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Vegetal Fiber Additives in Mortars: Experimental Characterization of Thermal and Acoustic Properties

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Abstract: This paper investigates the influence of adding vegetal fibers on thermal and acoustic performance based on natural hydraulic lime. Mortar samples with 10% weight of vegetal fibers were fabricated adding water to obtain easily workable mortars with good consistency; their performance was compared to mortar samples without vegetal fibers. The fibers were of different types (rice husk, spelt bran, and Khorasan (turanicum) wheat chaff) and size (*as-found* and ground form). Thermal performance was measured with the Small Hot Box experimental apparatus. Thermal conductivity was reduced in the 1–11% range (with Khorasan wheat chaff and rice husk); no significant reduction was found with spelled bran in the mixture. When ground, fibers were characterized by both good thermal and acoustic absorption performance; a reduction of 6–22% in thermal conductivity λ was achieved with spelled bran (λ = 0.64 W/mK) and rice husks (λ = 0.53 W/mK), whereas the Khorasan wheat chaff had the highest sound absorption average index (0.38). However, the addition of fibers reduced sound insulation properties due to their low weight densities. This reduction was limited for rice husks (transmission loss value was only 2 dB lower than the reference).

Keywords: vegetal fiber additives; lime mortars; grinded fibers; thermal performance; acoustic performance

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1. Introduction

In the coming years, one of the main global challenges is the fight against climate change through strategies oriented to environmental sustainability. In this context, adequate knowledge of environmental issues is required in order to reduce carbon dioxide emissions in the atmosphere and to promote rational use of renewable sources [1]. The two main sectors characterized by major environmental impact are construction and waste. For the construction industry, recovery and energy upgrades of existing buildings stock are key tools for sustainable development. On the other hand, in the waste sector, the adopted strategy to ecological transition consists in reducing waste production, and encouraging reuse and recycling. Agricultural products for the production of composite construction materials could be a valid solution for reducing the environmental impact of the construction and waste sectors. This solution offers both the advantage of retrofitting existing buildings stock [2] and reducing the construction of new buildings, exploitation of soil, and raw materials, and the benefit of reusing and recycling large amounts of waste as a resource.

In the last two decades, several studies focused on the properties of composite building materials containing different type of waste, especially natural ones, with a double objective: improving thermal performance, and reducing the composite weight and the structure design loads. Lertwattanaruk and Suntijitto [3] studied the properties of cement materials with coconut coir and oil palm fibers for residential building applications; the thermal conductivity of these natural fiber cements was 39–60% lower compared to that of the control specimen (λ = 0.68 W/mK). The study showed that the thermal conductivity of natural-fiber-reinforced mortar decreases when increasing the fiber volume in the mix. Values of 0.41, 0.38, and 0.37 W/mK were found for mortars with 5%, 10%, and 15% by weight of coconut coir fiber, respectively, and of 0.40, 0.30, and 0.27 W/mK for mortar containing the same percentages of oil palm fibers. Similar results were found in Khedari et al. [4] for lightweight composite construction materials with low thermal conductivity, composed of waste coconut and durian fibers. Samples with 20% weight of coconut fibers and 10% weight of durian fibers are characterized by the best thermal performance: λ values of coconut and durian fiber cements are lower than that of the reference (λ = 1.6452 W/mK) by about 85% and 79%, respectively. Chabbanes et al. [5] compared the results of experimental tests on lightweight insulating concrete with raw rice husks and hemp-fiber-reinforced mortars. As highlighted by other authors, thermal properties of natural-fiber-reinforced mortar decreased by increasing the fiber amount. The two composite materials showed similar values of dry thermal conductivity, in the 0.10–0.14 W/mK range for concrete with rice husks and in the 0.09–0.13 W/mK range for hemp mortar, for a base/additive mass ratio of 1.5–2.5 (corresponding to 70% and 40% of fiber, respectively). Similar behaviors in terms of thermal performance were demonstrated by Benmansour et al. [6] for natural mortar reinforced with date palm fibers, and for lightweight concrete reinforced with natural fibers of jute, coconut, sugar cane, sisal, and basalt by Asim et al. [7]. Conversely, a study of Pachla et al. [8] on the thermal, acoustic, and mechanical performance of a lightweight cementitious matrix composite reinforced with rice husks showed that the addition of fibers increased thermal conductivity. The composite material with 35% weight into the cement matrix was characterized by a thermal conductivity of 0.2756 W/mK, higher compared to that of the plain matrix specimens (λ = 0.2420 W/mK).

