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The fibre composite macroscale response to the impact force and its microscale structure

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Abstract. The paper provides the study of macroscale response of composites reinforced by long and short fibres to the impact force. The measured and analysed quantities are natural frequency and damping time. As the inner composite microscale structure can be of various modified configurations affected by production, we analysed influence to macroscale response.

1. Introduction

Economic reasons support the use of predictive methods for the study of dynamic behaviour of machines from the earliest stages of a design [1]. Dynamic response of material is in form of mechanical waves (vibrations) that propagate in continuum. Vibration is the oscillation of elastic body or environment where individual particles make mechanical oscillation [2,3]. In present, there is a great variety of the developing advanced materials and material combinations. Selection of the appropriate material for a specific machine structure is a crucial but challenging task [4]. Fibre reinforced and composite materials are particularly interesting for applications in machine tool structures due to their ratio of mechanical strength to density [4].

Moreover, the mentioned ratio influences the natural frequency and thus the dynamic properties that are so important for machine tools. Our research is focused on fibre composites and their reinforcing effect (more in [5]). As the composites consist of two or more distinct constituent phases (in our case fibres and matrix), they provide possibility to control their microscale structure in process of production and thus to control their directional mechanical (static and dynamic), also thermal, properties according to requirements, i.e. higher stiffness in required direction, high natural frequency, higher material damping in required direction, thermal isolator in required direction etc.

2. Measuring description

Figure 1 shows the measuring chain and samples of the fibre composites. To measure dynamic response of composites the sample is fixed into jaw of clamp of measuring stand on the one side and it is bumped by impact ball on the opposite side (figure 2). The vibrations (velocity of vibrations) caused by impact are measured by vibrometer Polytec. The impact ball rolls on the inclined groove of the measuring stand, then it impacts the sample (figure 2) by specific velocity applying the specific impact force on the sample.

The precise measuring of vibration velocity is based on a phenomenon of Doppler Shift in laser beam (laser-Doppler vibrometry). The light beam is reflected by moving surface and thus the frequency of light is shifted proportionally to its velocity. The accuracy of measurement is independent on reflected light intensity.

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To be able to make repeated measuring (accuracy of measuring) and impact the different samples with the same values of forces, the measuring stand was designed. It allows to change the angle *φ*, length of trajectory *l* and weight of impact body *m* (figure 2, equation (4)). Thus the value of force is affected.

