INVESTIGATION ON THE DAMPING FACTOR OF CEMENTITIOUS COMPOSITES REINFORCED WITH RUBBER WASTE

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Abstract. The disposal of scrap tyres from vehicles creates a significant environmental problem, especially when discarded indiscriminately in the nature, causing ecological damage and risks to public health. This work investigates the effect of rubber particle additions on the damping factor of cementitious composites. Besides offering a sustainable end use for this waste material, performance benefits may exist such as improved ductility and improved acoustic and thermal properties of cementitious composites. A full factorial design has been conducted to assess the influence of the volume fraction of rubber (10, 30 and 50%); and water/cement ratio (0.3 and 0.4) on the damping factor of the composites. The interactions of rubber fraction and water/cement ratio affected significantly the damping factor of the composites.

Keywords*: Damping Factor, Recycling, Rubber particles, Particulated composite.*

1. INTRODUCTION

The rubber of scrap tyres or retreading is a waste material which is often disposed improperly in the environment. The improper disposal of scrap tyres increases even more the environmental problem, being the focus for the proliferation of insects and pests (Marques *et al*., 2006).

The use of rubber particles into cement based composites can be an alternative recycling for this waste. This is true when analyzed the rubber particles as a dispersive phase of composites providing impact resistance and low density (Marques *et al*., 2006).

The addition of rubber particles as dispersive phase in cementitious composites presents interesting benefits when thermal and acoustic insulation are desired (Lima *et al*., 2000). However, the damping factor of such composites may not considered enhanced with rubber particles additions.

The damping or “internal friction”, is one of the most sensitive properties of materials and structures, both in macro and microscopic scale (Lazano 1968), being particularly sensitive to the presence of cracks and micro cracks (Banchmann and Dieterle, 1981). It is the phenomenon in which mechanical energy of a system is dissipated (Smith, 2007), mainly by the generation of heat and/or sound. The damping determines the vibration amplitude at resonance and vibration persistence time after interruption of the excitement.

Besides the classical application in the study of metals, the damping can also be applied for civil engineering applications, when the integrity of structures must be investigated in case of earthquakes (Coppola and Bradt, 1973; Tonnesen and Telle, 2007).

The damping of a structure or material can be classified in three main ways: internal, structural and fluidic. The internal is associated with defects related to the microstructure, grain aspects and impurities of the material and thermoelastic effects caused by local gradients of temperature. The structural damping is associated with energy losses due to friction in joints, screws and semi-rigid articulations. Finally, the fluidic damping occurs by the drag resistance of fluids, for example, the conversion of kinetic energy of a pendulum to thermal energy to air (Cossolino and Pereira, 2010).

There are several methods for determining the damping, which can be achieved basically in two ways: through the duration of the system response to a transient excitation, i.e. the logarithmic decrement method, or based on the system response as a function of frequency, i.e. bandwidth method. The logarithmic decrement method calculates the damping from the response attenuation to the vibrating movement of the material or structure after an excitation pulse. The bandwidth method calculates the damping by analyzing the frequency of the vibration signal derived from the relationship between bandwidth and center frequency of a resonance. Both methods consider a model for the calculations, usually the model of viscoelastic damping. The choice of the method depends primarily on the range of damping and vibration frequency (Smith, 2007).

Based on the full factorial design of experiment (DOE) this work investigates the volume fraction of rubber particles and the water cement ration on the damping factor response, measured by logarithmic decrement, cementitious composites.

2. MATERIALS AND METHODS

2.1. Materials

The particulated composites can be classified as a material containing two main phases, the dispersive phase of particles and the matrix phase, continuous and responsible for loading distribution. The matrix phase used in this experiment was the Portland cement ARI PLUS (ASTM Type III). The dispersive phase of rubber particles from scrap tyres were collected in Mantiqueira Recauchutadora de Pneus Company situated in São João del Rei-MG.

