EXPERIMENTAL FIRE PERFORMANCE OF WOOD BIO-CONCRETES: STUDY ON REACTION TO FIRE AND RESIDUAL STRENGTH

Bruno M. C. Gomes[1]; Amanda L. D. Aguiar [2,*]; Alexandre Landesmann[3]; Nicole P. Hasparyk[4], and Romildo D. Toledo Filho[5]

[1]Federal University of Rio de Janeiro/COPPE: brunocunhaeng@gmail.com
[2]Federal University of Rio de Janeiro/COPPE: amanda.aguiar@numats.coc.ufrj.br
[3]Federal University of Rio de Janeiro/COPPE, Brazil: alandes@coc.ufrj.br
[4]Departamento de Segurança de Barragens e Tecnologia, FURNAS-Centrais Elétricas S.A: nicole@furnas.com.br
[5]Federal University of Rio de Janeiro/COPPE, Brazil: toledo@coc.ufrj.br

ABSTRACT

Environmental issues have led to using biomass wastes in making cement-bonded construction materials to improve their thermal insulation, thus building energy-efficient performance. However, the use of biomass in bio-concrete is a cause of concern from the point of view of an accidental fire. Therefore, the present study aims to provide an overview of the flammability of the wood bio-aggregates and bio-concretes using a Mass Loss Cone Calorimeter, and the residual strength of bio-concretes after the cone calorimeter tests. For the production of bio-concretes, volumetric fractions of 40%, 45%, and 50% of wood shavings were used with a cementitious matrix composed of Portland cement and rice husk ash, and fly ash. Cone Calorimeter tests were performed at a heat flux of 50 kW/m^2. In addition, compressive strength tests were carried out in burnt samples. The main results indicate that the incorporation of an inorganic binder involving wood bio-aggregates inhibits ignition and the variation of volumetric fraction of wood shavings in the bio-concrete mixtures did not change the contribution of Heat Release Rate (HRR). After cone calorimeter tests, 29% and 15% reduction in the mechanical capacity were observed for WBC40 and WBC45, respectively.

KEYWORDS

Reaction to fire. Residual compressive strength. Wood bio-aggregates. Wood bio-concretes.

INTRODUCTION

The technologies and building works developed by Civil Engineering bring positive impacts on the quality of life by constructing buildings and infrastructure for the population, which attend to the socioeconomic needs of humanity (LEE et al., 2017). However, for this, the industry consumes a large portion of natural resources and thus contributes to environmental degradation through pollution and high rates of greenhouse gases (GHGs) release (ZHANG; WU; SHEN, 2015). Globally, this sector is responsible for the consumption of 60% of raw materials (BRIBIÁN; CAPILLA; USÓN, 2011), 40% of energy, 12% of water (SAID; BERGER, 2014), and up to 40% of GHG emissions (SON et al., 2011).

In this context, researchers and industries have joined efforts to make the construction field less harmful to the environment through integrated techniques that address waste and sustainability, ensuring that social and economic spheres are also contemplated (KHAN; AHMAD; MAJAVA, 2021). On the other hand, the construction industry uses a large amount of non-renewable natural resources that cause environmental degradation through their extraction and pollution (GOEL; GANESH; KAUR, 2019). One of the solutions to this problem is to reuse plant and agricultural residues that previously did not have an adequate destination and incorporate them into composite materials. These composites are capable of storing the CO sequestered during plant growth (BUMANIS et al., 2023; DA GLORIA et al., 2021; HERRERO; CAMAS; ULLAH, 2023; SONNIER et al., 2022).

Bio-concretes are composite materials whose final characteristics are, in general, linked to the properties of their constituent materials. Generally, those cement composites contain bio-aggregates bound by a cementitious matrix, water, and additives. Cementitious materials act as binders, providing resistance and durability, while bio-aggregate provides lower density, energy absorption capacity, and thermal acoustic insulation (MATOSKI, 2013). In Brazil, it is estimated that the civil construction industry is responsible for using about 70% of the wood extracted in the country, 54% of which is used raw as rafters and slats, 45% in agglomerates, and 1% in doors, and windows (DOS SANTOS et al., 2014). Thus, due to the high amount of products that need processing, a large amount of wood shavings is generated by carpentry without proper disposal, which makes it possible to use them as bio-aggregates in cementitious composites.

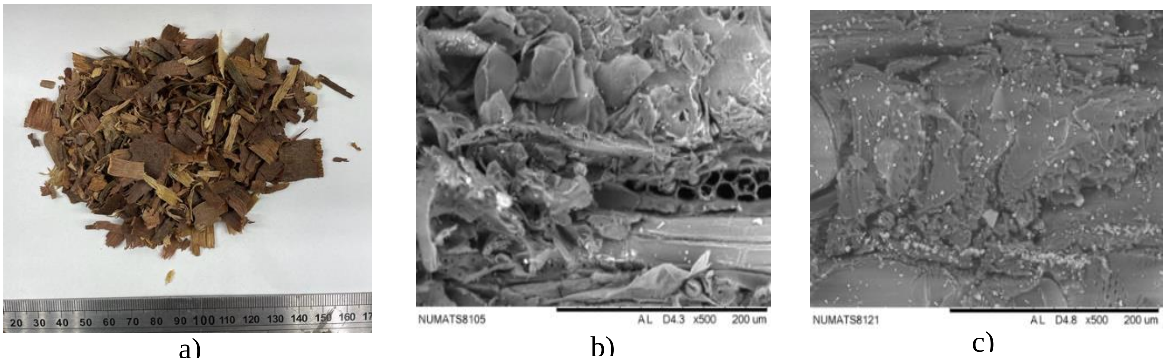
Some chemical components present in wood can negatively affect the performance of bio-concrete, which can reflect on hydration, hardening, and mechanical properties (AMZIANE; COLLET, 2017). Vaickelionis and Vaickelioniene (2006) state that extractives (resins, fatty acids, terpenes, simple sugars, phenolic compounds) and hemicellulose are mainly responsible for the negative effect on the hydration of bio-concrete, as they can be degraded by the high alkalinity of the cement and release by-products that delay the hydration of the cement. Beraldo et al. (2002) also state that the presence of sugars and extractives soluble in water or alkali slows down the setting time of the cement. Quiroga et al. (2016) explain that the presence of inhibitory substances promotes the formation of a membrane around the anhydrous cement grains, which prevents the access of water to them and causes a reduction in the cohesion of the material. Therefore, the bio-aggregates must be submitted to a previous treatment to inhibit these effects and be applied to bio-concretes. One of the solutions found is the treatment in an alkaline solution of calcium hydroxide, which proved to be a more efficient method than the thermal treatment when analyzing the compressive strength of bio-concrete produced with treated wood (AGUIAR et al., 2022).

