscoelastic materials under operational environmental conditions.

The complex modulus represents the behaviour of viscoelastic materials in frequency domain [1] :

$$E^*(\omega) = E'(\omega) + iE''(\omega) \tag{1}$$

Where $E'(\omega)$ is the storage modulus and $E''(\omega)$ the loss modulus

There are many experimental techniques for the evaluation of this quantity. Most of these techniques are limited to relatively narrow band of frequencies [2]. In order to obtain the values of complex modulus in the broad extent of frequencies experimental methods based on the wave propagation in long bars were developed [3]. In many cases it is impossible to obtain specimens of the tested materials in form of long bars. This is a reason for the use of Hopkinson Split Pressure Bar which uses specimens of relatively small dimensions. This method is commonly used for study of the constitutive properties of materials under conditions of high strain rates and large strains [4]. For a SHPB test to be considered valid, it is required that several conditions concerning the specimen be approximately fulfilled, namely the stress equilibrium in the specimen. Because of the time and strain required to establish equilibrium, it is difficult to estimate the modulus of elasticity at high strain rates from a classical SHPB test . In specimens made of polymeric materials it is particularly difficult to achieve equilibrium because of the low wave speeds. For cases where the classical SHPB analyses do not give acceptable results, a parametric identification method [5] has been developed which does not require equilibrium or axial uniformity of stress and strain.

The aim of this study was to use this procedure, which does not require equilibrium, for non-parametric identification of the complex modulus of a viscoelastic composites.

Material and Experimental Technique

For the experiments composite material composed from the low viscosity epoxy resin BASF Mastertop P605 was used as the binder and the Baytube multi-walled carbon nanotubes C150P as the reinforcement were prepared. The main mechanical properties of the tubes are given in the Table 1.

Tab. 1: Properties of the Baytube MWCNT

MWCNT	Tensile strength [GPa]	E modulus [TPa]	No. of walls	Outer diameter [nm]	Density [kg.m^{-3}]	Length [µm]
C150P	>10	>1	3-15	5-20	150-350	1->10

Their distribution is shown in the Fig.1.

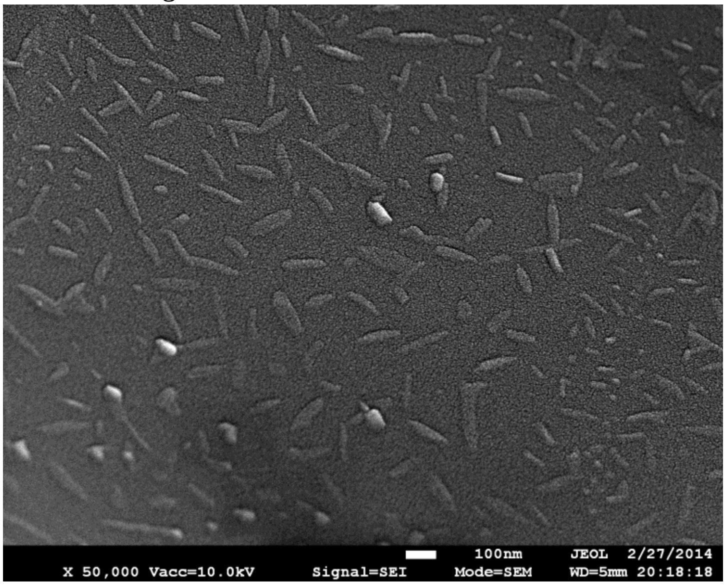

Fig.1: Distribution of carbon nanotubes.

The composites with different volume part of carbon nanotubes were prepared (1,2,3,4%). The different volume content was used to study the differences in mechanical parameters and behavior under blast load.

The main mechanical properties have been determined quasi static compression test. The results in the form of a dependence stress – strain are presented in the Fig.2.