Studies on the acoustic properties of composite biomaterials are less numerous. A composite material with 35% weight of rice husk fiber was characterized by the best performance in terms of acoustic absorption, but not statistically significant differences in acoustic insulation compared to plain matrix ones, as demonstrated in Pachla et al. [8].

Several studies of natural-fiber-reinforced composites demonstrated that natural fiber could enhance the mechanical characteristics of mortars. Comak et al. [9] investigated the effects of hemp fibers with different weight ratios (1%, 2%, and 3%) and different lengths (6, 12, and 18 mm) on the mechanical characteristics of cement-based mortar. Compared to the reference sample (compressive strength equal to 27.94 MPa), Comak et al. observed an increase in compressive strength at 28 curing days of up to 30% (36.46 MPa) for mortars added with 3% and 18 mm of length of hemp fibers. Furthermore, flexural strength increases by increasing the fiber amount: compared to the reference sample (5.02 MPa), the maximal value of flexural strength (5.87 MPa) was obtained for a sample reinforced with 1% of 18 mm long fibers. In a recent study of Danso [10], the effect of 0 and 2% weight of rice husks on the mechanical properties of cement-based mortar was studied. Experimental results revealed an improvement in both compressive and tensile strengths, with an increase of 6% (24.23 MPa) and 24% (3.39 MPa) with respect to the control specimens. A study of Fokam et al. [11] focused on cement mortar reinforced with palm nut fibers with a volume fraction between 0.5% and 3%. Results showed that compressive strength decreased from 42.4 MPa for the control specimens (0% fiber) to 31.1 MPa for the specimens, with 3% fibers. Conversely, flexural strength increases for samples reinforced up to 2% of fibers. The maximal value of flexural strength was equal to 11 MPa for the reinforced specimens compared to the control value of about 8.3 MPa.

Using natural fibers in construction offers clear environmental advantages: natural fibers are abundant, readily available, cheap, renewable, and ecofriendly from a circular-economy perspective. Moreover, the results of available studies demonstrate that natural fiber composites have good thermal, acoustic, and mechanical properties. Another benefit is represented by their low weight density. However, natural fibers are strongly affected by different factors even in the case of controlled cultivation, such as climatic and biotic factors, and agronomic and grinding techniques. For this reason, the properties of these biomaterials may be different based on the year, cultivation location, and genotype, resulting in different characteristics.

In this context, this paper presents the results of an experimental campaign aiming at the measurement of the thermal and acoustic performance of natural hydraulic lime mortars for structural applications. Different types of vegetal fibers (rice husk, spelt bran, and *turanicum* wheat chaff) were used in order to compare the performance of the different fiber types and to expand the literature data regarding not yet extensively studied natural fibers, such as spelt bran and *turanicum* wheat chaff.

2. Materials and Methods

2.1. Investigated Samples

Different types of vegetal fibers deriving from the husking, grinding, and threshing processes of crops were studied. This processing waste is mostly used in the livestock sector, in agriculture as fertilizers, in the production of pellets or as fillers for padding, although most is incinerated. Rice husk RH, spelled bran SB, and Khorasan (*turanicum*) wheat chaff KWC were analyzed both *as-found* (AI) and in ground form (GF) by means of a traditional mill available at FieldLab located in Papiano, near Perugia, in the Department of Agriculture, Food, and Environmental Sciences of the University of Perugia. Fibers were characterized through weighing and particle size analysis by sieving (Table 1); moisture was determined by comparing pre- and postdrying fiber weight. Rice husk and spelled bran were characterized by a similar moisture content (about 11%), whereas *turanicum* wheat chaff had much higher values (about 20% for the as-found material and 18% when ground). All tested materials were quite light, with a bulk density in the 61 kg/m^3–371 kg/m^3 range for the AI *turanicum* wheat chaff and GF rice husks, respectively. As found, the fibers of rice husks (RH_AI) and *turanicum* wheat chaff (KWC_AI), had a prevalent fiber diameter greater than 2.36 mm, whereas spelled bran ones (SB_AI) had a variable diameter, mostly greater than 0.6 mm; when ground, all fibers (RH_GF, SB_GF, KWC_GF) had a prevailing diameter of the particles of about 0.6 mm.