Since bio-concrete is a composite that can contain large fractions of plant material in its composition, its chemical composition content affects combustion properties (DOREZ et al., 2014). Thus, it is necessary to know the fire reaction properties of these materials and classify them based on fire safety standards. In the Euroclass system, building materials are divided into seven classes based on their fire reaction properties (BUMANIS et al., 2023). The highest class, the one with the greatest safety for fire retardant wood products, classified as A2, while low-density fiberboard is assigned to class E. Meanwhile, most products containing natural wood get European class D with known and stable fire performance (OSTMAN; MIKKOLA, 2006). In this regard, developing a composite that does not ignite and maintains its level of mechanical performance is one of the challenges faced by bio-based materials (GIANCASPRO; PAPAKONSTANTINOU; BALAGURU, 2009). Therefore, this study aims to provide an overview of the flammability of bio-aggregates and wood bio-concretes using a Mass Loss Cone Calorimeter, as well as the residual compressive strength of bio-concretes after cone calorimeter tests.

MATERIALS AND METHODS

RAW MATERIALS

In this work, wood shavings (WS) were collected from the state of Rio de Janeiro (Brazil) as residues, which contain a mix of four species: 1. Manilkara salzmanni, 2. Erisma uncinatum warm, 3. Cedrela fissilis and 4. Hymenolobium petraeum. This material went through processing to obtain the required characteristics for the production of bio-concrete. First, the WS particles were separated through mechanical sieving, and only the fraction of nominal diameter superior to 1.18 mm was used. After that, this material was treated in calcium hydroxide solution at a concentration of 1.85 g/l (BEZERRA et al., 2023). Finally, the treated material was air-dried and homogenized using the method of the elongated pile. The bulk density, moisture content, and water absorption of the treated WS were 530 kg/m^3, 19%, and 70%, respectively. In Figure 1-a it is possible to observe the visual appearance of the wood shavings, while in Figure 1-b it is possible to see the micrography of the bio-aggregates without any treatment, and in Figure 1-c the deposition of calcium hydroxide in the particles of wood shavings after alkaline treatment.



a) b) c)

Figure 1- Wood shavings used for the production of bio-concrete: a) Aspect of the bio-aggregate, b) SEM of wood shavings in natural state, and c) SEM of wood shavings after alkaline treatment

In addition to Portland cement Brazilian type CPIIF-40, fly ash and rice husk ash were used as SCMs to reduce cement consumption and CO_2. The chemical composition, determined by X-ray Fluorescence Spectrometry, and the specific density, obtained by a helium gas pycnometer, of these materials are presented in Table 1.

Table 1- Chemical composition and specific mass of cementitious materials.

Oxides	**Cement**	**Fly ash**	**Rice husk ash**
SiO_2	12.715%	54.434%	94.305%
Al_20_3	3.496%	31.133%	0.000%
Fe_2O_3	4.451%	5.350%	0.072%
K_2O	0.596%	3.512%	2.470%
CaO	73.927%	1.815%	1.092%
SO_3	4.013%	1.715%	1.483%
TiO_2	0.000%	1.104%	0.000%
BaO	0.000%	0.553%	0.000%
Tm_2O_3	0.000%	0.135%	0.000%
ZrO_2	0.000%	0.087%	0.000%
MnO	0.094%	0.056%	0.545%
ZnO	0.029%	0.040%	0.000%
SrO	0.348%	0.024%	0.000%
Y_2O_3	0.000%	0.014%	0.000%
CuO	0.028%	0.000%	0.017%
LOI*	9.78%	1.66%	5.19%
Specific Mass	3053 kg/m^3	1885 kg/m^3	2510 kg/m^3

*Loss on ignition

WOOD BIO-CONCRETE

Three volumetric fractions of WS (40%, 45%, and 50%) was adopted for the production of wood bio-concretes (WBC). The cement matrix was composed, in mass, of 45% of cement (CEM), 25% of rice husk ash (RHA) and 30% of fly ash (FA). As a setting accelerator, calcium chloride (CC) was used in the content of 2% in relation to the mass of cementitious materials of each mixture. The water-to-binder ratio was set at 0.30 for all blends. In addition to cement hydration water (Wh), a compensation water (Wc), referring to the water absorbed by the wood bio-aggregates, was considered to ensure good workability of the bio-concretes. Therefore, total water (Wt) is the sum of hydration water and compensation water. These percentages of materials were based on previous works (ARAUJO et al., 2022; DA SILVA et al., 2023). Table 2 presents the consumption of materials of all blends studied, in kg/m^3.

Table 2- Wood bio-concretes composition, in kg/m^3.