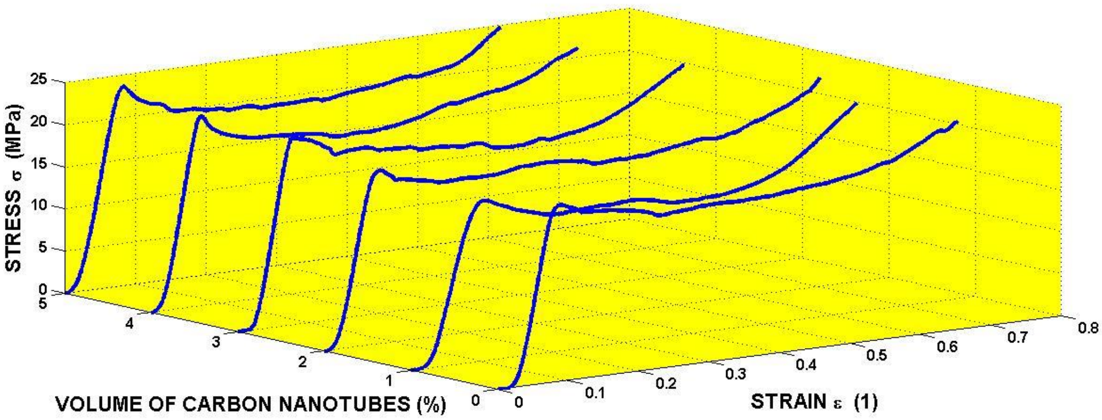

Fig.2: Stress strain curves at static compression.

It can be seen that the stress increases rapidly up to some value and than interval of nearly constant stress occurs. The content of the nanotubes does not influence the qualitative features of this dependence.The increase in the carbon nanotubes volume lead to some increase in the stress in the first region. In this region no permanent changes in the material structure occurs. The deformation is elastic and/or viscoelastic.

In the next step the dynamic response of the tested material was studied using of the split Hopkinson pressure bar (SHPB) technique. In this method a short test specimen is placed between two long bars, called pressure bars, and a wave is generated in one of the bars through axial impact – see Fig.3. with a striker bar. This incident wave propagates along the length of the incident bar until it encounters the specimen, whereupon the wave is reflected from and transmitted through the specimen. The wave reflected from the specimen is measured by means of a pair of strain gauges attached to the input bar, and the wave transmitted through the specimen is measured similarly by means of a pair of strain gauges attached to the output bar.

Experimental tests were carried out with bars made of Aluminium alloy. The behaviour of bars is linearly elastic. The penny shaped specimens ,15 mm in diameter and 7.5 mm in length were used.

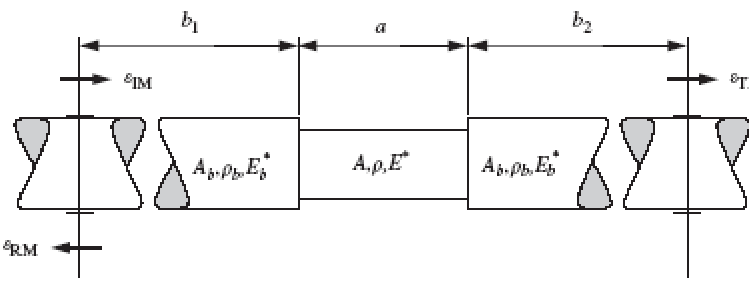

Fig. 3: Schematic of the central part of SHPB setup showing test specimen placed between two pressure bars.

Specimen with the different nanotubes volume were loaded by the stress pulses σ_I nearly of the same amplitude – see Fig.4.

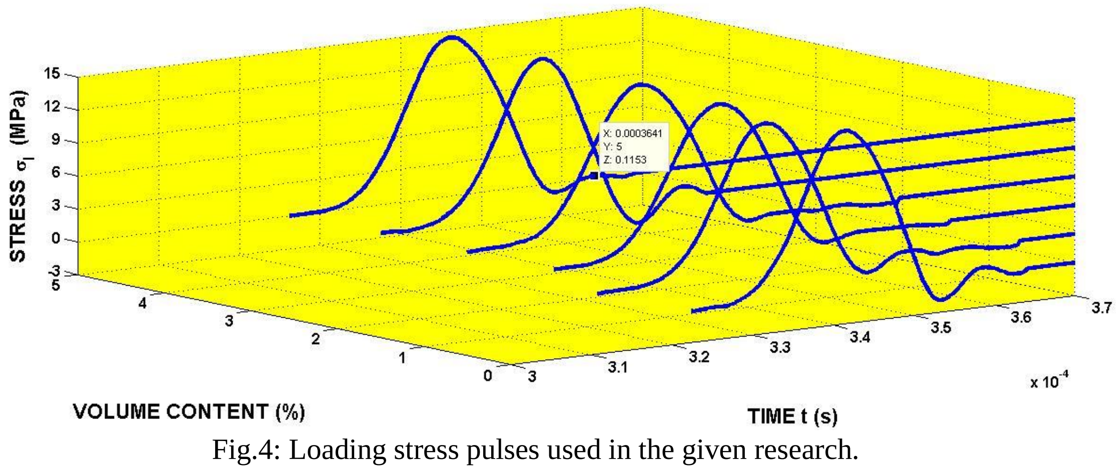

Fig.4: Loading stress pulses used in the given research.