The definition of the mortar mix design is a rather complex process. The mix is determined according to the consistency, resistance characteristics, and intended use of the mortar. The mix design was based on five crucial factors: (1) the amount of water in the mix, which depends on the required consistency (more or less fluid mortar, more or less workable mortar); (2) the water–cement ratio according to the resistance to be obtained; (3) the water–cement ratio, determined according to durability and exposure class. Starting from correlations (1–3), the correlation between the involved volumes is determined (4); the maximal diameter of the aggregate is fixed by balancing the volumes of water, cement, and air. Correlation between total aggregate volume and granulometric curves of the single aggregates, evaluated with respect to an optimal granulometric curve (correlation 5), allows for defining the volumes of fine and coarse aggregates.

Table 1. Main characteristics of analyzed vegetal fibers.

Fiber		Density (kg/m^3)	Humidity (%)	Prevalent Diameter (mm)	
Rice husk (RH)	AI	112	10.8	2.36	
	GF	371	10.3	0.6	
Spelled bran (SB)	AI	279	11.6	0.6–2.36	
	GF	304	11.2	0.6	
Khorasan wheat chaff (KWC)	AI	61	19.5	2.36	
	GF	247	18.2	0.6	

To use these mortars in structural applications, the research and development division of a company specialized in the production of mortars prepared the mix design of the base mortar on the basis of the NHL3.5 natural hydraulic lime, class M5 [12]. It consisted of 41.25% binder weight (37.5% NHL3.5 natural hydraulic lime, 3.75% CL 70 natural hydraulic lime), 36% fine aggregate weight (fine sand), 19% coarse aggregate weight (coarse sand), 4% additive weight (3.75% metakaolin, 0.2% sodium carbonate, and 0.05% C8352). We added 28% water for the mortar preparation. This mortar (BM) was especially formulated for this research, with compressive strength of at least 2 MPa, to serve as a reinforcement in retrofit interventions of masonry buildings.

Vegetal fibers were used in the mixing of six different types of fiber-additive mortars. In order to obtain an easily workable mortar with a good consistency, 10% weight of each fiber (both as-found AI and ground GF), previously dried in an oven at 105 °C for release of humidity, was added to the basic formula (control mortar with rice husk MRH; control mortar with spelled bran MSB; control mortar with Khorasan wheat chaff MKWC). The percentage of water in the mix, depending on the used fiber, was determined starting from the basic value (28%) and increasing by 1% at a time. A mortar mixer was used to prepare the mortars. Each type of tested mortar, fiber and water contents, bulk density, and the density of freshly mixed mortar are shown in Table 2.

Table 2. Tested mortars: characteristics and composition.

Mortar		Sample	Fiber (wt %)	Water (%)	Bulk Density * (kg/m^3)	Fresh Mortar Density ** (kg/m^3)
Control mortar		BM	-	28	1140	1920
Control mortar + RH	AI	MRH_AI	10	37	900	1560
	GF	MRH_GF		34	810	1350
Control mortar + SB	AI	MSB_AI		38	840	1530
	GF	MSB_GF		39	1030	1440
Control mortar + KWC	AI	MKWC_AI		46	990	1580
	GF	MKWC_GF		46	640	1500

*, before adding water; **, after adding water.

For each mortar, a 300 mm square sample (27–40 mm thick) was fabricated by means of a wooden mold, in order to investigate the thermal properties (Figure 1). Samples were cured for 28 days at ambient temperature and humidity. Two extruded polystyrene panels (4 mm thick, one for each side of the sample) [13] were used as support.

