

# The vibroisolation effectiveness of fiber reinforced natural composites compared to the elastomer materials produced from non-renewable resources

Arkadiusz Pawlik<sup>1,\*</sup>, and Stanisław Frackowiak<sup>1</sup>

<sup>1</sup>Faculty of Environmental Engineering, Wrocław University of Science and Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

**Abstract.** In this work, a number of test were carried out to evaluate the effectiveness of the vibroisolation composite consisting of a biodegradable polymer matrix (polylactid actid, PLA) and filler in the form of natural flax fibers, with a moisture content of 2.03% after drying in 80°C for 4 hours. To improve material dampening properties, PLA was plasticized with polyethylene glycol (PEG 400) and triethyl citrate (TEC). The flax fiber content of the composite was: 10, 20, 30 wt.%. Mechanical properties at bending and tensile were performed. For measurement of vibroisolation effectiveness, composite samples have been made the enable installation in the measurement system. The measuring system consisted of an unbalanced axial electric motor, resting on a steel frame placed on vibroisolators. For comparison the commercial grade vibroisolators were used. In order to evaluate the vibration damping of the system by vibroisolators, vibration engine frame vibration was forced by acceleration of the engine's rotational speed to specific frequencies. It has been proven that the type of the plasticizer used in the composite changes the vibroisolation parameter. Also length and weight% of the fibres results in lower material damping values.

## 1 Introduction

Vibration absorbers are an important part of the mechanical devices designed for versatile usage in any system where vibrations occur. Their role is to protect equipment or surrounding by dampening or absorbing vibrations various different machinery during their work cycle [1–4].

The most commonly used material for this type of application is rubber. Rubber springs working as an elastic component of an absorber can withstand multidirectional load and has decent absorption in high frequency vibration range. Metal-rubber components are widely used as an inexpensive mean to prevent propagation of harmful vibrations [5–9]. However,

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\* Corresponding author: [arkadiusz.pawlik@pwr.edu.pl](mailto:arkadiusz.pawlik@pwr.edu.pl)

in time their properties begin to deteriorate and eventually they end up as a waste, which can undergo mechanical recycling or landfilling [10–13].

In recent years there has been a great interest in the development of natural, possibly biodegradable, materials. Polymers, blends and various composites [14–16]. Natural polymers and fillers have great potential due to their low density, low price, good mechanical properties and most importantly biodegradability which allows the end consumer to dispose such material in a composting facility without polluting the environment. In order for a waste to be accepted for composting process it has to fulfil strict requirements such as not emitting any toxic compound during the biodegradation nor changing the compost parameters (pH, composition etc.) beyond allowed limits [17]. Therefore no metal fractions, non-biodegradable polymers nor fillers are suitable for this type of waste utilization.

Applications of biodegradable polymers in different areas i.e. packaging, construction, medical and others, have been closely investigated for several years [18–24]. One of the most well developed polymers is polylactid acid which presents a very promising alternative to conventional fossil fuel based polymers. It has good mechanical properties (similar to polystyrene), is fully biodegradable, biocompatible, of good chemical resistance and derived from renewable resources (e.g. corn starch) . Due to recent improvements in production technology it has become much more affordable for even low price applications. Mechanical properties of PLA are similar to those of polystyrene. It is a brittle (by comparison) and stiff material with typical elongation at break of 5%. There were many attempts to improve its properties to be more competitive with more flexible polymers (polyethylene or polyethylene terephthalate) by blending with biodegradable polymers or copolymerization with other polyesters [25–30]. One of the economically viable option is adding plasticizer which can greatly improve the mechanical properties of the end material and provides a time stable biodegradable blend that can later be used to produce other composites with properties tailored for specific application [27].

Furthermore with increased environmental consciousness of the society and with the reducing feedstock of non-renewable resources it has come for natural biodegradable composites to broaden their applications range including vibration dampening.

Plant fibers are a well-known building material for centuries, and due to their multiscale structure they have also a good potential for this type of applications. In this paper we have used flax fibers. They are composed of single fibers embedded in a pectin matrix creating a natural energy dissipating structure. Therefore embedding this complex structure in the biodegradable polymer can lead to creating a biodegradable man made vibration absorber.

