

COMPOSITION STUDY FOR OBTAINING MEDIUM-LIGHT MORTARS BY USING SPENT MUSHROOM SUBSTRATE

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Abstract: Besides other lignocellulose waste resulting from agriculture, spent mushroom substrate is a major concern due to the high amount of waste, usually improperly disposed. Also, sand-based mortars require the use of this non-renewable and exhaustive aggregate and problems of environment protection arise. The study aims to analyze the possibilities of sand replacement in mortars composition with grounded substrate. The ratio between cement and sand in the studied compositions was 1:1, 1:2, and 1:4. The hardened mortars are analyzed in terms of colorimetric changes, density decrease, mechanical strength, hydrophobic properties, and freeze-frost resistance. Thus, medium-light mortars for applications that require moderate strengths, with ecological implications results when up to 15% of sand is replaced with spent mushroom substrate. The results can be used for a deeper research, considering also a detailed life cycle assessment of the waste and, secondly, combining the replacement material with other waste types.

Keywords: spent mushroom substrate, cement to sand report, medium-light mortars, mechanical properties, hydrophobicity

1. INTRODUCTION

The construction industry uses a lot of sand-based mortars, which is considered a non-renewable, exhaustible aggregate, with increased demand every year [1]. Its replacement, especially with waste materials, can bring a new perspective on maintaining a natural balance, on protecting the environment and on the conscious use of raw materials [2].

Mortars are used in different construction projects, for new masonry work or to ancient buildings' consolidation [3-5]. The use of residual materials as a substitute for sand in mortar composition is meeting the international requirements for reducing the amount of waste through prevention, reduction, recycling and reuse, while also reducing intense marine pollution from sand mining [6].

Wood is considered one of the major wastes of industry, being mostly landfilled and then causing important environmental issues. Its reutilization has benefits both for reducing the pollution and for economical circuit of natural resources. Wood chips or sawdust, with different shapes and forms, results by processing wood waste, for example by cutting, scraping, drilling, etc.

Sawdust was used in many studies as an additive in construction materials, in most cases to replace sand in mortar composition [7]. It can improve mortars' properties in terms of building structural elements

reduced size, lower density and thermal insulation. Sawdust was used in cement material to obtain lightweight mortars and aggregate concrete that can reduce the construction cost and effort, being also a "green" building material [8]. As a replacement of fine aggregate, sawdust can transform a normal weight mortar to a lightweight concrete composite, with up to 25% without decreasing the mechanical properties and thermal insulation [9-12].

One of the waste materials used to replace sand in masonry mortars is agricultural waste [13]. Among these, using the spent substrate resulting from mushroom cultivation (SMS) may be of interest.

SMS is a lignocellulosic waste, being mainly composed of sawdust, wood chips, ground corncobs, cottonseed meal, gypsum, etc. It could contain also extracellular fungal enzyme, fungus mycelia, proteins, minerals, or diverse carbohydrates [6, 7, 14]. The amount of SMS resulting from this activity is enormous, for every kg of cultivated mushrooms being used 5 kg of sawdust [15].

SMS improperly disposed or reuse contributes to environment pollution including soil, water and air pollution and subsequently causes health problems. Thus, it is desirable to find some methods of recycling it. Mushroom producers tried to overcome the difficulties related to SMS reuse and recycling, and thus to respect the environmental laws, by bioremediation soil agent,

animal feed, clay bricks, etc. [16, 17]. Using spent mushroom substrate into mortar compositions was found to reduce the material density and maintain suitable properties according to construction standards, and also to reduce CO₂ emissions by using less sand and not burning SMS waste [6, 18].

The present study aimed to obtain lightweight / medium lightweight, ecological mortars by replacing in volume percentages the fine aggregate from mortar composition with spent mushrooms substrate with similar dimensions, in order to obtain mortars with suitable properties for constructions. The cement to sand ratio was varied in order to identify optimized composition for resulting proper construction materials.

2. EXPERIMENTAL PART

The lignocellulosic waste resulted from the cultivation of Pleurotus mushrooms, with depleted mycelium (depleted substrate - SMS). SMS was first grounded and the granulometric fraction with a maximum size of 0.5 mm was used for obtaining the mortars.

The inorganic components of the mortar were: cement - normally used for internal and external strength structures and sand with grain size below 0.5 mm (fraction obtained by sieving the commercial sand). The cement to sand ratio was 1:1, 1:2, and 1:4. The samples were obtained by replacing a volumetric percentage of sand with a corresponding amount of SMS fraction < 0.5 mm, according to Figure 1. The water amount was varied to obtain the same consistency of the mortar and it was dependent by the amount of SMS, due to the affinity of this material for water.

