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# Anticipation of damage presence in a fibre reinforced polymer plate through damping behaviour

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**A B S T R A C T**

Failure of composite materials due to poor anticipations of damages occur very frequently. Damages in composite materials may exist as visible or non-visible with different configurations and identities. Thus, investigation of damages existence in composite materials has to have prior attention to avoid the failure of structures. The current work investigates the damping response offered by a damaged fiber-reinforced polymer plate. The plate is put under three different conditions regarding the damage existence. The focus is to measure the loss factor in all cases and determine whether there is a difference among them to prove damage presence in the composite part. The loss factor is experimentally measured by measuring the reverberation time $RT_{60}$. The resulting data of loss factors show a well-distinguished difference that might lead to predicted damages and to do a more expanded analysis of this issue.

## 1. Introduction

The consumption of composite materials in general and fibre reinforced polymer in particular, has significantly increased in recent years (Rajak et al., 2019). Due to their increased strength, durability, fatigue resistance, and their light weight, fibre reinforced polymer composites are widely used in aerospace, automobile, and civil industries (Ozbakkaloglu et al., 2016). Compared with other materials, the design flexibility and light-weight property of composite materials are other attractive characteristics of composite materials. Glass, carbon, and aramid are the most commonly used reinforcing fibres. However, the use of natural fibres as reinforcement and eco-friendly resin as matrices of polymer based composites has been an interest. This is due to the awareness of the environmental issue raised from using plastic fibres with synthetic resin (Petrone et al., 2015). However, composite materials during manufacturing or service life are susceptible to damages (Jollivet et al., 2013). Operation conditions like fatigue or impact may induce visible or even non-visible damages such as delamination, matrix cracking, and fibre breakage (Hou et al., 2012). These types of damages and others can decrease the strength and stiffness of the material as well as the load bearing capacity of the structure causing deterioration and failure (Razali et al., 2014). Thus, composite structures have to be continuously monitored and inspected by means of structural health monitoring (SHM) in order to keep the integrity and reliability. Estimation of damages existence at early stages decreases the risk of failure and keeps the structure at service by reducing the scheduled inspections and conducting the maintenance when it is needed, not based on the number of operation hours (Ghobadi, 2017).

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Many approaches have been used as structural health monitoring techniques for damage detection in composite structure. Among these methods which have been used repeatedly by researchers are the non-destructive tests (NDT) such as ultrasonic guided wave, acoustic emission, X-ray radiography and others (Doliński et al., 2018; Endrizzi et al., 2015; Gholizadeh, 2016; Katunin, 2015; Murat et al., 2016; Soleimanpour et al., 2017). Vibration based damage detection methods are among the most widely used methods in the topic of SHM for composite structure (Sadarang et al., 2018; Vo-Duy et al., 2016). Many researchers have been studying the vibration characteristics in structural damage detections (Carden et al., 2004; Fan et al., 2011) and particularly for composite structure (Alsarayefi et al., 2019; dos Santos et al., 2016; Kessler et al., 2002; Montalvão et al., 2006; Oruganti et al., 2008; Yam et al., 2003; Zhang et al., 2018; Zou et al., 2000). On the other hand, the damping properties of composite materials are superior to other metallic materials. Since, the assessment of damping properties of composites is not an easy process, they are not commonly considered in the design and analysis processes(Treviso et al., 2015). Few researches and reviews were done regarding the topics of composite materials damping (Benchekchou et al., 1998; Chandra et al., 1999; Finegan et al., 1999). However, damping of composites is distinctly higher than that of other traditional engineering materials. Based on the designed composite part, the damping depends on the fibre properties, the matrix properties, the interface between them, the number of lamina and their sequence, and the attached viscoelastic layers if they exist (Berthelot et al., 2008). The focus of this experimental investigation is to analyse the damping response of a composite plate made of glass fibre reinforced polymer in order to predict damage existence. The plate is on three conditions regarding damage presence, and damping measurements are done for each condition. The loss factor which is obtained through the measurement of the reverberation time $RT_{60}$ is measured for the three cases of the plate. The obtained data of each one is investigated individually and compared with each other attempting to conclude an overview of damages presence in the tested component.