## 2 Materials

Composites were prepared by melt mixing of polymer matrix, PLA 3052D from NatureWorks, with flax fiber of 4mm length received from Ekotex Poland. For improving polymer mechanical properties, two types of plasticizers were used. Poly(ethylene glycol) (PEG | MW = 400 g/mol) and triethyl citrate (TEC | MW = 276.28 g/mol) from Sigma Aldrich.

### 2.1 Composite and vibration absorbers preparation

Composites were prepared in two groups, depending which plasticizer was used. PEG or TEC, both of 10 wt.%. Each polymer-plasticizer system was used to prepare composites with filler weight ratio of 10, 20 and 30%. Materials were prepared by melt mixing using Thermo Scientific Polylab QC equipped with internal mixer. Processing temperature was set to 160°C and rotor speed of 80 RPM. Mixing time varied depending on on-line torque measurements

– when torque value reached equilibrium (after ca. 6–7 minutes) the compounding process was completed.

### 2.1.1 *Vibration absorbers*

Material obtained by melt mixing was converted into granules (ca. 5 mm in diameter) using mill for plastics (Wanner Technik GmbH). Absorbers were prepared using the press molding technique. Material in the form was initially compacted and the form inserted into a heating chamber with the temperature of 190°C under a constant pressure of  $25.5 \times 10^3$  Pa. Pressing time was 50 min.

After the process the form was water cooled and the sample removed. For every material composition four identical samples were prepared. The press molded samples were in a form of a cylinder with the H/D of 90/50.

## 2.2 Composite and vibration absorbers preparation

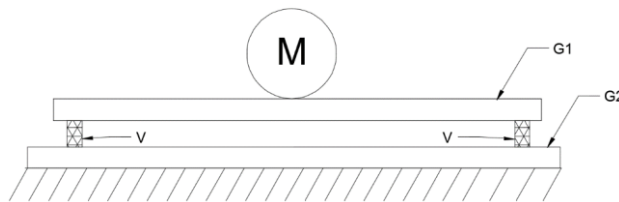
### 2.2.1 *Mechanical properties*

Mechanical properties at uniaxial tensile were evaluated at room temperature using the universal testing machine Lloyd 10K (Lloyd Instruments). Samples for tensile and bending tests were prepared according to ISO 3167 by injection molding using the laboratory injection molding machine from Proma-Torun. Process parameters were as follows: cylinder temperature of 160°C and injection pressure of 8 bar for beam and dumbbell shaped samples.

### 2.2.2 *Acoustic properties*

The vibration damping efficiency tests were performed using geophone equipped with an analog mixer Yamaha AG06. For signal analysis a computer with Reaper v5.91/x64 and Sigview ver. 3.2.0 software was used.

As a controlled vibrations generator an unbalanced electric engine on a steel frame was used. Four frame supports were originally metal-rubber absorbers and the load of each support is 500N (based on the weight of the engine and its frame). The experiment setup is presented on Fig. 1.



**Fig. 1.** Setup for vibration absorbers testing. M – rotating engine, V – vibration absorbers, G1, G2 – geophone attachment.

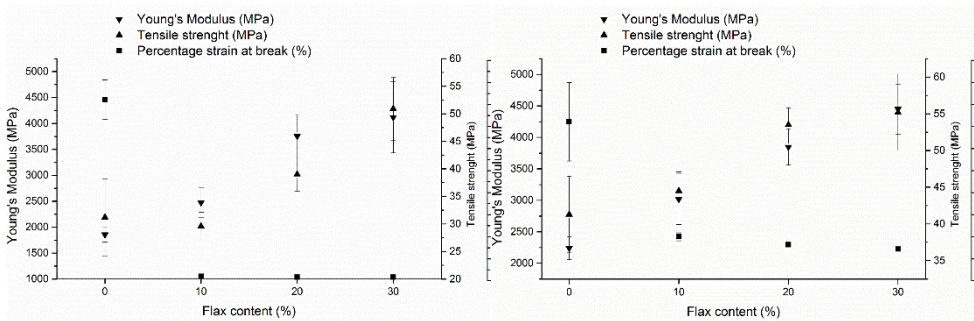
### 3 Results and discussion

#### 3.1 Mechanical testing

Addition of flax fibers to plasticized PLA resulted in a significant change of composite’s mechanical properties. As expected (Fig. 2 ), one can observe general improvement in tensile strength with reduced elongation and increased Young Modulus. We have proposed in our previous study [31] a modified rule of mixture to model how mechanical properties of fiber reinforced composite are affected by fiber loading, where for aligned fibers composite modulus is given by:

$$Y_c = (\eta_l \eta_0 Y_f - Y_m) V_f + Y_m \tag{1}$$

where  $Y_c$ ,  $Y_m$ ,  $Y_f$  are modulus of the composite, matrix and the fiber respectively,  $V_f$  is the fiber volume,  $\eta_0$  is the orientation efficiency factor and  $\eta_l$  is the length efficiency factor.



**Fig. 2.** Mechanical tensile properties of PLA/flax composites with PEG (left) and TEC (right) plasticized matrix.

Summary values for composites based on PLA plasticized with TEC and PEG were presented in table 1. Higher values of elongation at break for PLA/PEG when compared to PLA/TEC system suggest that the first plasticizer is more efficient for PLA, because plasticizer makes composite more flexible very successfully. This is confirmed by research carried out in 2013 [31]. Higher content of flax in each of the composites makes the Young's modulus values for each of them become comparable, but still PLA/PEG has lower values, even in 30% content of flax.

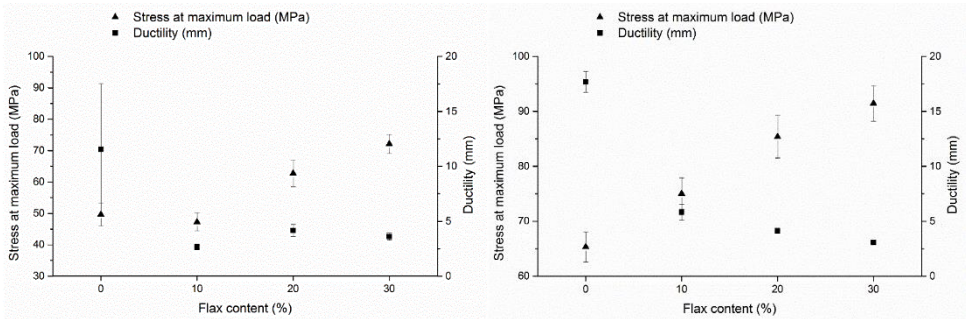
**Table 1.** Mechanical properties of plasticized PLA/flax composites at tensile.

Materials	E (Std) (MPa)	$\sigma_{max}$ (Std) (MPa)	$\epsilon_{max}$ (Std) (%)	E (Std) (MPa)	$\sigma_{max}$ (Std) (MPa)	$\epsilon_{max}$ (Std) (%)
	TEC			PEG		
PLA	2242 (183)	41.3 (5.2)	31.1 (8.9)	1860 (149)	31.2 (7.0)	164.4 (17.8)
PLA+10%flax	3018 (399)	44.5 (2.6)	5 (0.9)	2475 (284)	29.6 (2.5)	4.1 (1.3)
PLA+20%flax	3847 (283)	53.5 (2.3)	3.2 (0.2)	3758 (412)	39 (3.1)	3.4 (0.5)
PLA+30%flax	4449 (398)	55.2 (5.2)	2.2 (0.4)	4119 (686)	50.9 (5.7)	3.4 (0.3)

The results of ductility tests show that composites based on PLA plasticized with TEC are less ductile than PLA/PEG. Ductility values for PLA/TEC when compared to PLA/PEG are decreasing with a higher gradient with increasing fiber loading.

**Table 2.** Mechanical properties of plasticized PLA/flax composites at bending.

Materials	$\sigma_{max}$ (Std) (MPa)	y (Std) (mm)	$\sigma_{max}$ (Std) (MPa)	y (Std) (mm)
	TEC		PEG	
PLA	65.33 (2.74)	17.69 (0.95)	49.61 (3.64)	11.55 (5.95)
PLA+10%flax	75.02 (2.87)	5.80 (0.73)	47.25 (2.85)	2.64 (0.25)
PLA+20%flax	85.41 (3.84)	4.13 (0.17)	62.72 (4.23)	4.17 (0.54)
PLA+30%flax	91.45 (3.21)	3.07 (0.23)	72.13 (3.03)	3.60 (0.30)