The experimental factors investigated were volume fraction of rubber particles and water content in the mixture. Factors were kept constant in the experiment such as: type of matrix (cement), rubber particle size, mixing time (2 min.) and curing time (7 days). The rubber particles were classified by sieving process using the particle size range of 20/48 US Tyler (0.850mm/0.300mm). The experimental levels of the factors are presented in Tab. 1.

Table 1. Factors and levels of experiment

Experimental factors	Levels
Rubber fraction (volumetric)	1. 10% 2. 30% 3. 50%
Water content	1. 30% 2. 40%

The full factorial design of the type n^k consists in investigating all possible combinations of the experimental factors (k) and its respective levels (n). The result of the factorial n^k corresponds to the number of the investigated experimental conditions (Montgomery 1997). Based on the factors and levels presented in Tab. 1, the factorial design of type $2^1 3^1$ was obtained, corresponding to the six experimental conditions analyzed (see Tab. 2).

Table 2. Experimental conditions, full factorial design ($2^1 3^1$)

Full factorial design		
Experimental conditions	Factors	
	Water content (%)	Rubber fraction (%vol.)
C1	30	10
C2	30	30
C3	30	50
C4	40	10
C5	40	30
C6	40	50

Four specimens of size 153x19x8 mm were fabricated for each experimental condition. Considering the adoption of 2 replicas and 6 experimental conditions, 48 specimens were manufactured. Replica consists in repetition of the experimental condition, providing an estimate of experimental error of an individual response. The extent of this error is important to decide whether there are significant effects that may be attributed to the action of the factors (Montgomery, 1997; Werkema and Aguiar, 1996).

The cement and the rubber particles were firstly mixed in a plastic container with no water in order to obtain a better homogeneity of the mixture, then the water amount was added. The mixing time was 2 min and the cure time was 7 days. Figure 1 shows the specimens for each experimental conditions.

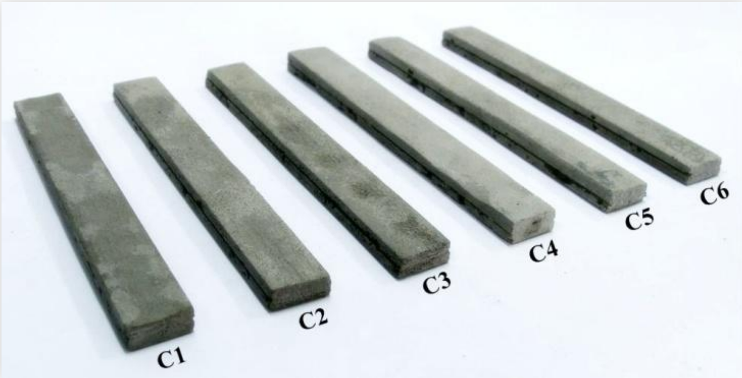

Figure 1. Specimens for each experimental conditions

2.2. Damping testing

The damping tests were performed using a signal acquisition program developed in Matlab (A); a data acquisition board of National Instruments, NI USB 6251 BNC 8SE/DI, 1.2 MS / s, 16 bits (B); a signal conditioner, constant current source CTC PSO3 Power Suply (C); an impact hammer Brüel & Kjær, type 8206, 55936 with silicon tip (D) and a Deltatron accelerometer Brüel & Kjær 4517, 60309 (E), as shown in Fig. 2 and Fig. 3.