The transmitted and reflected pulses were recorded.

Experimental Results.

The transmitted and reflected stress pulses are displayed in the Fig.5.

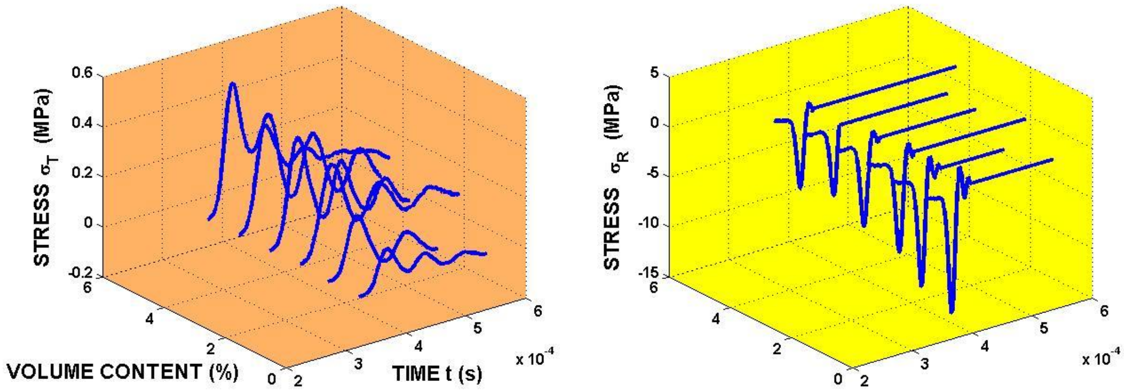

Fig.5: Experimentally recorded transmitted,σ_T, and reflected,σ_R,,stress pulses.

The classical evaluation of the given records follows in the determination stress,strain and strain rate in the specimen. This procedure is based on the assumption of the stress equilibrium in the specimen. This condition is very difficult to achieve namely in the specimen made from polymeric materials. In this case a new procedure was developed . By considering the propagation of waves in the bars and the specimen, and the continuity of velocity and force at the bar–specimen interfaces, one obtains the frequency–domain relation (Mousavi et al.,2005) :

$$\frac{\hat{\varepsilon}_{RM}}{\hat{\varepsilon}_{TM}} = \frac{1}{2}\left(\frac{Z}{Z_b} - \frac{Z_b}{Z}\right)\sinh\left(i\omega a\sqrt{\frac{\rho}{E^*}}\right)$$

where $\hat{\varepsilon}_{RM}$ and $\hat{\varepsilon}_{TM}$ are the Fourier transforms of the measured strains associated with the reflected and transmitted waves, respectively,ω is the angular frequency, and

$$Z = A\sqrt{\rho E^*} \qquad Z_b = A_b\sqrt{\rho_b E_b^*}$$

are the characteristic impedances of the specimen and the bars, respectively.

The use of this procedure is based on the frequency representation of the transmitted and reflected stress pulses. The representation of these pulses in the frequency domain is given by the Fourier transform. Owing to the fact that the bars behave linearly elastic we can use the identity :

$$\frac{\hat{\varepsilon}_{RM}}{\hat{\varepsilon}_{RM}} = \frac{\hat{\sigma}_R}{\hat{\sigma}_T}$$

Where $\hat{\sigma}_{R,T} = \int_{-\infty}^{+\infty} \sigma_{R,T}(t) e^{-i\omega t} dt$

The Fourier transform of the stress pulse is generally a complex function which can be expressed as :

$$\hat{\sigma} = |\hat{\sigma}| e^{i\varphi}$$

Where $|\hat{\sigma}|$ is the magnitude and φ is the phase.