## 2. Damping of materials

Materials have the capacity to extinguish the vibration energy which is introduced to them. The reason for this is the internal friction or damping in materials, which can be caused by a variety of combinations of fundamental physical mechanisms, depending upon the specific material. For metals, these mechanisms include thermo-elasticity on both the micro and macro scales, grain boundary viscosity, point-defect relaxations, eddy-current effects, stress-induced ordering, and electronic effects (Fahy, 2003). For non-metallic materials, such as polymers and elastomers, the physical micro-mechanisms operative is also known and considerable phenomenological data have been obtained. Due to the long-range molecular order associated with their giant molecules, polymers exhibit rheological behaviour intermediate between that of a crystalline solid and a simple liquid. The damping and stiffness are markedly depending on frequency and temperature. The loss factors correspond to pure internal damping, thus radiation losses and the damping at the connections of some compounds (e.g. spot-welded connections) must be separately treated (Botelho et al., 2005). The damping behaviour can be described with several measures; the mainly used are shown below:

- Bandwidth of half-power points under steady-state sinusoidal excitation,
- Loss tangent under steady-state sinusoidal excitation (tan $\varphi$),
- logarithmic decrement ($\Lambda$),
- loss factor ($\eta$),
- damping ratio ($\xi$),
- Lehr's damping (D) etc.

There are certain inter-relationships among these measures, e.g.:

$$\eta = tan\varphi = 2 \cdot \xi = \Lambda / (\mathrm{n} \cdot \pi) = (2 \cdot \mathrm{D}) / \mathrm{n} \qquad (1)$$

### 2.1. The Relation between Loss Factor and Reverberation Time

Damping loss factor gives an indication about the dissipated energy in the structure. It is a dimensionless quantity that defines as the ratio of amount of energy dissipated per radian to the total energy of the system (Cherif et al., 2015). Or it is the ratio of the power dissipated $Dp$ , the total stored mechanical energy $E$, and the angular frequency $\omega$ (Cremer et al., 2005).

$$\eta(\omega) = Dp \,/\, E.\omega \tag{2}$$

where $\omega$ is the angular frequency where the loss factor is calculated. However, the estimation of the loss factor is also possible by the measurement of reverberation time $RT_{60}$. $RT_{60}$ is defined as the time at within which the energy of the vibration is reduced to one millionth of its initial value (-60 dB) as shown in Fig. 1. In other words it could be defined as the time in which the signal level is decreased by 60 dB after the source has been switched off (Nowoświat et al., 2017).

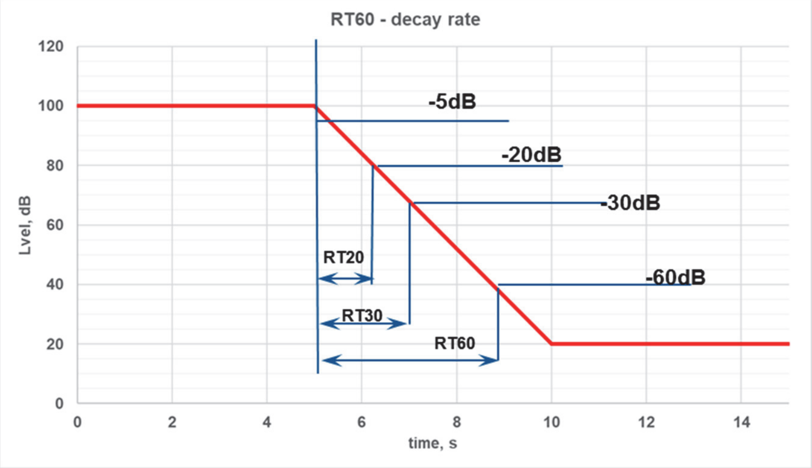


**Fig. 1**. Decay rate curve

To measure $RT_{60}$, the system at which the decay rate tested has to be excited with a mechanical impulse (e.g. impact hammer) or with a burst random signal (electro-dynamic shaker). The time signal or the response has to be measured using an accelerometer. When the system excitement stops, a gradual drop of the acceleration level within a certain time can be observed in the signal. The period of this time is depending on the internal damping of the material. The drop of the energy level by $10^6$ (or by 60 dB) in the measured time means the so called $RT_{60}$ decay rate which is filtered for every third octave frequency band. The filtered $RT_{60}$ is related to loss factor over the frequency by the following formula (Nowoświat et al., 2017; Topa et al., 2012):

$$\eta(f) = 2.2 \,/\, f.RT_{60} \tag{3}$$

where
$f$ : is the mid frequency of a third octave band in Hz.
$RT_{60}$: is the decay rate for each third octave mid frequency in s.