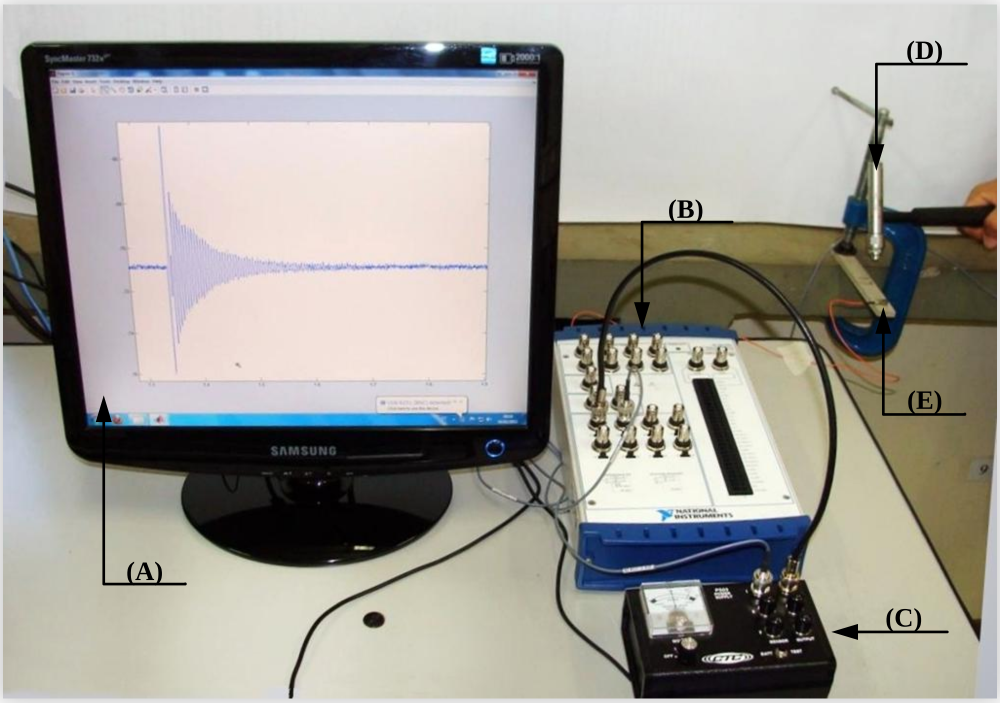

Figure 2. Experimental bench

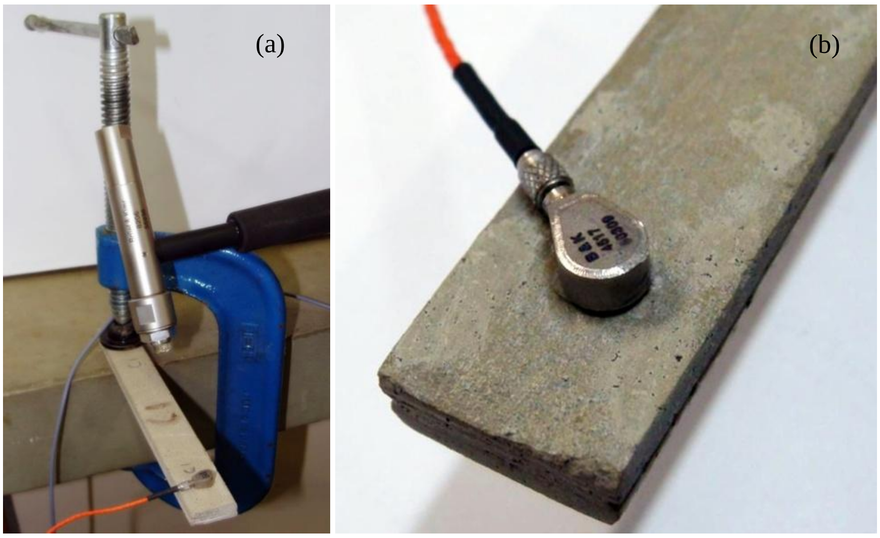

Figure 3. Impact hammer (a) and accelerometer fixing (b)

Based on the damping signal graph exhibited in Fig. 4, the first (x_0) and the last (x_n) notable point of the signal were selected to obtain a better accuracy of data results. The beginning of the curve is a transitory moment which was not considered in the analysis.

The logarithmic decrement (δ) was calculated using Eq. (1), and the damping factor (ξ) was obtained using Eq. (2), (Cossolino and Pereira, 2010; Umashankar *et al*., 2010).