WBC	WS	CEM	FA	RHA	CC	Wh	Wc
WBC40	212.00	375.82	250.55	208.79	16.70	250.55	148.40
WBC45	238.50	344.50	229.67	191.39	15.31	229.67	166.95
WBC50	265.00	313.18	208.79	173.99	13.92	208.79	185.50

Production process of bio-concretes followed adaptations of the Brazilian Standard ABNT NBR 16697 (2018). The procedure began with mixing the wood shavings and cementitious materials for 1 minute. After that, total water, previously mixed with calcium chloride, was added progressively over 1 minute. A total mixing time of 4 minutes was necessary to obtain a homogenous bio-concrete. The samples were cast in two layers in prismatic molds of 100 x 100 x 25 mm (length x width x thickness) and each layer was mechanically vibrated on a vibration table (68 Hz) for 10 seconds. After 24 hours, the samples were demolded and stored in a room at a temperature of 22±3ºC and relative humidity of 55± 5% until reaching 28 days of age. Figure 2 shows the wood bio-concrete samples before the fire reaction tests.

Figure 2- Samples of WBCs before heat flux: a) WBC40, b) WBC45, and c) WBC50

CONE CALORIMETER TESTS

A Mass Loss Cone Calorimeter (MLCC), model FTT-0014/2012 (Figure 3), was used to perform reaction to fire tests on wood bio-aggregates and wood bio-concretes. The wood bio-aggregates were tested in natural conditions (NW) and treated in ($Ca(OH)_2$) conditions (TW) and the bio-concretes with the volumetric fractions of biomass previously indicated: 40% (WBC40), 45% (WBC45), and 50% (WBC50). A heat flux of 50 kW/m^2 was chosen because it represents a heat flux of a developed fire. Nowadays, this equipment operates the most advanced method to evaluate the reaction to fire properties of a material on a reduced scale. Six samples of each type were tested. All faces of the samples, except for the top face, were wrapped with aluminum foil. The specimens were exposed to the heat flux under the cone located at 25 mm from the sample surface to begin the test.

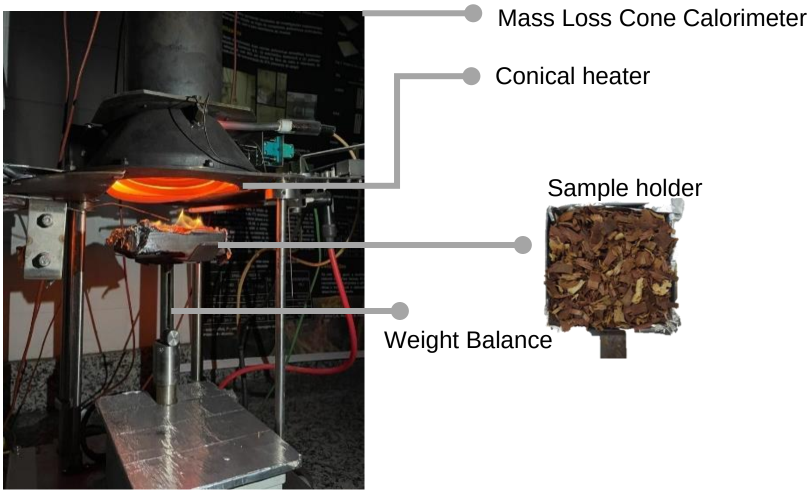


Figure 3- General scheme of the Mass Loss Cone Calorimeter

The test procedure was performed according to the standards ISO 17554 (2014) and ISO 13927 (2005). In all tests, the samples were examined in horizontal position up to 2 minutes after the flame ceases, or up to 10 minutes if the sample does not ignite. During the test, the following reaction to fire properties were determined: heat release rate (HRR), peak of HRR (PHRR), medium value of HRR (MHRR), total heat released (THR), total mass loss (TML), effective heat of combustion (EHC), maximum temperature reached (MTR), time to ignition (TTI), and time to flame out (TTF).

COMPRESSIVE STRENGTH

The bio-concrete compression tests were performed on 6 specimens of each mix. In order to evaluate the residual strength of wood bio-concrete, samples were tested before and after cone calorimeter tests. For this, a Bionix– 25 kN was used with a displacement speed of 0.3 mm/min. The samples, after being subjected to the fire reaction tests, were cut in smaller samples with dimensions of 25 x 25 x 50 mm (length x width x height). The mass and dimensions were measured to verify variation in their density after cone calorimeter tests.

RESULTS AND DISCUSSION

ANOVA analysis of all data indicated that all reported in this study, where found to fall within the 95% confidence interval band for having a normal distribution and one analysed by the Tukey Test method to identify significant difference between the variables.

REACTION TO FIRE

The main results of the reaction to fire properties are presented in Table 3. In addition, data of thickness and density of the samples were provided. The coefficient of variation is shown in parentheses.

Table 3- Combustion properties of wood bio-aggregates and wood bio-concretes.