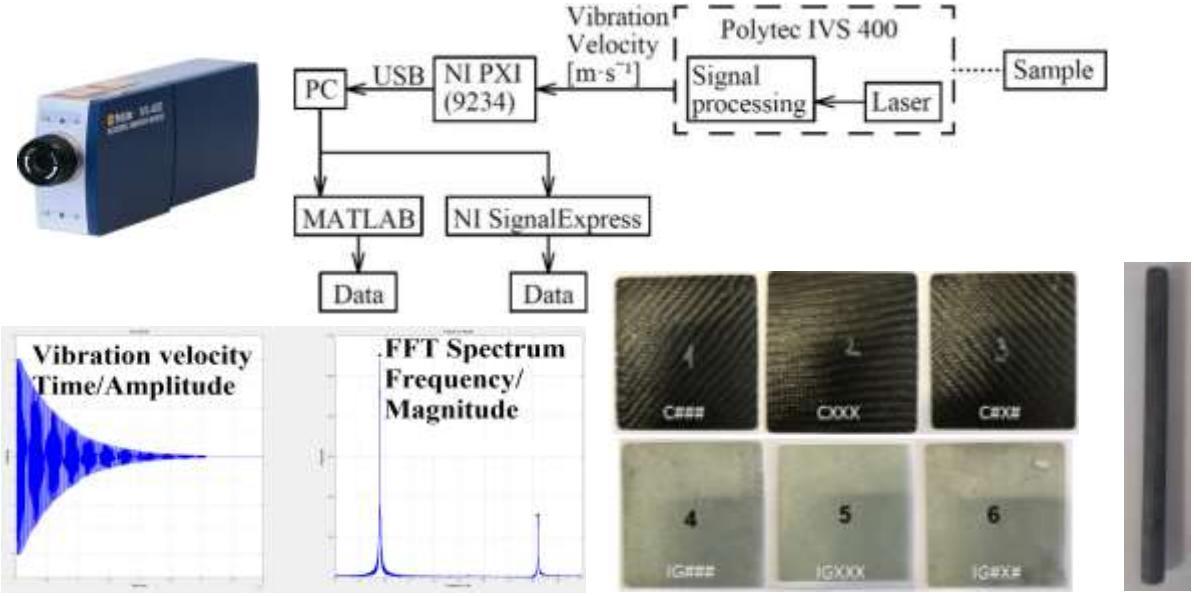

Figure 1. Measuring chain and samples

2.1Materials and dimensions of samples

1. Long-fibre composite (laminate): 3 layers, twill fabric, carbon fibres C200g/m^2, epoxy resin and fixative of mutual ratio 5:2;
    a. C###, fibres orientation parallel to the edges in all layers of the sample,
    b. CXXX, diagonal fibre orientation (45°) in all layers of the sample,
    c. C#X#, combination.
2. Long-fibre composite (laminate): 3 layers, twill fabric, glass fibres IG280g/m^2, epoxy resin and fixative of mutual ratio 5:2.
    a. IG###, fibres orientation parallel to the edges in all layers of the sample,
    b. IGXXX, diagonal fibre orientation (45°) in all layers of the sample,
    c. IG#X#, combination.
3. Short-fibre composite: ceramic composite, matrix Sic, carbon fibres in rovings 12k (1k=1000 filaments) of length 3-6 mm.
    a. SiC/C random, carbon fibres are randomly distributed,
4. Standard construction steel.

Dimensions of samples: Long-fibres composite: 115x115x0.9 mm; short-fibre composite: tube, Ø 8 mm, wall thickness 1 mm, length 110 mm; standard construction steel: tube, Ø 8 mm, wall thickness 2 mm, length 110 mm.

The fibres are usually oriented either randomly or preferably with unidirectional orientation or woven. The fibre composites can be reinforced by long continuous (continuous) and short (discontinuous) fibres. The criteria of classification are very coarse and needs to be clarified and completed. According to [6], if the aspect ratio, i.e. the ratio of the fibre length *L* to the diameter *D, L*/D is less than 100 (*L*/D <100) then the fibre is short. However, the diameter of nanotubes can be 5 nm and length even more than 1 mm, i.e. length to diameter ratio *L*/D is more than 200 000. Such fibres should be named relatively short fibres [5,7].

2.2 Impact force

Impact force for measurement was estimated according to theoretical method using several assumptions based on Newton's elementary theory of impact (according to [2]). In generally, the impact can be divided into two periods: 1st period starts with contact of bodies (collision) and finishes in moment of their maximum deformation when the bodies are moving by common velocity. 2nd period starts in moment of maximum deformation and finishes by separation of bodies. The large surface load appears in contact surface. The resultant force of surface load is impact force lying on the normal line of impact (figure 2).

The impact body (ball) of mass m moves downward the inclined groove with the angle of inclination φ (figure 2). The initial velocity at point A is $v_0 = 0$. After passing the trajectory l, the ball impacts a barrier (test sample) at the velocity v_1. The ball performs an inelastic (do not conserve kinetic energy) inclined impact on a fixed barrier.

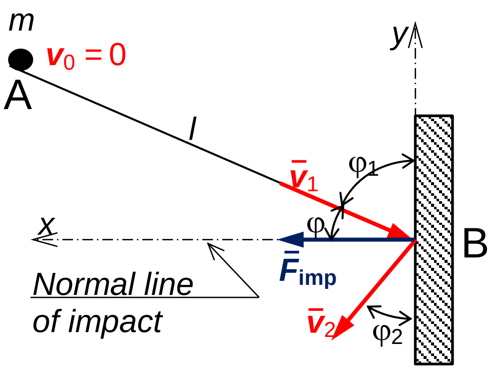

Figure 2. Schema of impact and experiment

The magnitude of the dynamic effect of the impact force on the body is expressed by the impulse of the impact force $\vec{I}_{imp}$:

$$\vec{I}_{\text{imp}} = \int_0^{\tau} \vec{F}_{\text{imp}}\,\mathrm{d}t = \int_0^{t_1} \vec{F}_{\text{imp}}\,\mathrm{d}t + \int_0^{t_2} \vec{F}_{\text{imp}}\,\mathrm{d}t = \vec{I}_{\text{imp1}} + \vec{I}_{\text{imp2}} = \vec{F}_{\text{imp}\,avg}\,\tau \qquad (1)$$

where $\vec{F}_{\text{imp}}$ is impact force acting on body, t_1 time of 1st period of impact, t_2 time of 2nd period of impact, $\tau = t_1 + t_2$ is time of impact, $\vec{I}_{\text{imp1}}$ is impulse of impact force in 1st period of impact, $\vec{I}_{\text{imp2}}$ is impulse of impact force in 2nd period of impact, $\vec{F}_{\text{imp}\,avg}$ is mean impact force.