The value of 2.2 is derived from the energy drop to the one millionth of the initial value.

## 3. Experimental Work

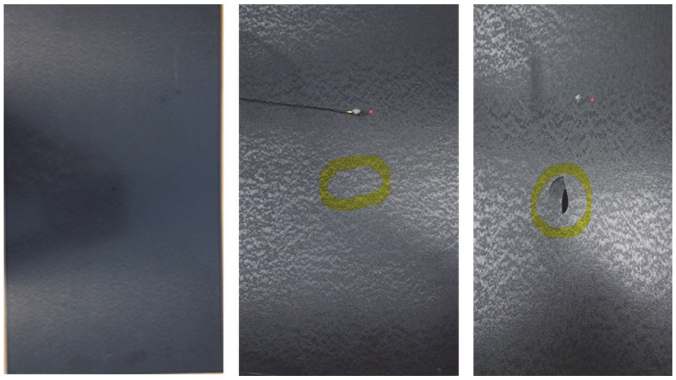
### 3.1 Characteristics and Geometry of the Test Specimen

A composite material type MF GC 201 is selected to be tested in this experimental work. It is a plate of a rectangular shape with dimensions of 500 x 200 x 3 $mm^3$ as shown in Fig. 2. The material is a glass fabric bonded with melamine resin forming a glass – melamine laminate.

**Fig. 2**. The rectangular FRP test specimen.

### *3.2 Damage Generating Process*

As mentioned that the specimen is tested under three conditions regarding the damage presence in it. Two damages were created in order to have three damage cases considering the free of damage one as the third case (see Fig. 3). Few attempts were done to create damages such as free fall of the bearing ball and others before choosing to use an airgun. This airgun of type Diana 300R cal.177 has the maximum kinetic energy of E = 7.5 J at the muzzle. The gun "fires" lead pellets of the weight m = 0.53g of a calculated speed at the muzzle of 170 m/s. The first damage was created by firing from a distance of 10 m which is seen as the contact point of the pellet on the plate. The other damage which is about a 5 mm gap in the plate was created by firing from a distance of 1.5 mm. Test equipment were chosen as: (i)B&K Pulse data acquisition; (ii) B&K 4397 accelerometer; (iii) Impact hammer (hand-made from a B&K 4397 accelerometer) and (iv) the software. Fig. 4 shows also the representation of the test set up.



Original Damaged-1 Damaged-2

**Fig. 3.** The three conditions of the test specimen

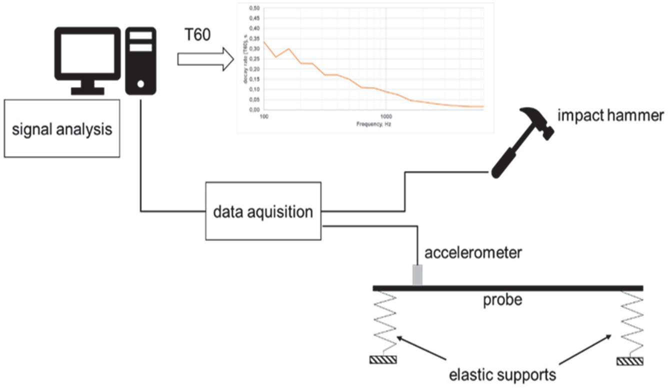


**Fig. 4.** Schematic representation of the test setup

### *3.2. Performing the Test*

The evaluation of the loss factor of the specimen is done by measuring the $RT_{60}$. To do so, the specimen is laid on elastic foam supports on both ends. On one side of the plate, three excitation points and one measurement point were determined to perform the hits and record the response. The first excitation points are in the middle of the specimen, while the second and third were (10, 10) and (3, 5) from the lower edge respectively. The measurement point is horizontally in the middle and vertically in the upper one-third of the part. The test is done three times according to the three different cases of damage existence. First time, the specimen is free of damage while the second time the specimen is damaged but the defect is barely seen by eye supposing that there are damages in the microstructure of the part which may be detected by the resulting signal. The third test is done when the specimen is fully cracked as there is a gap in the spacemen. During each time of the test, the excitation points are respectively hit ten times by the hammer and the recorded data were averaged. All recorded data are analysed by the Room Acoustic Wizard software and graphs are generated.