Frequency dependence of the magnitude and phase is shown in the Figs.6 -8.

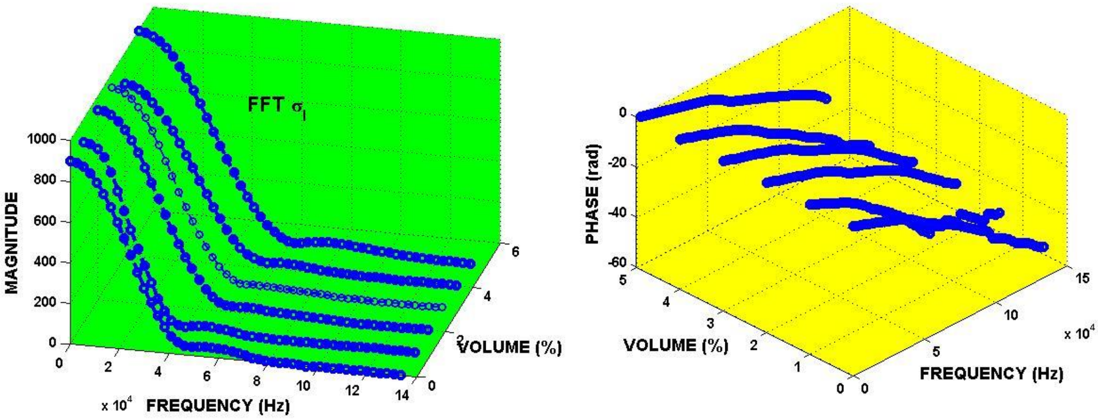

Fig.6: Spectral characteristics of the incident stress pulses.

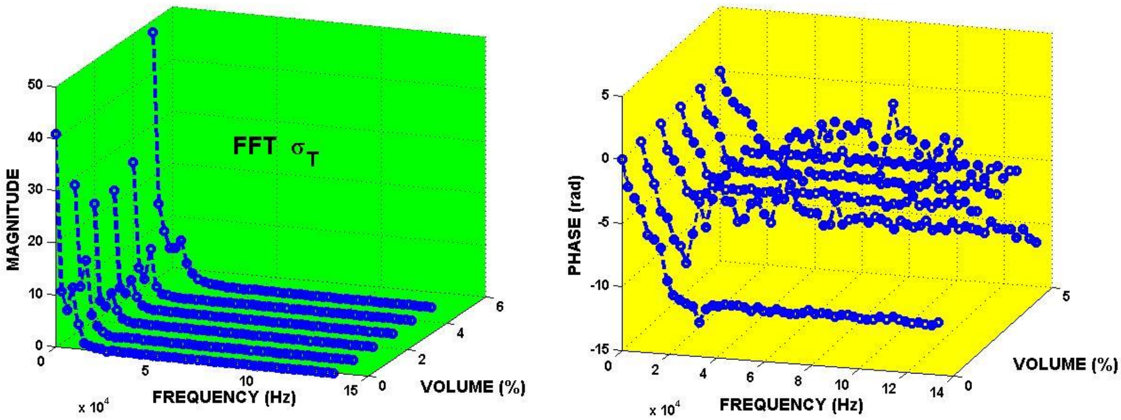

Fig.7: Spectral characteristics of the transmitted stress pulses.