(a) (b) (c) (d) (e)

Figure 1. Fabrication of a sample with rice husk vegetal fiber: (**a**) Dry base formula; (**b**) rice husk fiber; (**c**) mixed compound; (**d**) adding water into the mix; (**e**) mortar into the square mold.

For the acoustic measurements, cylindrical molds 100 mm diameter were used in order to assembly samples curing for 28 days at ambient temperature and humidity; the sample thicknesses were in the 22–26 mm range, and weight density increased when grinded fibers were used as additive in the mortar (Table 3).

Table 3. Characteristics of samples for acoustic measurements.

Sample	Weight (kg)	Thickness (m)	Density * (kg/m^3)
BM	0.277	0.025	1436
MRH_AI	0.194	0.024	1024
MRH_GF	0.203	0.025	1087
MSB_AI	0.155	0.023	873
MSB_GF	0.202	0.026	993
MKWC_AI	0.142	0.022	836
MKWC_GF	0.172	0.023	1002

* of the dried sample.

2.2. Thermal and Acoustic Measurements

The thermal properties of the mortars were evaluated with the Small Hot Box apparatus [14,15] (Figure 2) at the Department of Engineering (University of Perugia). The experimental facility is composed of a very insulated hot chamber heated by a wire (maximal power, 50 W) with a temperature control system. A sandwich insulated panel closes the system, and a square opening (300 × 300 mm^2 dimensions) is present in its central part for the sample location. The cold side of the system is the laboratory room, kept at constant temperature thanks to the HVAC system. The hot- and cold-side temperature difference was equal to 20 °C. Heat flux (q) was measured through a thermal flux meter installed in the central part of the sample; four thermal resistance probes were applied on each side of the sample for the measurement of the surface temperatures (T_{SH} and T_{SC} in the hot and cold side, respectively). The value of thermal conductivity λ could be calculated from thermal resistance R during the selected period (about 2–3 h) and the thickness of the specimen s, as shown in Equation (1):

$$\lambda = (q \times s)/(T_{SH} \times T_{SC}) \quad (1)$$

Figure 2. Small Hot Box apparatus.

The contribution of each mortar layer was calculated from the total thermal resistance of the composed sandwich (polystyrene panel + mortar + polystyrene panel), with polystyrene panel thermal resistance R_{pp} being known, as shown in Equation (2):

$$R_{tot} = R_{pp} + R + R_{pp} = 2\cdot(s_{pp}/\lambda_{pp}) + s/\lambda \quad (2)$$

For each test, the relative uncertainties (type B) $\dot{u}(\lambda)$ were calculated in compliance with JCGM 100:2008 [16] considering rectangular probability distribution.

Acoustic characterization was carried out by measuring sound absorption (normal incidence absorption coefficient) and insulation (transmission loss, TL) properties using an impedance tube (Kundt's tube, Brüel and Kjær, model 4206; 1/4 in. microphones Brüel and Kjær, model 4187) [17] (Figure 3). Absorption coefficient values were measured using the two microphones' configuration, according to the ISO 10534-2 standard [18], as the absorbed part of the acoustical energy of a wave incident on the tested sample in a specific configuration with respect to the total incident energy (the no absorbed part is reflected back to the source side). TL values were evaluated as noise abatement measured with the four microphones' configuration: two microphones were installed between samples and sound generator source, and the other two on the back of the sample. It was related to the sound transmission coefficient (τ) as follows:

$$TL = 10\cdot\log(1/\tau) \quad (3)$$

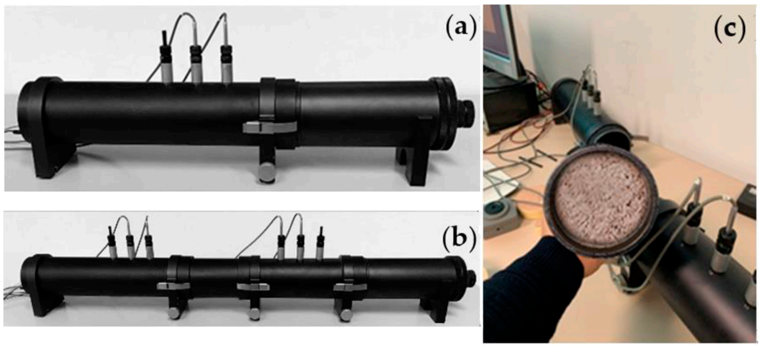

Figure 3. Impedance tube: (**a**) absorption and (**b**) TL measurements configurations; (**c**) Khorasan wheat chaff sample in the tube.