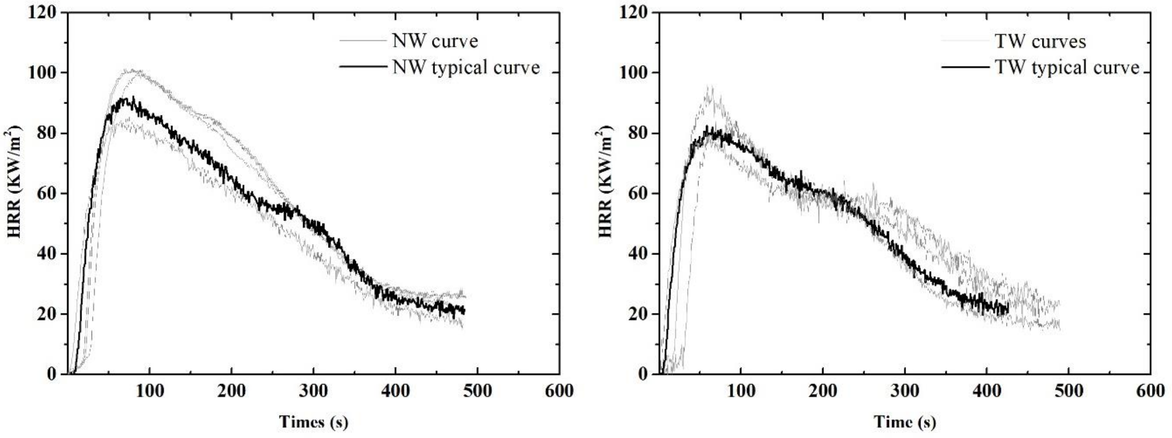
	NW	**TW**	**WBC40**	**WBC45**	**WBC50**
1 Thickness (mm)	25	25	25.5 (3.83)	25.1 (0.56)	24.5 (1.86)
2 Density (kg/m^3)	-	-	1353.5 (1.20)	1322.5 (3.22)	1090.6 (2.11)
3 PHRR (kW/m^2)	93.99 (7.01)	83.74 (11.19)	13.25 (15.97)	13.07 (9.74)	14.32 (5.54)
4 MHRR (kW/m^2)	65.34 (7.51)	57.07 (13.10)	9.64 (18.66)	9.51 (11.46)	11.41 (6.21)

5 THR (MJ/m^2)	22.3 (7.37)	18.6 (13.56)	6.3 (15.08)	5.8 (11.29)	6.9 (5.89)
6 TML (%)	84.14 (4.14)	77.48 (3.71)	11.72 (7.85)	11.73 (5.91)	13.42 (3.89)
7 EHC (MJ/kg)	7.88 (2.98)	7.49 (13.79)	1.57 (18.87)	1.48 (10.65)	1.93 (6.05)
8 MTR (°C)	777 (1.10)	765 (0.28)	477 (2.69)	475 (1.75)	483 (0.77)
9 TTI (s)	21 (14.20)	15 (31.10)	-	-	-
10 TTF (s)	362 (4.04)	348 (9.92)	-	-	-

The heat release rate (HRR) was defined as the heat release per unit area evaluated under a constant heat flux, using Eq. (1).

$$\dot{q}''(t) = \frac{q(t)}{A} = \frac{1.1c}{A}\,\frac{\Delta Hc}{r_0}\,\sqrt{\frac{\Delta P}{T_e}}\cdot\left[\frac{X^{o}_{O_2}-X_{O_2}(t)}{1,105-1.5\,X_{O_2}(t)}\right] \quad (1)$$

Where $\dot{q}''$ is the HRR (kW/m2); q(t) is the heat released (kW); A is the area initially exposed in horizontal orientation (m2) before the test, and Δ_{hc} is the net heat of combustion (kJ/kg). In fire reaction studies, the heat release rate is the most important parameter considered, required in zone and field models, as it concerns the fire control characteristics and indicates the contribution to the fire development. Figure 4 shows the heat release rate curves measured in samples of wood shavings in their natural state (Figure 4-a) and after alkaline treatment (Figure 4-b). Because of concerns about incorporating plant residues in the production of concrete due to the incompatibility between bio-aggregates and the cementitious matrix (SUN; TOMPKINSON, 2003), the use of methods that reduce the percentage of extractives present in the biomass, which are mainly responsible for delaying cement hydration (BERALDO et al., 2002; DELANNOY et al., 2020), has become an interesting and widely technique for the viability of bio-concrete production (DAYO et al., 2018; DELANNOY et al., 2020; SUN; TOMPKINSON, 2003; ZEGAOUI et al., 2018). In wood bio-concrete, extractives can affect mechanical properties, density and moisture content (BODIG; JAYNE, 1982). In the fire reaction properties, a reduction of approximately 11% on the heat release rate was observed between natural and treated bio-aggregates. It occurs because the alkaline treatment removes the extractives from wood shavings, which are the components that release the most heat during burning (DIETENBERGER; HASBURGH, 2016), with their content reduced the biomass will release less heat.

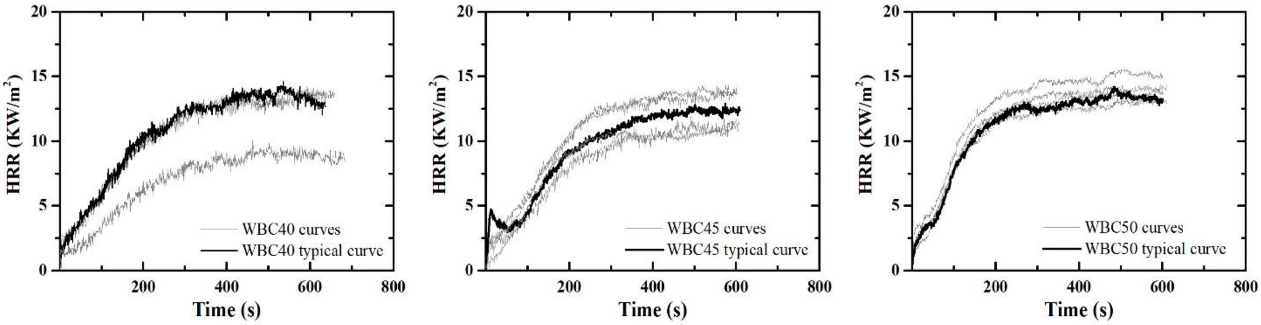


a) b)