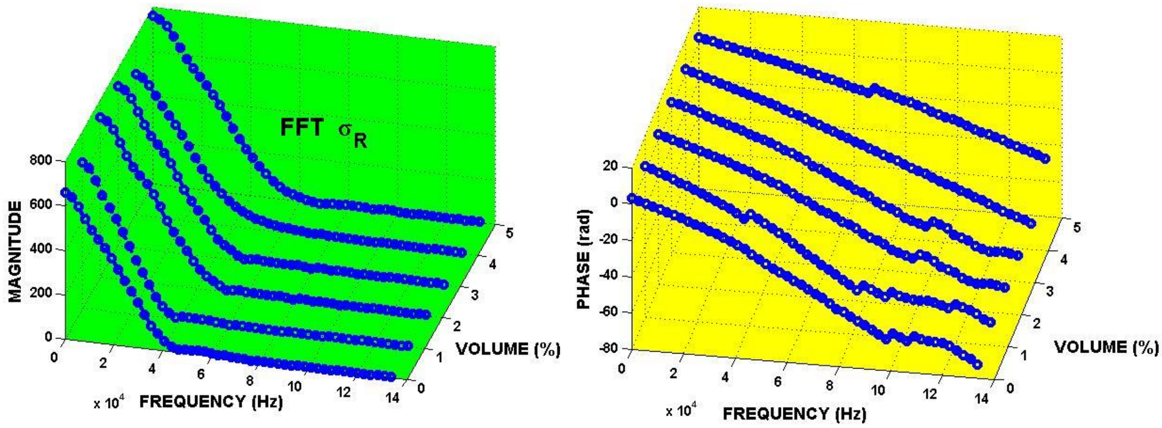

Fig.8: Spectral characteristics of the reflected stress pulses.

It is obvious that the most important are frequencies up tu about 10^4 Hz. Fig.8 shows the frequency dependence of the complex modulus for the specimens with the different volume content of the nano carbon tubes.

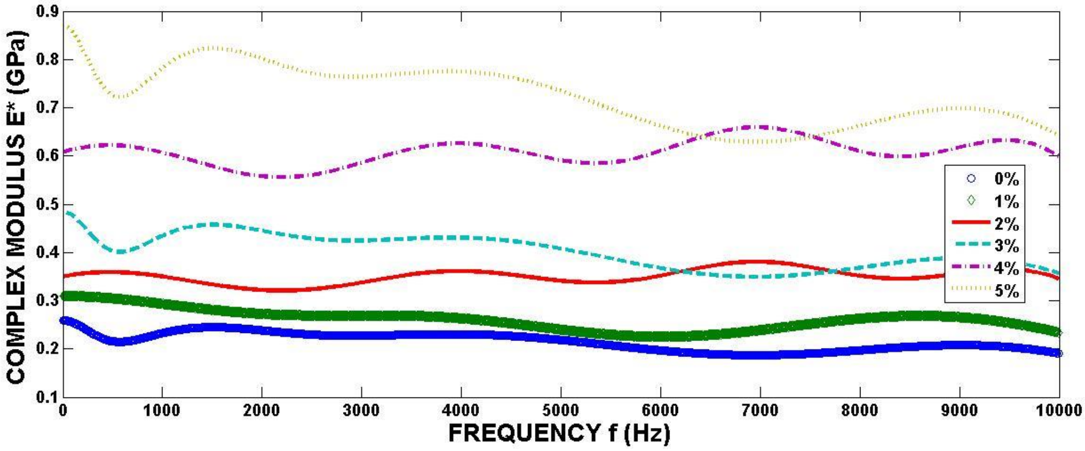

Fig.8. Complex modulus of tested specimens.

One can see that the complex modulus exhibits an oscillations. Its value increases with the value of volume content of nano carbon tubes for the most of frequencies. The detail analysis shows that the storage modulus E' is greater than the loss modulus E''.

Conclussion.

In the given paper a method method for identification of complex modulus using of the Hopkinson Split Pressure Bar technique was applied to the study of the dynamic response of composites filled bz nano carbon tubes. Spectral analysis of the waves reflected from and transmitted through the specimen was carried out to extract the complex modulus. Results show influence of the volume kontent of the carbon nanotubes on the value of the komplex modulus. At the same time the influence of the frequency is relatively less signifiant.

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References

[1] Nashif, A.D., Jones, D.I.G., Henderson, J.P., Vibration Damping. Wiley Interscience, New York (1985)

[2] Kulik, V.M., Semenov, B.N., Boiko, A.V., Seoudi, B.M., Chun, H.H., Lee, I., Measurement of dynamic properties of viscoelastic materials. Exp. Mech. 49, (2009) 417–425.

[3] Ahonsi B, Harrigan JJ, Aleyaasin M., On the propagation coefficient of longitudinalstress waves in viscoelastic bars. Int J Impact Eng .45(2012) 39-51.

[4] Gray III GT., Classic split Hopkinson pressure bar testing. ASM Handbook Vol 8, Mechanical testing and evaluation. ASM, 2000. p. 462–76.

[5] Mousavi,S.,Welch,K.,Valdek,U.,&Lundberg,B., Non-equilibrium split Hopkinson pressure bar procedure for non-parametric identification of complex modulus.Int.J.Impact Engng.31(2005)1133-1151.