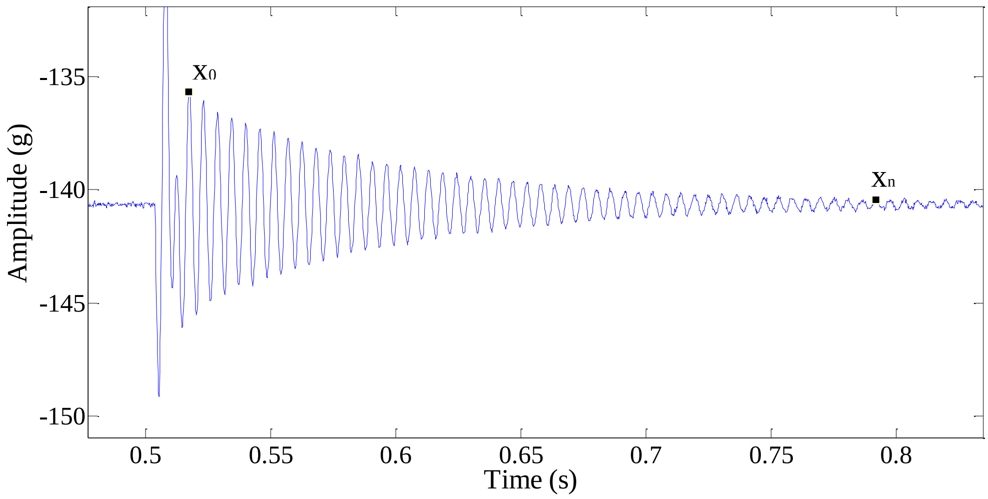

Figure 4. Damping signal

$$\delta = \frac{1}{n}\ln\left(\frac{x_0}{x_n}\right) \tag{1}$$

$$\xi = \frac{\delta}{\sqrt{4\pi^2 + \delta^2}} \tag{2}$$

Where n corresponds to the number of periods between x_0 and x_n.

3. RESULTS

The statistical technique DOE (*Design of Experiment*) and the ANOVA (*Analysis of Variance*) provides the significance of each experimental factor on the response damping factor. Considering the complexity of the calculations involved in this planning, the statistical computer program, Minitab *version 14* was used for data manipulation and analysis of results.

Table 3 presents the results of analysis of variance (ANOVA) for means of the investigated response variables. Factors related to P-value less than or equal to 0.05 (95% confidence) are considered significant, and these are underlined. The main effect of one factor must be individually interpreted only if there is no evidence that the factor does not interact with other factors. When one or more interaction effects of higher order are significant, the interacting factors must be considered together (Montgomery, 1997; Werkema and Aguiar, 1996).

The value of R^2 (93.15%) displayed in ANOVA measures the proportion of variability present in the observations of the response variable *y* that is explained by these predictor variables presents in the regression equation. The closer to 1 (or 100%) be R^2, the better will be the fitted equation quality to the data (Montgomery, 1997; Werkema and Aguiar, 1996).

Table 3. Analysis of variance (ANOVA) for the response variable damping factor

ANOVA		P-value $\leq$ 0.05
	Experimental factors	
Main factors	Rubber fraction	0.001
	w/c ratio	0.083
Interaction of factors	Rubber fraction * w/c ratio	0.007
	R^2 (adj)	93.15%

The results obtained in the ANOVA are shown in the graphs of "main effects" and "interactions". The graphics of "main effects" are used to compare changes in the average level, investigating which factors have significant effect on the response variable. Graphs of interactions are used to visualize the effect of interaction of two or more experimental factors on the response variable and compare the relative significance between of effects (Werkema and Aguiar, 1996).

3.1. Damping factor

The values of the damping factor ranged from 0.152×10^{-3} to 0.379×10^{-3}. The P-values (0.001 and 0.007) underlined in Tab. 3 show that the main factor "fraction of rubber" and the interaction "fraction of rubber and water content" significantly affect the response. According to Werkema and Aguiar (1996) if one or more interaction effects of higher order are significant, the interacting factors must be considered together, in this way only the second order effect will be analyzed. The R^2 was 93.15%, indicating that the fit of the model was satisfactory. The normal probability residual graph shown in Fig. 5 validates the ANOVA model used in this study, exhibiting a distribution of points near the line.