3. Experimental Results

3.1. Thermal Performance

Thermal performance of the studied mortar is shown in Table 4; the value λ_{pp} obtained for polystyrene panels was used to calculate the thermal conductivity of the investigated materials according to Equation (2). For each specimen, two tests were carried out by setting the hot chamber temperature at 45 and 50 °C. As expected, thermal conductivity value increases with set temperature. For all tests, relative uncertainty values were in the 2–7% range, in compliance with the measurements error of the apparatus (5–6%). Data, measured at a mean surface temperature in the 32–35 °C range, were reported at a standard temperature of 10 °C in compliance with ISO 10456 [19], considering temperature conversion coefficients of 0.0036 1/K and of 0.001 1/K for polystyrene and mortar respectively, as suggested by the standard. Thermal conductivity equal to 0.034 W/mK was obtained for the insulated support panel, close to the value declared in the technical sheet (λ = 0.033 W/mK, [13]).

Table 4. Thermal results of investigated samples: thermal flux meter methodology (Small Hot Box).

Sample	Hot Side Test Conditions (°C)	λ (W/mK)	$\dot{u}(\lambda)$ (%)	λ at 10 °C Mean Value (W/mK)
Polystyrene panel (40 mm thick)	45 50	0.038 0.038	2 3	0.034
BM (26.8 mm thick)	45 50	0.692 0.714	3 3	0.684
MRH_AI (28.2 mm thick)	45 50	0.621 0.626	4 3	0.608
MRH_GF (29.1 mm thick)	45 50	0.525 0.564	4 6	0.531
MSB_AI (36.6 mm thick)	45 50	0.701 0.718	4 7	0.691
MSB_GF (29.3 mm thick)	45 50	0.646 0.669	3 4	0.641
MKWC_AI (39.3 mm thick)	45 50	0.695 0.702	4 4	0.680
MKWC_GF (29.5 mm thick)	45 50	0.617 0.621	3 5	0.603

Adding as-found SB and KWC fibers did not cause changes in thermal performance (Figure 4). However, the RH mortar exhibited an improvement of its thermal performance (thermal conductivity was reduced of about 11% with respect to control mortar). When considering ground fibers into the control mortar, thermal conductivity values were significantly reduced (λ = 0.53 W/mK for MRH, λ = 0.64 W/mK for MSB, and λ = 0.60 W/mK for MKWF); the reductions were about 22%, 6%, and 12% with ground MRH, MSB, and MKWC, respectively.