## 4. Results

Figs. 5-8 show the relation of the loss factors for the three different damage conditions of the same specimen. Up to 1000 Hz there is no difference in damping behaviour. Beyond 1000 Hz significant differences of the loss factors can be observed (see Fig. 8).

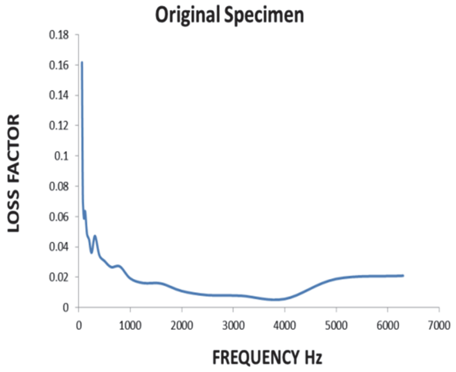


**Fig. 5**. The loss factor of the original specimen

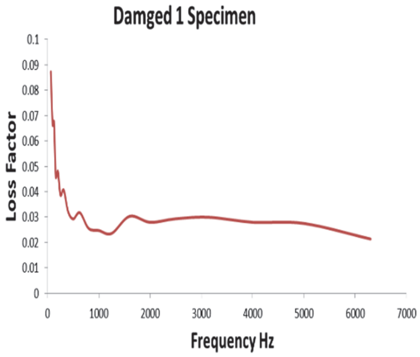


**Fig. 6**. The loss factor of damaged-1 specimen

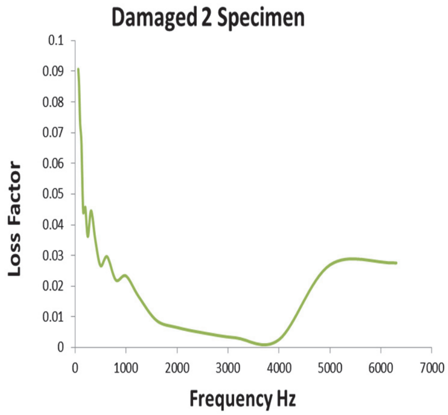


**Fig. 7**. The loss factor of damaged-2 specimen

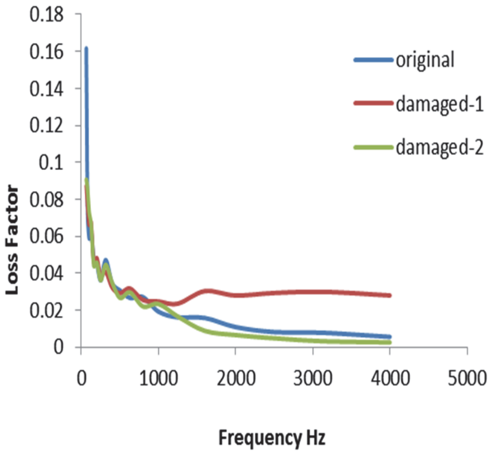


**Fig. 8**. The loss factor of the three cases

The loss factor of the damaged-1 specimen is three times higher than that of the original. The damage-1 condition means only a barely visible crack in the plate, so that micro-sliding occurs. This is producing the Coulomb friction between the cracked surfaces, which is finally dissipating the vibration energy faster than in the original condition. In case of damaged-2, material area of (0.5 × 2 cm) is cracked out from the specimen, so this area fragment is practically missing. In this case, over 1000 Hz, the loss factor is roughly half as high as in the original condition. Due to the missing material fragment the Coulomb friction cannot take effect, so the loss factor is reduced. In addition, the missing material fragment means also less internal damping generating micro-mechanisms, with the result of less damping than the original. It is quite surprising that such a small missing part causes a significant drop of the loss factor. This has to be further investigated in the near future. The determination of loss factor for components made of FRP material seems to be an efficient method to evaluate the damage condition. The possibility of damage localization with damping measurements has to be further investigated, but the decision of an OK/Not OK component selection is possible.