Figure 4- Variation of heat release rate over time: a) NW, and b) TW

In all curves presented in Figure 4, it was observed that the rate of heat release increased suddenly when the specimen was ignited and then dropped after the material was degraded by heat. For studies carried out in wood using Cone Calorimeter, the presence of two peaks in the curves is commonly reported in the literature (CHUNG, 2010; KIM; LEE; KIM, 2012; LEE et al., 2011). However, when it comes to particulate material, oxygen levels are higher inside the sample than solid materials. Therefore, the heat can spread faster and maximize the damage caused by fire, reducing the ignition time. The initial peak is mainly caused by ignition followed by the formation of the carbonization layer that occurs in the first seconds of tests. After the occurrence of the first peak, the rate of heat release tends to decrease. When the fire reaction behavior of wood samples in their natural state is evaluated, the samples are not completely burned since a charred layer that forms on the surface of the sample contributes to increasing the residual capacity of the member protecting the interior of the section (XU et al., 2015). As the wood shavings are in particulate format, this protection is minimized and the material is easily degraded, having a lower fire resistance than if evaluated in a solid format.

Figure 5 shows, respectively, the HRR curves over time for the bio-concretes produced with 40, 45, and 50% of bio-aggregates (Figure 5-a, 5-b, 5-c). However, even with different fractions of plant biomass, the variables did not show different statistical behavior among themselves. Two phases are observed in the presented curves. The first release of heat occurs in a more accentuated way, which is caused by the burning of the wood shavings that are on the surface of the sample. The second phase occurs around 300 seconds after starting the test, where there was a stabilization in the heat release rates of the samples that remain practically constant until the end of the test. Table 3, line 3 presents the PHRR values for all variables. The NW samples presented a value of 93.99 kW/m², while the TW samples presented a value of 83.74 kW/m², i.e. about 11% lower than the natural samples. Thus, the removal of extractives from biomasses caused by the alkaline treatment resulted in a reduction in the PHRR values of bio-concretes. When comparing the different bio-concretes, data are not discrepant. For the average values of MHRR (Table 3, line 4), comparing WBC40 with WBC50 it is possible to notice that there was an increase in this property of 18% with the increase of the biomass content. However, all bio-concretes maintain low heat release and no ignition.



a) b) c)

Figure 5- Variation of heat release rate over time: a) WBC40, b) WBC45, and c) WBC50

THR refers to the total heat of combustion released by the material during the test. The higher the value of THR, the greater the potential of thermal energy available for the combustion of the material to occur. In Table 3, line 5 the THR values are presented. When comparing bio-concrete with wood particles, it is possible to verify that the cementitious matrix acts on the bio-aggregates as an insulator for the propagation of heat. It provides for the material, in addition to becoming incombustible, decreasing the heat released under the fire conditions.

The total mass loss (Table 3, line 6) corresponds to the variation in the mass of the sample during the entire firing process, which is calculated using five-point numerical differentiation equations in cone calorimeter tests (ISO 17554:2014). It changes depending on material properties such as the level of pyrolysis, volatilization, and burning under constant heat flux. In addition to being directly related to the HRR, TML is also associated with specific extinguishing area and CO_2 produced during burning. A material that has a lower mass loss rate is indicative of a lower susceptibility for flame propagation. Figure 6-a shows the evolution of the mass loss rate over time for all variables studied and it was highlighted in the final 40 seconds of the evaluated bio-concrete samples.

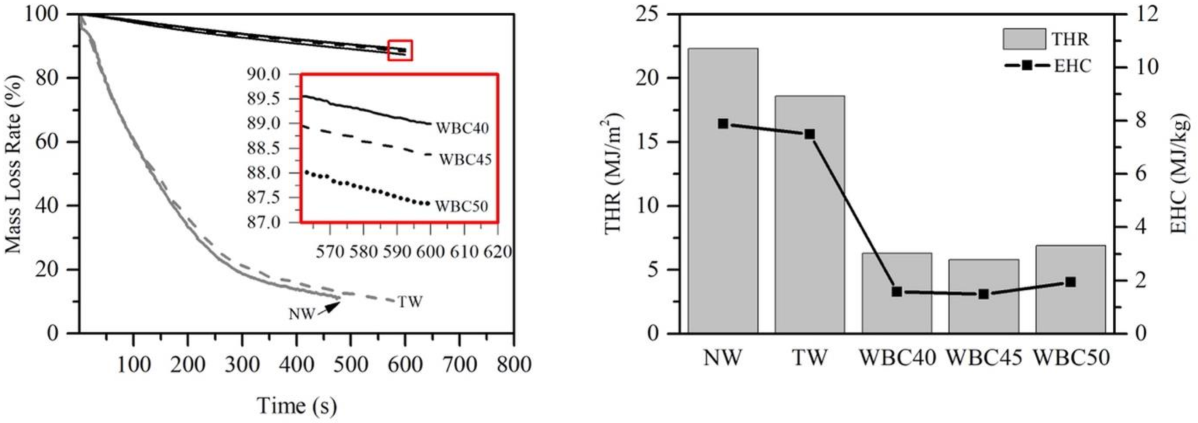


Figure 6- Reaction to fire properties: a) total mass loss over time, and b) total heat release and effective heat of combustion

The cementitious matrix behaved as a thermal insulator for the wood bio-aggregates, making the heat transfer more difficult and turning the composite into an incombustible material. In Figure 6-a, it is possible to observe that the bio-concretes had a small mass loss and the average values presented in Table 3, line 6 did not show discrepancy for the bio-concretes produced with volumetric fractions of 40% and 45%. For WBC50, there was an increase of 14% in TML compare to WBC40 and WBC45 due to the higher content of wood shavings and higher porosity in the matrix. Thus, despite the difference of 10% in the biomass content, the results for these properties did not vary significantly.