Line of action of impact force is perpendicular to surface of object. The change of the momentum of the impact ball is only in direction of impact force. In direction of x-axis, the ball makes the inelastic direct central impact. Since the location of the test sample does not change, the common (centroid) velocity at the end of two impact phases is $v_s = 0$. For our case, based on (1) and the momentum change theorem, the impulse of the impact force in the first stage of the collision is in the x-axis direction (with respect to coordinate system in figure 2):

$$I_{\text{imp1}} = \int_{v_1}^{v_s} m\mathrm{d}v = m\left(v_s - v_{1x}\right) \quad \Rightarrow \quad I_{\text{imp1}} = -m\,v_{1x} \qquad (2)$$

Based on the kinetic energy change theorem, we determine the velocity of the impact body on the AB trajectory. The velocity of the impact body at the moment of impact is the following:

$$v_1 = \sqrt{2\,g\,l\sin\varphi} \qquad (3)$$

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Taking into account and adjusting the previous equations, we get a formula for the calculation of the impact force magnitude at the end of the first period of the impact:

$$F_{\mathrm{imp}}\, t_1 = \left| m\, v_1 \cos\varphi \right| \qquad \Rightarrow \qquad F_{\mathrm{imp}} = \frac{m \cos\varphi \sqrt{2\, g\, l \sin\varphi}}{t_1} \tag{4}$$

3. Results

The samples of long fibre composites are of different material configuration (described in 2.1) which cause the modification of natural frequency values and material damping time. The graph in figure 3, left, evaluates the measured first and second natural frequencies of samples based on the FFT (Fast Fourier Transformation) analysis of the measured vibration velocity values. The measuring was repeated by exciting the samples of four impact forces values (in direction of velocity v_1) 332 N, 680 N, 2917 N and 5978 N in order to obtain more reliable results. We found out some modification of natural frequency by material configuration, but the natural freqency is not influenced significantly.

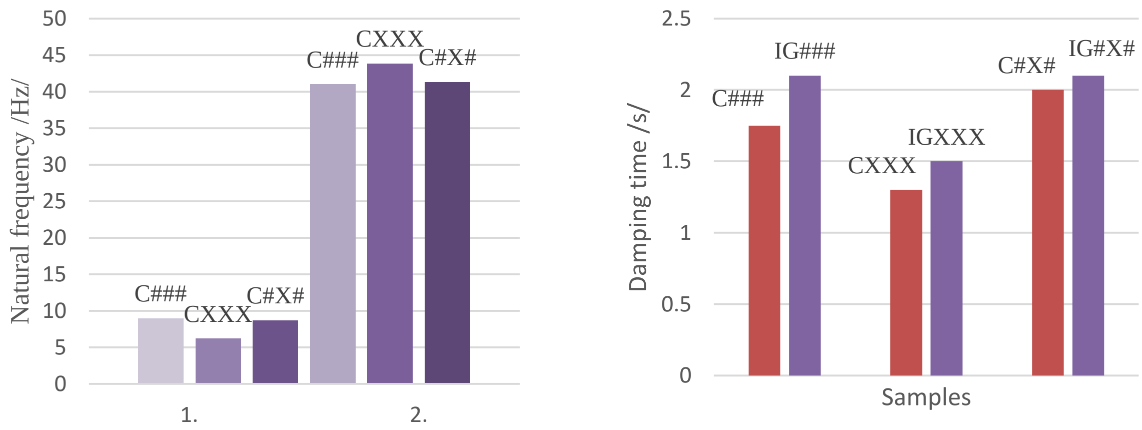

Figure 3. Natural frequency (left) and damping time

The samples of different material configuration are of different material damping time (figure 3, right). We confirm that the damping properties of carbon fibre composite are better comparing to glass fibre composite. The shortest damping time is for configuration XXX and even the configuration #X# make the damping time longest in that boundary conditions. We can make statement that the material configuration significantly change the damping time.

Figure 4 presents vibration velocity plot. The circles marks the jumps in plot. These jumps are of various size and in different time for individual samples. The detail of such jump involve the phase change, i.e. the distortion of waviness. We assume the reason of the phase change is interface layer-layer that shortens the damping.