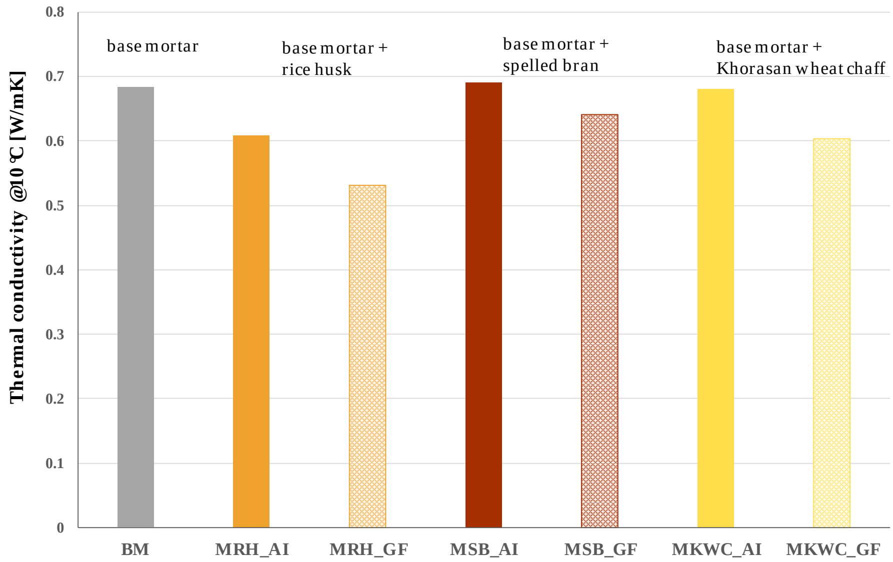

Figure 4. Thermal conductivity values at 10 °C: influence of vegetal fibers in mortars (base mortar with (+) fiber).

3.2. Acoustic Performance

Absorption coefficient α and sound insulation TL vs. frequency at normal incidence in the 100–1600 Hz frequency range are plotted in Figures 5 and 6. At least three measurements for each sample were carried out by modifying its position inside the tube. Vegetal fibers improved the mortar properties in terms of absorption coefficient with respect to control mortar, and a further increase was noted for grinded fibers. The sound absorption average index (SAA) (number rating the sound absorption properties at the twelve 1/3 octave bands from 200 to 1600 Hz, according to ASTM C423-09A Standard [20]) varied in the 0.26–0.38 range for samples with rice husk (MRH_GF) and Khorasan wheat chaff (MKWC_GF), respectively. It increased by 42–60% with respect to the control mortar (SAA = 0.15). The mortar mix with as-found vegetal fibers was characterized by less scattered acoustic absorption values (SAA = 0.24–0.25). The mix with rice husks had slightly worse performance than that of the other ones. When thickness increased, the first peak of the curves moved to a lower frequency: spelled bran mortar with fibers as found (0.023 m thick) had an α-peak at about 1120 Hz, whereas the samples with ground fibers (0.026 m thick) had a peak at about 900 Hz.

With respect to control mortar, adding fibers reduced density and sound insulation properties (Figure 6), according to the Mass Law. However, TL values of the sample with rice husks were similar to those of control mortar ones (TL = 5–21 dB for MRH_GF and TL = 7–23 dB for BM). The spelled bran mortar and *turanicum* wheat chaff mortars had worse sound insulation performance (maximal value of TL is about 13 dB at 1700 Hz). Lastly, ground fibers increased TL values with respect to as-found fibers in all the mixtures due to the higher densities; values were nonetheless lower than those of the control mortar.

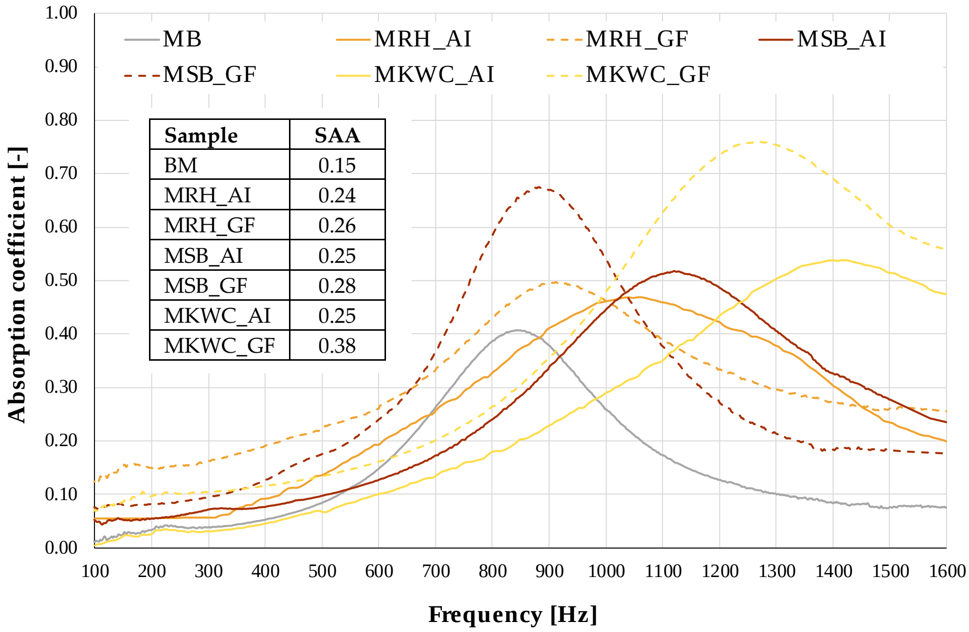

Figure 5. Normal incidence absorption coefficient and SAA index of the samples.