Average chemical heat of combustion, determined in the MLCC, is defined as the effective heat of combustion (EHC) (TEWARSON, 2002). This parameter corresponds to what would be expected in a fire where incomplete combustion occurs, when a material is not completely burned. EHC is a parameter that depends directly on the level of irradiance and time that corresponds to the heat released from the volatile portion during the combustion of the material, which can be calculated using Eq. (2) (JIANG; LI; GAO, 2015). Where MLR is the mass loss rate.

$$\mathrm{EHC} = \frac{HRR}{MLR} \tag{2}$$

Table 3, line 7 presents the mean EHC values found in this study for pilotless ignition conditions. It is possible to notice that the EHC values did not show significant differences for the three studied bio-concretes (See Figure 6-b). Hull *et al.* (2008) mentioned that the EHC is influenced by fire dynamics and combustion efficiency. For the NW and TW samples, which presented ignition, there was a variation in the EHC values up to 80% when compared to the bio-concretes.

WBC40, WBC45 and WBC50 did not present significant variation in EHC values (1.48 – 1.93 MJ/kg) due to the fact that they did not present ignition and released low heat, the peak value is very close to the average value. On the other hand, the samples of wood shavings, presented a very pronounced HRR peak, and, therefore, higher values of EHC (7.88 MJ/kg for NW and 7.49 MJ/kg for TW). Ignition time is the time required to establish a sustained flame on the sample surface. This is an important parameter to evaluate the combustion behaviour of materials, since the shorter the ignition time, the more flammable the material. In Table 3, line 9, the ignition time of the NW was 21 seconds and TW samples was 15 seconds (28% lower than NW). For the bio-concretes, there was no ignition.

RESIDUAL COMPRESSIVE STRENGTH

Figure 7 shows the average values of residual compressive strength of the studied bio-concretes. Since conventional concrete is a non-combustible material, little attention is paid to its reaction to fire properties. On the other hand, when exposed to heat, the material suffers a degradation and loss of its mechanical properties that affect its compressive and tensile strength, as well as its modulus of elasticity. This occurs because of chemical-physical processes that the material undergoes due to the high temperatures that induce widespread cracking and damage to the matrix and aggregates (ROSSINO et al., 2013, 2015).

Fire spalling phenomenon, occurs when there is a sudden detachment of layers or pieces of concrete from the surface of the element when exposed to extreme temperatures in fire situations. When this phenomenon occurs, depending on its magnitude, a significant decrease in the geometry of the cross-section can occur, exposing the reinforcement directly to flames, compromising the structural load capacity (ROSSINO et al., 2015). The literature reports two physical mechanisms that are associated with fire spalling: (i) the increase in pore pressure due to water vaporization (a thermo-hygro mechanism) and (ii) the introduction of thermal stresses due to high-temperature gradients (a thermo-mechanical mechanism) (BAZANT, 1997; KALIFA; MENNETEAU; QUENARD, 2000). For bio-concrete, as it may have a high content of bio-aggregates, thermal degradation of the biomass occurs, leading to a weakening of the composite.

The shrinkage suffered by the cementitious matrix and the carbonization of the vegetal biomass caused the decrease in bio-concrete density, which damaged its microstructure and, therefore, decreased its mechanical performance. As a composite material, when exposed to fire conditions and high temperatures, the bio-aggregate loses mass faster than the cementitious matrix, causing damage in the interface between them. Another point concerns the porosity present in the particles and their internal moisture content. When heated, water is easily eliminated in the form of vapor, which causes damage to the matrix. From Figure 7-a, a decrease of around 29% and 15% for WBC40 and WBC45, respectively after the cone calorimeter test, indicate a weakening of the bio-aggregate/cementitious matrix interface. For WBC50, which has a less resistant matrix, even without the action of the heat flux, the surface burning effect did not affect this mechanical property due to the high porosity that enable the release of heat from the sample, reducing damage caused at the interface due to heat buildup. Aguiar et al. (2022) showed that increasing the biomass content improves the thermal stability of wood bio-concrete.

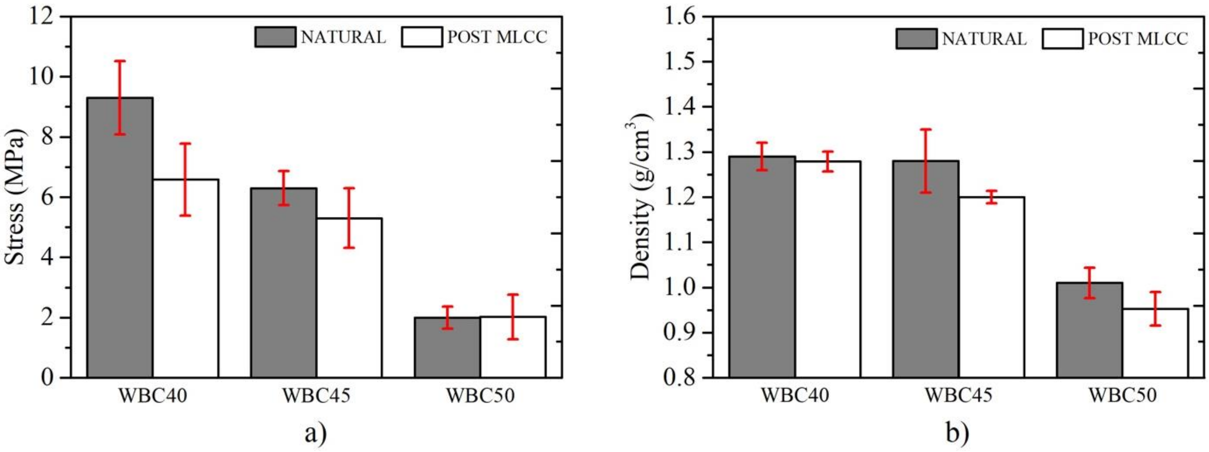


Figure 7- Post MLCC analysis of wood bio-concretes: a) residual compression, and b) density variation

According to the Analysis of Variance statistical tool (ANOVA) and the Tukey test performed, there is a significant difference for the residual compression test when comparing the WBC40 results before and after exposure to fire conditions. The WBC45 and WBC50 samples showed no significant difference. When analysing the density of the materials, the shrinkage caused by the heat flux was proportional to the mass loss and therefore the samples did not present statistically significant differences.