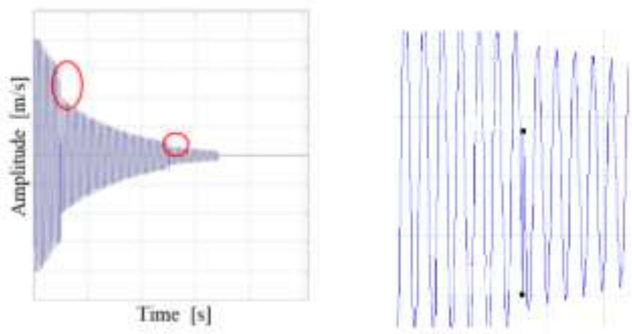

Figure 4. Amplitude of vibration velocity behaviour and detail

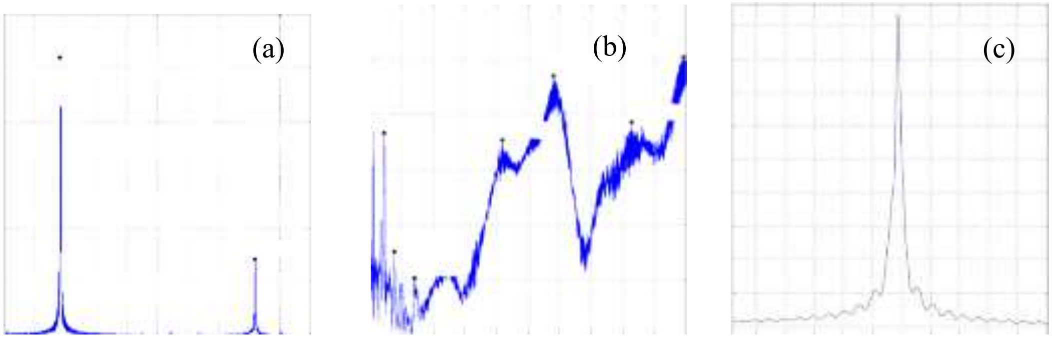

Figure 5. Typical courses of FFT spectrums (natural frequency/magnitude) of layered long fibres laminate, (a), short fibre composite (b), steel (c)

FFT (Fast Fourier Transformation) spectrums (figure 5) of layered long fibre laminate and steel is characterized by one sharp resonance peak comparing to several peaks of short fibre composite. These several peaks form the wide resonance range which cause the desired weak resonance phenomenon. Comparing FFT spectrums of both composites (figure 5, (a), (b)), the difference is visible. Mainly, the short fibre composites provide appropriate dynamic response because of high energy dissipation capability due to larger interface surface.

4. Conclusions

The study of various fibre (long and short) composites focused on impact load showed the specific and useful properties of fibre composites for dynamic load. Fibre reinforcement is beneficial for dynamic performance since the short fibre interfaces contributes energy dissipation.

We confirm that macroscale dynamic properties (mainly material damping) of fibre composites can be modified by microscale inner structure. It provide options to control macroscale dynamic properties through the microscale material configuration.

Acknowledgement

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References

[1] Genta G 2012 Vibration of Structures and Machines: Practical Aspects, 2nd ed., (New York: Springer-Verlag)
[2] Záhorec O and Caban S 2002 Dynamika (Dynamics) (Košice: Faculty of Mechanical Engineering, Technical University of Košice)
[3] Norton M P and Karczub D 2003 Fundamentals of Noise and Vibration Analysis for Engineer, 2nd ed., (Cambridge: Cambridge University Press)
[4] Möhring H C, Brecher C, Abele E, Fleischer, J and Bleicher F 2015 Materials in machine tool structures. *CIRP Annals-Manufacturing Technology*, *64*(2), pp 725-748
[5] Kompiš V, Murčinková Z and Žmindák M 2015 Toughening mechanisms for the fibre of middle-large-aspect-ratio-reinforced composites *Toughening mechanisms in composite materials*, ed Qin, Q H and Ye J (Cambridge: Elsevier; Woodhead Publishing) chapter 5, pp 137-159
[6] Jancár J 2003 Úvod do materiálového inženýrství polymerních kompozitu (Introduction to Materials Engineering of polymer composites) (Brno: VUT in Brno, Chemical faculty)
[7] Murčinková Z, Kompiš V, Adamčík P, Dobrovič S and Murčinko J 2017 Design of Fibrous Composite Materials for Saving Energy. *Handbook of Composites from Renewable Materials, Design and Manufacturing*, Vol. 2, ed Thakur V K, Thakur M K and Kessler M R (Scrivener Publishing Wiley), chapter 3, pp 49-93