## 5. Conclusion

Since there has been an increased demand of composite materials structures in automobiles, aerospace, and other various applications, the need for the structural health monitoring SHM is also revealed as a major topic. Damages of composites structures can be visible or non-visible and have many types and configurations. Therefore, many methods to detect composite damages have been used and investigated. Current work aims to predict composite damages in a FRP plate by studying the damping behaviour of the plate. The damping response is studied under three different conditions based on damage existence. Firstly, the plate is investigated as free of damages. After that, two artificial damages are made respectively in the plate and studied separately. The loss factor is measured for all cases to determine whether there is difference among them in order to prove damage presence in the composite part. The measurement of the loss factor is experimentally done by evaluating the reverberation time $RT_{60}$. A well-distinguished difference is revealed by the resulted data proving the difference occurring by the damages of the plate. The results may lead to expanding the research by focusing on the location and identity of the damages.

## References

Alsarayefi, S. J., & Jalics, K. (2019). The change of the NVH characteristics of composite vehicle components as a result of visible and not visible damages. *Advances and Trends in Engineering Sciences and Technologies III- Proceedings of the 3rd International Conference on Engineering Sciences and Technologies, ESaT 2018*.

Benchekchou, B., Coni, M., Howarth, H. V. C., & White, R. G. (1998). Some aspects of vibration damping improvement in composite materials. *Composites Part B: Engineering*, *29*(6), 809-817.

Berthelot, J. M., Assarar, M., Sefrani, Y., & Mahi, A. El. (2008). Damping analysis of composite materials and structures. *Composite Structures*, *85*(3), 189–204.

Botelho, E. C., Campos, A. N., De Barros, E., Pardini, L. C., & Rezende, M. C. (2005). Damping behavior of continuous fiber/metal composite materials by the free vibration method. *Composites Part B: Engineering*, *37*(2–3), 255–263.

Carden, E. P., & Fanning, P. (2004). Vibration based condition monitoring: a review. *Structural Health Monitoring*, *3*(4), 355-377.

Chandra, R., Singh, S. P., & Gupta, K. (1999). Damping studies in fiber-reinforced composites–a review. *Composite structures*, *46*(1), 41-51.

Cherif, R., Chazot, J. D., & Atalla, N. (2015). Damping loss factor estimation of two-dimensional orthotropic structures from a displacement field measurement. *Journal of Sound and Vibration*, *356*, 61-71.

Cremer, L., Heckl, M., & Petersson, B. A. T. (2005). Structure-borne sound: Structural vibrations and sound radiation at audio frequencies. In Structure-Borne Sound: Structural Vibrations and Sound Radiation at Audio Frequencies.

Doliński, Ł., Krawczuk, M., & Zak, A. (2018). Detection of Delamination in Laminate Wind Turbine

Blades Using One-Dimensional Wavelet Analysis of Modal Responses. *Shock and Vibration*, *2018*.

dos Santos, F. L. M., Peeters, B., Van der Auweraer, H., Góes, L. C. S., & Desmet, W. (2016). Vibration-based damage detection for a composite helicopter main rotor blade. *Case Studies in Mechanical Systems and Signal Processing, 3,* 22-27.

Endrizzi, M., Murat, B. I. S., Fromme, P., & Olivo, A. (2015). Edge-illumination X-ray dark-field imaging for visualising defects in composite structures. *Composite Structures*, *134*, 895-899.

Fahy, F. (2003). Foundations of Engineering Acoustics. In Foundations of Engineering Acoustics.

Fan, W., & Qiao, P. (2011). Vibration-based damage identification methods: A review and comparative study. In Structural Health Monitoring.

Finegan, I. C., & Gibson, R. F. (1999). Recent research on enhancement of damping in polymer composites. *Composite Structures*.

Ghobadi, A. (2017). Common Type of Damages in Composites and Their Inspections. *World Journal of Mechanics*.

Gholizadeh, S. (2016). A review of non-destructive testing methods of composite materials. *Procedia Structural Integrity*, *1*, 50–57.