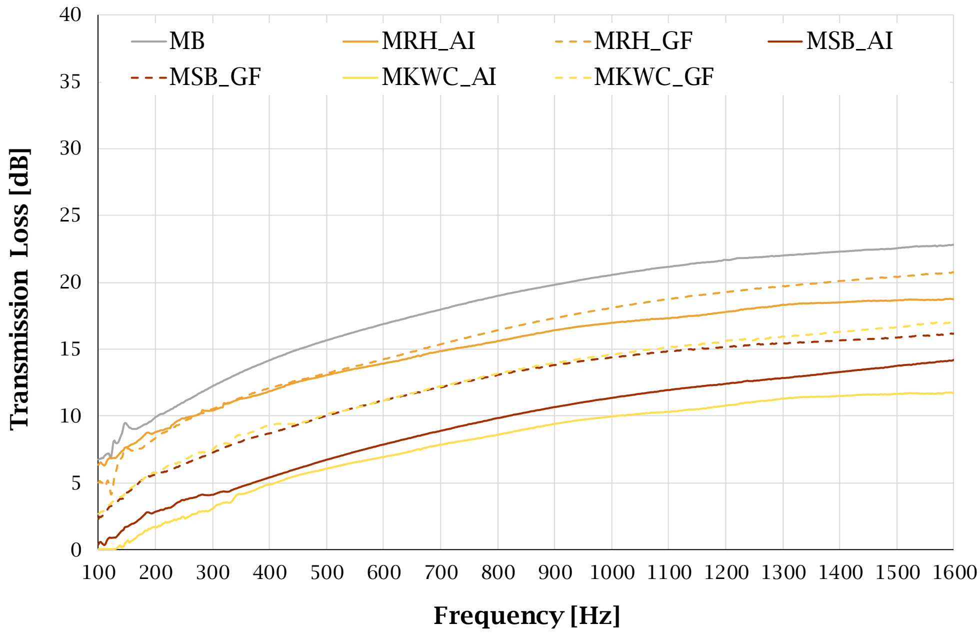

Figure 6. Normal incidence TL of the samples.

4. Discussion

Table 5 compares the thermal performance of the mortar samples with available studies. Several researchers [21] identified plastic and metal fibers as the most viable waste material for reinforcing cementitious matrices, promoting circular economy processes. Mortars reinforced with brass fibers obtained from electrical manufacturing process were studied in [22]. Thermal conductivity increases with the amount (0.5–4% by vol.) and length (10, 15, and 25 mm) of the fibers: values in the 1.2–1.8 W/mK range were obtained, much higher than the studied vegetal-additive mortars ones. However, by using brass fibers, mechanical performance improved. In order to reduce the environmental impact, several studies focused on natural fibers as a sustainable alternative to conventional mortars. In general, increasing the fiber volume in the mix proportion increases pore volume and the formation of air voids through porous fibers, leading to higher porosity and lower bulk density. This aspect tends to decreased thermal conductivity due to the reduction in heat transfer, leading to better thermal insulation. Better thermal performance (λ = 0.07–0.11 W/mK) was shown for natural hydraulic lime containing either hemp shives or hemp shives and fibers [23]. Ground rice husks, spelled bran, and Khorasan wheat chaff investigated in the present paper had thermal properties that agreed with natural-fiber-reinforced mortars [3,4,24–26]. Palm oil fly ash in the replacement of cement (up to 10%) and oil palm fibers as additive (0–1.5 wt %) in a sustainable mortar involve a reduction of about 40% in thermal conductivity with respect to conventional mortar matrix [24]. The reduction reached over 70%, incorporating a large amount (50%) of waste rice husk ash (λ = 0.22 W/mK with respect to 0.82 W/mK of the conventional mortar) [25,26]. λ values in the 0.63–0.58 W/mK range were obtained with 10% weight, depending on different burnt processes of the fibers, close to the ones of the present study (0.61 and 0.53 W/mK with as-found and ground rice husks, respectively). Natural coconut coir and oil palm fibers cement materials are characterized by λ values equal to 0.41–0.37 and 0.40–0.27 W/mK depending on fiber percentage (5–15%). Depending on different fiber length and sizes of sand in the composite, thermal conductivity equal to 0.65–0.95 and 0.35–0.8 W/mK was achieved with 10% of coconut and durian, respectively [4]. However, the increased amount of fibers resulted in a lower mechanical performance, even if within the standard recommended range for mixture in most cases.

