Proceedings of the 29th Polish-Slovak Scientific Conference on Machine Modelling and Simulations 2024, Poland

Comparison of Dissipation Energy in PLA, ABS and PETG Materials Used in 3D Printing

B. Drvárová[a,*], L. Deganová[a], P. Novák[a], J. Zapomňel[b] and V. Dekýš[a]

[a] *University of Žilina, Faculty of Mechanical Engineering, Univerzitná 8215/1, 01001 Žilina, Slovakia*
[b] *VŠB — Technical University of Ostrava, Faculty of Mechanical Engineering, 17. listopadu 15, 70833 Ostrava, Czech Republic*

Doi: 10.12693/APhysPolA.145.810 *e-mail: barbora.drvarova@fstroj.uniza.sk

This paper presents the results of an experimental investigation of the dissipation energy for three types of composite material printed using the 3D printing technique. These materials are PLA (polylactic acid), ABS (acrylonitrile butadiene styrene) and PETG (polyethylene terephthalate glycol-modified). The fabricated samples were excited by pulse. The response of the samples was recorded non-contact using a portable digital vibrometer. The damping ratio of the samples was evaluated from the time signal and only the oscillation at the first natural frequency, which corresponds to the first bending shape of the oscillation, was considered. The logarithmic decrement method and the envelope curve method were used to process the measurements. The two methods were compared. After finding the damping ratio of the samples, the damping force with respect to the mass of the samples was calculated. Subsequently, the dissipation energy per unit mass was calculated. Finally, the results of the experimental measurement of the dissipation energy of the composite materials were compared.

topics: composites, dissipative energy, damping, 3D printing

1. Introduction

3D printing technology belongs to additive manufacturing. It is a modern way of creating three-dimensional (3D) objects based on a digital model. A prevalent method of 3D printing is FDM (fused deposition modeling), in which a thermoplastic material is extruded through a heated nozzle and deposited in layers until the final object is formed. In this paper, we will discuss the most commonly used materials designed for the FDM method of 3D printing, namely PLA (polylactic acid), ABS (acrylonitrile butadiene styrene) and PETG (polyethylene terephthalate glycol). PLA has a natural origin (e.g., from corn, potato, or sugar cane), so it is biodegradable and easy to print. ABS is an oil-based thermoplastic and has higher strength and elasticity compared to PLA. PETG is a combination of PLA (which is easy to print) and ABS (that has good mechanical properties). All of the above-mentioned composites differ in mechanical properties or printing methods [1]. In this paper, the damping ratio and dissipation energy of the samples made from the given composites will be compared. The processes in composite materials are different from those in metals and alloys. Damping in composites can be affected by damage, i.e., energy dissipation occurs in the area of cracks or damages in the fibres, or slip occurs at the fibre interface, creating damping due to friction, etc. [2]. The number of reviews focusing on this topic is limited, which makes it difficult to consider the damping of composite materials in design and analysis. The damping of composite materials has the potential to be several orders of magnitude higher than that of traditional materials, making them a more attractive choice for components subjected to dynamic loads [3, 4].

1.1. Samples for measurement

In Fig. 1 you can see the dimensions and shape of the composite samples. Each sample consisted of 25 layers whose orientation was 45° and −45° with respect to each other.

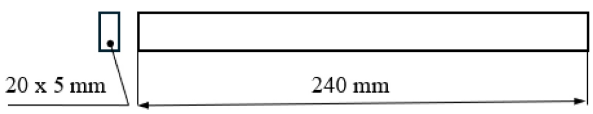

Fig. 1. Sample dimensions.

1.2. Methods used for the evaluation

Two techniques were applied to evaluate the damping ratio measurements:

(i) The logarithmic decrement method is used to measure the damping ratio from the time waveform of a signal. It can be applied to a system that oscillates, assumes viscous damping, and is built up in a pulsed manner. The sample is brought out of equilibrium and its instantaneous velocity, acceleration or deflection is sensed. The latter has following form

$$x(t) = A_0 \, \mathrm{e}^{-\xi t} \sin(\omega_d t + \varphi_0), \tag{1}$$

where A_0 is the initial amplitude, ξ is the damping ratio, ω_d is the damped angular velocity of the oscillation, t is time, and φ_0 is the initial phase angle.