Hou, W., & Zhang, W. (2012). Advanced composite materials defects/damages and health monitoring. *Proceedings of IEEE 2012 Prognostics and System Health Management Conference, PHM-2012*.

Jollivet, T., Peyrac, C., & Lefebvre, F. (2013). Damage of composite materials. *Procedia Engineering*.

Katunin, A. (2015). Nondestructive damage assessment of composite structures based on wavelet analysis of modal curvatures: State-of-the-art review and description of wavelet-based damage assessment benchmark. In Shock and Vibration.

Kessler, S. S., Spearing, S. M., Atalla, M. J., Cesnik, C. E. S., & Soutis, C. (2002). Damage detection in composite materials using frequency response methods. *Composites Part B:Engineering*.

Montalvão, D., Maia, N. M. M., & Ribeiro, A. M. R. (2006). A review of vibration-based structural health monitoring with special emphasis on composite materials. In Shock and Vibration Digest.

Murat, B. I. S., Khalili, P., & Fromme, P. (2016). Scattering of guided waves at delaminations in composite plates. *The Journal of the Acoustical Society of America*, *139*(6), 3044–3052.

Nowoświat, A., & Olechowska, M. (2017). Estimation of Reverberation Time in Classrooms Using the Residual Minimization Method. *Archives of Acoustics*, *42*(4), 609–617.

Oruganti, K., Mehdizadeh, M., John, S., & Herszberg, I. (2008). Vibration-based analysis of damage in composites. *Materials Forum*, *33*, 496

Ozbakkaloglu, T., Chen, J. F., Smith, S. T., & Dai, J. G. (2016). Applications of Fiber Reinforced Polymer Composites. In International Journal of Polymer Science.

Petrone, G., D'Alessandro, V., Franco, F., & De Rosa, S. (2015). Damping evaluation on eco-friendly sandwich panels through reverberation time (RT 60) measurements. *JVC/Journal of Vibration and Control*, *21*(16), 3328–3338.

Rajak, D. K., Pagar, D. D., Menezes, P. L., & Linul, E. (2019). Fiber-reinforced polymer composites: Manufacturing, properties, and applications. *Polymers*, *11*(10), 1667.

Razali, N., Sultan, M. T. H., Mustapha, F., Yidris, N., & Ishak, M. R. (2014). Impact Damage on Composite Structures – A Review. *The International Journal Of Engineering And Science, 3*(7), 08-20.

Sadarang, J., Nayak, S., Nayak, G., Panigrahi, I., & Nayak, R. K. (2018). Dynamic analysis for delamination detection in carbon fiber composite beam. *IOP Conference Series: Materials Science and Engineering*, *402*(1).

Soleimanpour, R., & Ng, C. T. (2017). Locating delaminations in laminated composite beams using nonlinear guided waves. *Engineering Structures*, *131*, 207–219.

Topa, M. D., Toma, N., Kirei, B. S., Saracut, I., & Farina, A. (2012). Experimental acoustic evaluation of an auditorium. *Advances in Acoustics and Vibration*, *2012*(1), 1–9.

Treviso, A., Van Genechten, B., Mundo, D., & Tournour, M. (2015). Damping in composite materials: Properties and models. *Composites Part B: Engineering*, *78*, 144–152.

Vo-Duy, T., Ho-Huu, V., Dang-Trung, H., Dinh-Cong, D., & Nguyen-Thoi, T. (2016). Damage detection in laminated composite plates using modal strain energy and improved differential evolution algorithm. *Procedia Engineering*, *142*, 182–189.

Yam, L. H., Yan, Y. J., & Jiang, J. S. (2003). Vibration-based damage detection for composite structures using wavelet transform and neural network identification. *Composite Structures, 60*(4), 403-412.

Zhang, Z., He, M., Liu, A., Singh, H. K., Ramakrishnan, K. R., Hui, D., ... & Morozov, E. V. (2018). Vibration-based assessment of delaminations in FRP composite plates. *Composites Part B: Engineering*, *144*, 254-266.

Zou, Y., Tong, L. P. S. G., & Steven, G. P. (2000). Vibration-based model-dependent damage (delamination) identification and health monitoring for composite structures—a review. *Journal of Sound and vibration*, *230*(2), 357-378.