Table 5. Thermal performance: comparison with literature data.

	Λ [W/mK]	Reference
Brass fibers reinforcing mortar (0.5–4%)	1.18–1.80	[22]
Hemp aggregate concrete	0.07–0.11	[23]
Oil palm fiber reinforced mortar (1.5%)	0.97–0.58	[24]
Rice husk ash mortar (10–50%)	0.60–0.22	[25,26]
Coconut coir cement (5–15%)	0.41–0.37	[3]
Oil palm fibers cement (5–15%)	0.40–0.27	[3]
Coconut composite material (10%)	0.65–0.95	[4]
Durian composite material (10%)	0.35–0.80	[4]
Rice husk mortar (10%)	0.53–0.61	Present work
Spelled bran mortar (10%)	0.69–0.64	Present work
Khorasan wheat chaff mortar (10%)	0.68–0.60	Present work

Regarding acoustic characterization, limited analysis could be conducted, since the existing literature is limited. The acoustic properties of mortars strongly depend on their porous structure and density. The addition of fibers reduces density and increases porosity, with a consequent increase in sound absorption performance (vegetal-fiber-additive mortars with respect to base). Results agree with the literature data [23]; SSA coefficient of unrendered hemp concreate was in the 0.3–0.9 range, depending on binder dosage and frequency. The properties significantly reduced when hemp concretes were rendered. Conversely, TL values decrease with density, and air resistance is lower for fiber mortars.

5. Conclusions

In a circular economy and sustainable development perspective, the use of waste materials from agricultural processes is very promising. Several fibro-additive mortars were manufactured by adding 10% by weight of vegetal fibers in a base mix design, in order to study the use of composites with low embodied energy as thermos-insulating materials, also for the refurbishment of existing buildings. Blends with rice husk, spelled bran, and Khorasan (*turanicum*) wheat chaff were fabricated both as-found and ground, and their thermal and acoustic properties were investigated with respect to the base mortar. Spelled bran and Khorasan wheat chaff did not demonstrate significant improvement in thermal performance, whereas thermal conductivity was reduced of about 11% with rice husks. Mortars with grinded vegetal fibers exhibited the best performance in terms of both thermal and absorption properties; the lowest thermal conductivity value (0.53 W/mK) was obtained with rice husks (reduction of about 22% compared to base mortar), whereas the highest SAA value was obtained with *turanicum* wheat chaff (+60%, SAA = 0.38). Fibro-additive mortars that had lower density than that of the base mortar showed slightly lower TL values according to the mass low; the TL of ground rice husk was, however, up to 21 dB at 1600 Hz, only 2 dB lower than the value of base mortar.

Biomaterials are never the same: the same matrix changes with the cultivated genotype and, even for the same genotype, it varies from year to year and from location to location. It depends on climate factors (pluviometric trend, thermal trend, etc.), biotic factors (i.e., fungal diseases, in turn influenced by environmental variables), agronomic techniques (sowing density, dose and timing of nitrogen fertilization, etc.), and grain milling techniques.

The subject of future studies affects the mechanical performance of these fibro-additive mortars with vegetal fibers, characterized by good thermal and sound absorption properties; above all their great added value is the lower environmental impact, which could be investigated by means of life-cycle analysis.

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