Damping causes the amplitude of the oscillation to decrease exponentially with time. This drop can be detected by the ratio of two consecutive amplitudes. The value of the logarithmic decrement is then found by the natural logarithm of this amplitude ratio. The damping ratio is then calculated according to the relations that apply to the appropriate damping model used [3].

(ii) As can be seen the amplitude decreases exponentially with time according to the relation $A_0 \, \mathrm{e}^{-\xi t}$. Using the envelope curve method, the parameters of the given dependence can be found.

2. Experimental setup

In Fig. 2 you can see the workplace where the experimental measurement was performed. The composite specimen is woven against the rigid column (no. 1) using a clamp. A beam from the portable Doppler vibrometer — Polytec PDV 100 (no. 3) — was focused on its opposite end (no. 2). The reason why we used a non-contact measurement with the portable Doppler vibrometer is the light weight of the samples. By non-contact sensing of the sample response, we minimized signal distortion. We excited the sample at location no. 2 by deflecting it out of the equilibrium position and releasing it. Data were collected using an A/D converter NI USB-4431 analyzer. The collected data were further processed and recorded using a computer (no. 4) and SignalExpress software.

You can see the coordinate system at the response sensing location of the sample in Fig. 2. The individual layers of the sample were superimposed in the XY plane. The sample response was recorded in the Y axis. The first bending shape of the oscillation was the most excited. There were 10 measurements performed on each sample.

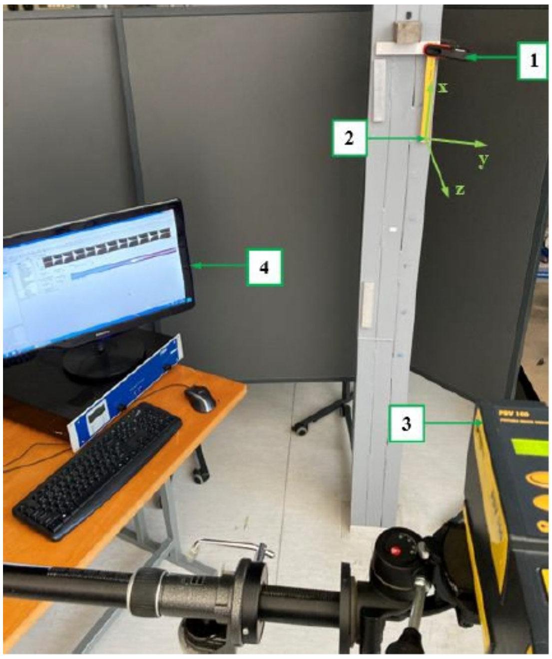

Fig. 2. Workspace for performing experimental measurements.

3. Processing the results of experimental measurements

From the experimental measurements, we obtained the time waveform of the signal. The portable Doppler vibrometer was used to measure the vibration speed of the sample end. The data obtained were analyzed in MATLAB software. First of all, we modified the signal so that it does not contain transient phenomena, but only a steady harmonic motion. To evaluate the damping, we used an interval in which the amplitude dropped from 400 to 50 mm/s. Evaluating the damping at lower amplitudes is not recommended because the signal may be loaded with noise. The MATLAB program created calculates the envelope curve parameters and determines the correlation coefficient. It must be around 99.9 for the curve to be considered optimal. It also evaluates the damping ratio obtained using logarithmic decrement. The average value of the damping ratio obtained using both methods and the deviation between the methods used can be seen in Table I.

Damping is essentially a mechanical property of materials that can tell us how much energy is lost during oscillation, i.e., how much energy is dissipated. For viscous damping, the damping force is proportional to the velocity of motion

$$F_d = -c\,\dot{x}, \tag{2}$$

where $\dot{x}$ is the oscillation speed and c is the damping coefficient. The negative sign in (2) means that

TABLE I

Measured damping ratio (ξ) and angular velocity (ω) for different materials.

	Unit	PETG	PLA	ABS
ξ_{log}	[-]	0.00374	0.00687	0.00800
ξ_{curve}	[-]	0.00370	0.00678	0.00797
$\Delta\xi$	[%]	1.17	1.2	0.3
ω	[rad/s]	151.83	166.38	159.95

TABLE II

Variables for calculation of the dissipation energy.

	Unit	PETG	PLA	ABS
c_{log}	[-]	0.0182	0.0339	0.0323
c_{curve}	[-]	0.0180	0.0334	0.0322
k	[N/m]	368.42	410.03	323.21
m	[g]	26.136	24.22	20.659

TABLE III

Magnitude of dissipation energy (E_{diss}) and standard deviation (std) for individual materials.