CONCLUSIONS

This paper investigated the fire behaviour of bio-concrete produced with volumetric fractions of 40, 45, and 50% of wood shavings in a Mass Loss Cone Calorimeter and its post-fire residual compressive strength. Parameters such as time to ignition (TTI), Heat Release Rate (HRR), peak of HRR (PHRR), medium value of HRR (MHRR), total heat released (THR), total mass loss (TML), and effective heat of combustion (EHC) were studied and the following conclusions can be addressed:

- Alkaline treatment, contributed positively to the reduction of PHRR, MHRR, THR, and TML, despite not being indicated as a technique to improve fire reaction parameters. However, due to the high variability found in materials of plant origin and the non-applicability separately of wood shavings, effects of treatment in the reaction to fire properties becomes secondary;
- All analyzed bio-concretes presented a firing process in two stages. The first results from an increased release of heat by burning the bio-aggregate located in the samples surface, and the second by a smaller release of heat from the matrix cement;
- The paste of cementitious materials behaved as an insulating material promoting incombustibility to the composite since no bio-concrete ignited;
- The difference of 10% of bio-aggregate (WBC40 – WBC50) was not enough to bring significant differences in the fire reaction properties of the bio-concretes;
- The conditions similar to a fire caused a reduction of the mechanical capacity of the bio-concretes and a decrease in density for the WBC40 while statistically this behaviour was not significant for the WBC45 and WBC50.

ACKNOWLEDGEMENTS

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REFERENCES

AGUIAR, A. L. D. et al. Environmental Performance of Wood Bioconcretes with Different Wood Shavings Treatments. **Construction Technologies and Architecture**, v. 1, p. 69–76, 2022.

AGUIAR, A. L. D.; TOLEDO FILHO, R. D. **Influence of High Temperatures on the Mechanical Properties of Wood Bio-Concretes**. Construction Technologies and Architecture. **Anais**...Trans Tech Publ, 2022

AMZIANE, S.; COLLET, F. **Bio-aggregates based building materials: State-of-the-art report of the RILEM technical committee 236-BBM**. [s.l.] Springer, 2017. v. 23

ARAUJO, A. et al. **Potential of Earth-Based Bamboo Bio-Concrete in the Search for Circular and Net-Zero Carbon Solutions to Construction Industry**. IOP Conference Series: Earth and Environmental Science. **Anais**...IOP Publishing, 2022

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 16697: Cimento Portland-Requisitos. 2018. , [s.d.].

BAZANT, Z. P. Analysis of pore pressure, thermal stress and fracture in rapidly heated concrete. 1997.

BERALDO, A. L. et al. Compósitos à base de resíduos vegetais e cimento Portland. **ENCONTRO BRASILEIRO EM MADEIRA E EM ESTRUTURAS DE MADEIRA**, v. 8, 2002.

BEZERRA, C. G. et al. Caracterização reológica de pastas ternárias para o desenvolvimento de bioconcretos leves de casca de arroz. **Matéria (Rio de Janeiro)**, v. 28, 2023.

BODIG, J.; JAYNE, B. A. Mechanics of wood and wood composites. 1982.

BRIBIÁN, I. Z.; CAPILLA, A. V.; USÓN, A. A. Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. **Building and environment**, v. 46, n. 5, p. 1133–1140, 2011.

BUMANIS, G. et al. Fire Resistance of Phosphogypsum-and Hemp-Based Bio-Aggregate Composite with Variable Amount of Binder. **Journal of Composites Science**, v. 7, n. 3, p. 118, 2023.

CHUNG, Y.-J. Comparison of combustion properties of native wood species used for fire pots in Korea. **Journal of Industrial and Engineering Chemistry**, v. 16, n. 1, p. 15–19, 2010.

DA GLORIA, M. Y. R. et al. A comprehensive approach for designing workable bio-based cementitious composites. **Journal of Building Engineering**, v. 34, p. 101696, 2021.

DA SILVA, N. A. et al. Bond-Behavior of Bamboo Strips and Bamboo/Wood Bio-Concretes. In: **Proceedings of the 75th RILEM Annual Week 2021: Advances in Sustainable Construction Materials and Structures**. [s.l.] Springer, 2023. p. 923–933.

DAYO, A. Q. et al. The influence of different chemical treatments on the hemp fiber/polybenzoxazine based green composites: Mechanical, thermal and water absorption properties. **Materials Chemistry and Physics**, v. 217, p. 270–277, 2018.

DELANNOY, G. et al. Impact of hemp shiv extractives on hydration of Portland cement. **Construction and Building Materials**, v. 244, p. 118300, 2020.

DIETENBERGER, M. A.; HASBURGH, L. E. Wood products: thermal degradation and fire. **Reference module in materials science and materials engineering**, p. 1–8, 2016.