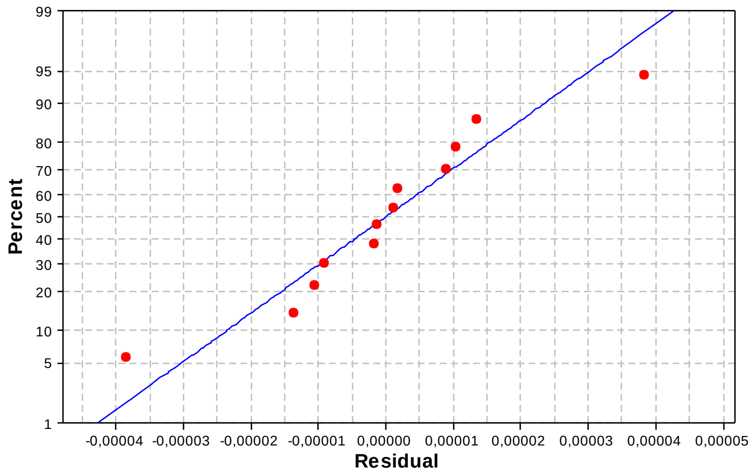

Figure 5. Residual plot of normal probability for damping factor response

Considering a significant interaction of factors, the effect of main factor will not be analyzed individually. Figure 6 shows the interaction plot "fraction of rubber and water content" for the response variable damping factor. It is observed that the increase of rubber fraction provides the reduction of the damping factor of composites. This effect is more evident for composites made with lower water content exhibiting a percentage variation of 140% (Fig. 6). This behavior can be attributed to the elastic properties of rubber particles, which can act similarly to a "spring" leading to the increase of vibration time attenuation of the bar, thus reducing the damping factor. According to Panzera *et al*., (2008), the increase of water content in cementitious composites with rubber particles provides not only the increase of the apparent porosity but also the reduction of stiffness of the material. The cementitious composites containing a higher percentage of rubber consume a smaller amount of water, since the particles are elastomers (impermeable). For this reason, the water content of 40% in the composite with 50% fraction of rubber increases the formation of pores, which in turn will be responsible for the reduction of stiffness and increased damping factor of the composites as shown in Fig. 6.

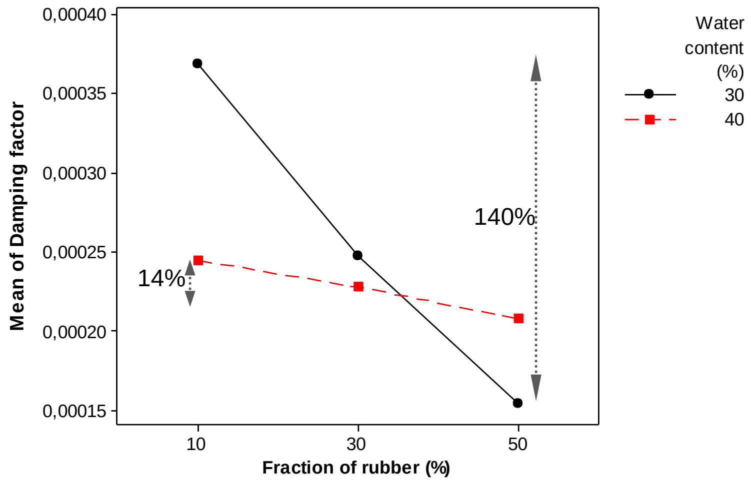

Figure 6. Interaction effect plot of fraction of rubber and water content for damping factor response

4. CONCLUSION

The interaction of the factors rubber fraction and water content significantly affected the damping factor. It was concluded that increasing the water content affects the microstructure of material, which increases the damping factor of the cementitious composites. The increase of rubber fraction from 10 to 50% caused the reduction of damping factor of the composites which can be attributed to the decreasing of material´s specific mass.

Although there are other more accurate methods of estimating the damping factor of a structure, the method used in this study proved to be satisfactory according to the required goals, besides being a simple and efficient methodology.

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