**Fig. 3.** Properties of PLA/flax composites with PEG (left) and TEC (right) plasticized matrix at bending.

The results of ductility tests (Table 2) shows that PLA plasticized with TEC present a better mechanical properties at bending when compared with PLA plasticized with PEG. They are less prone to mechanical loading (higher maximum stress values, 65.33 MPa for TEC and 49.61 MPa for PEG respectively). Also TEC plasticized PLA presents a much higher ductility values (in comparison with PEG) which suggests a better chain mobility under load. Furthermore, observed behaviour can be related to better miscibility as PEG is reported to have a critical concentration values above which it tends to form a separated phase inside PLA matrix reversing its properties back to nonplasticized state. [32]

Graphical representation of bending test results (Fig. 3) confirms a proposed model for fiber reinforced composites. Addition of flax fibers decreases material deformation ratio with increasing fiber loading. The composite presents brittle fracture and is able to withstand a higher stress under load.

### 3.2 Acoustic measurements

Effectiveness of prepared vibroisolators was compared to commercial grade rubber vibroisolators at three different frequencies. Alternating voltage applied to engine was correlated in order to obtain the desired frequency value.

**Table 3.** Correlation of AC voltage with the engine frequency.

Frequency of working engine	Alternating voltage given to engine
26 Hz	90V
34 Hz	114 V
41 Hz	138 V

Six measurements were carried out for each composite prepared. Three measurements were taken with geophone mounted on engine frame and the second three measurements were taken with geophone mounted on frame placed on the ground. Signal generated from geophone was recorded with Reaper program. The signal sampling frequency was set to 48 kHz and buffer was set to 256 samples. Recorded signal was processed by a SigView program for capturing frequency with the highest amplitude. Table 4 presents amplitude frequency recorded for geophone mounted on the engine frame (left) and on the ground (right).

**Table 4.** Amplitude frequency recorded for geophone mounted on the engine frame and on the ground, where composite vibroisolators prepared with different plasticizers (TEC and PEG) and GUM is the rubber commercial grade absorber.

		Hz						
FLAX CONTENT		26	26'	34	34'	41	41'	
TEC	10%	<b>112</b>	107	<b>119</b>	110	<b>124</b>	115	dB
	20%	<b>114</b>	106	<b>117</b>	107	<b>123</b>	116	dB
	30%	<b>113</b>	106	<b>116</b>	108	<b>125</b>	115	dB
PEG	10%	<b>114</b>	108	<b>121</b>	112	<b>126</b>	119	dB
	20%	<b>114</b>	108	<b>114</b>	109	<b>125</b>	118	dB
	30%	<b>114</b>	108	<b>118</b>	112	<b>126</b>	118	dB
GUM	-	<b>120</b>	105	<b>124</b>	112	<b>118</b>	99	dB

**Table 5.** Effectiveness of absorbing amplitude for each vibroisolator.

		Flax	26	34	41	Hz
TEC	10%		5	9	9	dB
	20%		8	10	7	dB
	30%		7	8	10	dB
PEG	10%		6	9	7	dB
	20%		6	5	7	dB
	30%		6	6	8	dB
GUM	-		15	12	19	dB

With reference to rubber vibroisolators, composites plasticized with TEC have better vibration isolating effectiveness when compared to composites plasticized with PEG, despite

the fact that composite PLA/PEG are more flexible in mechanical tests. Increase of filler content makes vibroisolators more effective at higher excitation frequencies.

## 4 Conclusions

The composite behaviour under load was predictable, i.e. an increase in the amount of filler increased the sample's resistance to tensile and resulted in fragile type of break. Comparison of the effectiveness of composite vibroisolators between rubber vibroisolators and the produced composites proves that PLA/flax fiber composites require further development in order to achieve similar damping properties as commercially available elastomer based absorbers. Possible ways to improve material properties are to optimize the filler content, with a special regard to prevent filler aggregation. This will be achieved in our next studies where we will implement a better forming technique with higher pressures and better master batch preparation formula. Introducing of high frequency sound waves in order to separate the fiber bundles prior to melt mixing is in order. Nevertheless the obtained material presents a great application potential for disposable vibration absorbers as it is capable of withstanding time variable load and is fully compostable, leaving a relatively small carbon foot print when compared to market available materials.

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