DOREZ, G. et al. Effect of cellulose, hemicellulose and lignin contents on pyrolysis and combustion of natural fibers. **Journal of Analytical and Applied Pyrolysis**, v. 107, p. 323–331, 2014.

DOS SANTOS, M. F. N. et al. Comparative study of the life cycle assessment of particleboards made of residues from sugarcane bagasse (Saccharum spp.) and pine wood shavings (Pinus elliottii). **Journal of Cleaner Production**, v. 64, p. 345–355, 2014.

GIANCASPRO, J.; PAPAKONSTANTINOU, C.; BALAGURU, P. Mechanical behavior of fire-resistant biocomposite. **Composites Part B: Engineering**, v. 40, n. 3, p. 206–211, 2009.

GOEL, A.; GANESH, L. S.; KAUR, A. Sustainability integration in the management of construction projects: A morphological analysis of over two decades research literature. **Journal of Cleaner Production**, v. 236, p. 117676, 2019.

HERRERO, Y. R.; CAMAS, K. L.; ULLAH, A. Characterization of biobased materials. In: **Advanced Applications of Biobased Materials**. [s.l.] Elsevier, 2023. p. 111–143.

HULL, T. R. et al. Comparison of toxic product yields of burning cables in bench and large-scale experiments. **Fire Safety Journal**, v. 43, n. 2, p. 140–150, 2008.

ISO 13927. Plastics – Simple heat release test using a conical heater and a thermopile detector. Brussels: CEN – Comité Européen de Normalisation. 2005. , [s.d.].

ISO 17554:2014, International Organization for Standardization, "Reaction to fire tests — Mass loss measurement". , [s.d.].

JIANG, J.; LI, J.; GAO, Q. Effect of flame retardant treatment on dimensional stability and thermal degradation of wood. **Construction and building materials**, v. 75, p. 74–81, 2015.

KALIFA, P.; MENNETEAU, F.-D.; QUENARD, D. Spalling and pore pressure in HPC at high temperatures. **Cement and concrete research**, v. 30, n. 12, p. 1915–1927, 2000.

KHAN, I. S.; AHMAD, M. O.; MAJAVA, J. Industry 4.0 and sustainable development: A systematic mapping of triple bottom line, Circular Economy and Sustainable Business Models perspectives. **Journal of Cleaner Production**, v. 297, p. 126655, 2021.

KIM, J.; LEE, J.-H.; KIM, S. Estimating the fire behavior of wood flooring using a cone calorimeter. **Journal of thermal analysis and calorimetry**, v. 110, n. 2, p. 677–683, 2012.

LEE, C. et al. Social conflict management framework for project viability: Case studies from Korean megaprojects. **International Journal of Project Management**, v. 35, n. 8, p. 1683–1696, 2017.

MATOSKI, A. Utilizacao de po de madeira com granulometria controlada na producao de paineis de cimento-madeira. 2013.

OSTMAN, B. A.-L.; MIKKOLA, E. European classes for the reaction to fire performance of wood products. **Holz als Roh-und Werkstoff**, v. 4, n. 64, p. 327–337, 2006.

QUIROGA, A.; MARZOCCHI, V.; RINTOUL, I. Influence of wood treatments on mechanical properties of wood-cement composites and of Populus Euroamericana wood fibers. **Composites Part B: Engineering**, v. 84, p. 25–32, 2016.

ROSSINO, C. et al. **Concrete spalling sensitivity versus microstructure: Preliminary results on the effect of polypropylene fibers**. MATEC Web of Conferences. **Anais**...EDP Sciences, 2013

ROSSINO, C. et al. **HPC subjected to high temperature: a study on intrinsic and mechanical damage**. Key Engineering Materials. **Anais**...Trans Tech Publ, 2015

SAID, H.; BERGER, L. Future trends of sustainability design and analysis in construction industry and academia. **Practice Periodical on Structural Design and Construction**, v. 19, n. 1, p. 77–88, 2014.

SILVA, N. A. DA. Estudo da aderência bambu-bioconcreto. 2019.

SON, H. et al. Implementing sustainable development in the construction industry: constructors' perspectives in the US and Korea. **Sustainable Development**, v. 19, n. 5, p. 337–347, 2011.

SONNIER, R. et al. Fire behaviour of hemp, clay and gypsum-based light biobased concretes and renders. **Construction and Building Materials**, v. 331, p. 127230, 2022.

SUN, R. C.; TOMPKINSON, J. Comparative study of organic solvent and water-soluble lipophilic extractives from wheat straw I: yield and chemical composition. **Journal of wood science**, v. 49, n. 1, p. 47–52, 2003.

TEWARSON, A. Generation of heat and chemical compounds in fires, Section 3rd, Chapter 5. **SFPE Handbook of Fire Protection Engineering,(3rd edn), PJ DiNenno, Editor-in-Chief. National Fire Protection Association: Quincy, Massachusetts**, 2002.

VAICKELIONIS, G.; VAICKELIONIENE, R. Cement hydration in the presence of wood extractives and pozzolan mineral additives. **Ceramics Silikaty**, v. 50, n. 2, p. 115, 2006.

XU, Q. et al. Combustion and charring properties of five common constructional wood species from cone calorimeter tests. **Construction and Building Materials**, v. 96, p. 416–427, 2015.

ZEGAOUI, A. et al. Morphological, mechanical and thermal properties of cyanate ester/benzoxazine resin composites reinforced by silane treated natural hemp fibers. **Chinese Journal of Chemical Engineering**, v. 26, n. 5, p. 1219–1228, 2018.

ZHANG, X.; WU, Y.; SHEN, L. Embedding "green" in project-based organizations: the way ahead in the construction industry? **Journal of Cleaner Production**, v. 107, p. 420–427, 2015.