	Unit	PETG	PLA	ABS
E_{diss}	[J]	37.424	45.753	43.612
std	[J]	0.278	1.483	1.33
ΔE_{diss}	[%]	−14.19	+4.91	ref.

the energy dissipates with time [3, 4]. Using the damping ratio ξ, we can calculate damping coefficient, thus

$$c = 2\xi\sqrt{mk}. \tag{3}$$

where k is the stiffness of the sample and is calculated from the natural angular velocity of the damped oscillation, and m is the mass of the sample [5].

4. Results

Table II shows the partial results needed to calculate the dissipation energy. The dissipation energy is given by

$$E_{\text{diss}} = \int_0^T c\,\dot{x}^2(t)dt, \tag{4}$$

where T is the oscillation period and is the inverse of the natural frequency of the damped oscillation that we found in the measurement. We integrated 20 periods and then divided the result by 20. This result is more accurate. A computational model was also created and a computer simulation of the oscillations (modal analysis) was performed. The purpose of the modal analysis was to find out what part of the mass was oscillating, knowing that the sample was perturbed and that near the perturbation

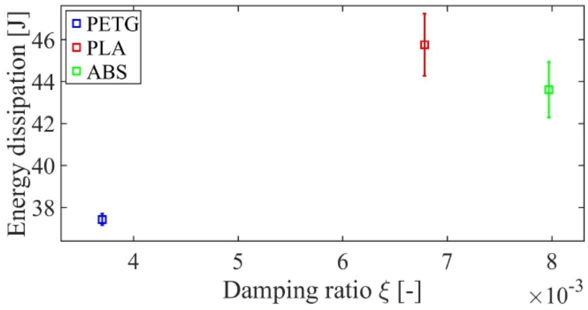

Fig. 3. Dependence of dissipation energy on the damping ratio.

the mass did not oscillate. From the analysis it was clear that only 61.15% of the mass of the rod was oscillating, which was also taken into account when evaluating the measurements.

We evaluated 10 measurements for each sample and then took the arithmetic mean of these results. The dissipation energy values for one oscillation period for each material can be seen in Table III.

In Fig. 3 you can see the dependence of the dissipation energy of the samples during the oscillation on the relative attenuation of the samples.

It is evident that the PETG samples have a much lower damping ratio and dissipation energy. This may be due to the fact that the PLA and ABS samples were printed at the same time. The PETG samples were printed approximately one and a half years earlier. This means that the samples were aged at room humidity and temperature. It can be concluded that ageing and humidity can have a significant effect on the damping ratio, but also on the dissipation of energy in the samples during oscillation. To verify this idea, measurements of the damping ratio and dissipation energy need to be made on the PETG samples that are about to be printed.

5. Conclusions

The paper aimed to provide an insight into the behavior of composites during oscillation. The results show that the energy dissipated during oscillation varies with the material. It was shown that the samples made of ABS material (ref. or reference value) have 4.91% lower dissipation energy than the samples made of PLA material. However, samples made from PETG material have up to 14.19% lower dissipation energy than ABS (ref.) samples. The dissipation energy of PETG samples is significantly lower than that of the other two materials. As mentioned, the PETG material samples were significantly older. Thus, it is up for consideration how much influence aging and moisture have on the damping ratio or the dissipation energy produced by oscillation on the composite samples.

Acknowledgments

This work was supported by UNIZA grant system, the project entitled "Research on damping of composites, polymers and metallic materials", KEGA 011ŽU-4/2022 and VEGA 1/0753/24.

References

[1] B. Ryder, *The 3D Printing Holy Trinity: PLA, ABS, and PETG*.

[2] Y.A. Parvez, S.S. Abuthakeer, in: *Materials Today* **44**, 1794 (2021).

[3] C. de Silva, *Vibration: Fundementals and Practice*, CRC Press LLC, 2000.

[4] S.S. Rao, *Mechanical vibrations*, 5th edition, ISBN-13: 978-0-13-212819-3, Pearson Education, Prentice Hall 2004.

[5] A. Bilošová, *Aplikovaný mechanic jako součást týmu konstruktérů: Část modální zkoušky*, ISBN 978-80-248-2758-2, VŠB Technická univerzita Ostrava, Ostrava (2012).