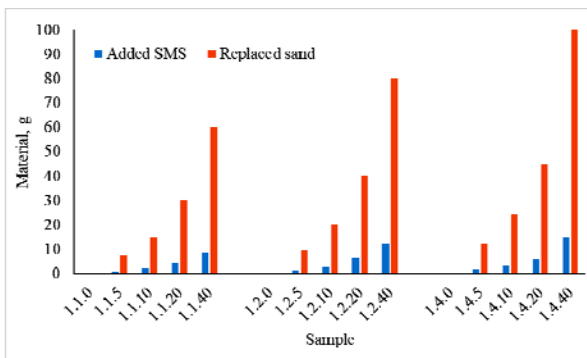


Figure 1 The correlation between the volumetric sand replacement with SMS

The first step in obtaining the mortar was to mix the solid components using a paddle mixer for approx. 4 minutes, until a homogeneous composition is obtained. The second step consisted of gradually adding water and maintaining thorough mixing. The obtained mortar

samples were subsequently cast into silicone molds of size 2 x 2 x 7 cm and 5 x 5 x 5 cm (L x W x H) for further testing, with conditioning the samples at room temperature for 28 days. The mortar specimens, after complete drying, were tested by:

- determining the bulk density of hardened mortar, according to BS EN 1015-10[19], using dried samples (1 x 1 x 1 cm) of each composition; the determination was made in triplicate;

- colorimetric analysis using a Konica Minolta colorimeter, Chroma-meter CR-410. Ten measurements were performed for each sample, with D65 illuminant and a 2° observer angle.

- mechanical strength - using a Silver Schmidt L-type hammer, by measuring the number of rebound and transforming the value into mechanical strength, MPa.

- peeling test (exfoliation of the outer layer) using a 1 x 1 cm adhesive tape and weighing it before the test and after pressing it on the brick surface 10 times with the same pressure.

- porosity - by ImageJ software processing; the pores' dimensions were measured based on the stereomicroscopic images for each sample.

- water absorption - by weighing before and after immersion in water for 24 hours at room temperature.

- freeze-thaw test – by subjecting the mortar specimens to 20 cycles of freezing and then thawing in water and weighing each sample in a dry state / saturated with water before the first cycle / the thawed sample at the end of the test. The possible degradations produced by temperature fluctuations in mortar surface were visually analyzed after the 20 cycles and the gelivity coefficient was determined.

- analysis of the costs involved in obtaining these materials in order to select the efficient option both from an economic and technological point of view, based on the determined properties.

3. RESULTS AND DISCUSSION

The results of the average bulk density of the 28-days hardened concrete mixtures is shown in Figure 2. It can be observed that the density of samples without SMS is dependent of the composition, higher values with higher amount of sand. This change can be determined by the superior gravity of sand, of 2.55 g/cm³, as compared to cement, 1.44 g/cm³. The volumetric replacement of sand with SMS shows a downward slope, with lower values of the bulk density of dried specimens depending of the cement to sand proportion.

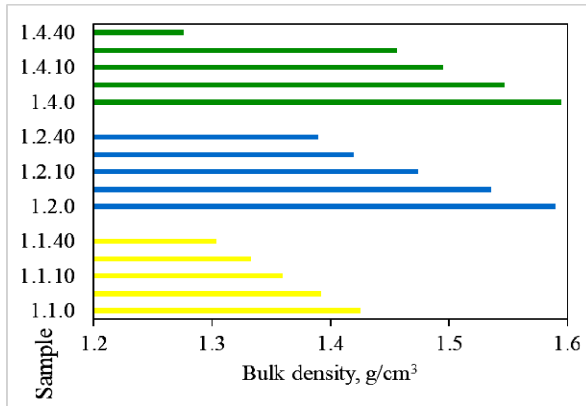


Figure 2 The variation of bulk density with mortars' composition

Mortar compositions with dry density between 2.24 and 2.45 g/cm³ are considered normal mortar while light mortar has densities of 0.30-2.00 g/cm³ [20, 21]. From Figure 2, it can be observed that most of the studied compositions satisfy the lightweight mortars' requirement, if more than 10/15% sand is replaced with SMS. Smallest values are obtained for 1:1 and 1:2 compositions. A higher amount of SMS can ensure a more compact structure, less porous. The density is smaller with 4-28% than the control samples for 1:1 and 1:2 set of samples, and with 2-22% for 1:4 specimens as compared to the control, evidencing once again the differences of structure with increasing the percent of replaced sand and the proportion between cement and sand. Lightweight mortars can be use in non-structural applications, having a reduced weight, thermal insulation, and acoustic performance, obtained with economic benefits regarding the cost of materials, transport and energy, and easy labor [21, 22]. Similar results can be found in other studies [6, 12], mortar compositions with 15-30% smaller density resulting from sawdust adding. Thus, the studied compositions could meet the density requirement for lightweight mortars. But in practice, the density value must be correlated with the mechanical properties and durability of the mortar under real conditions.

Although in many applications the color changes given by sand replacement with SMS is not considered important, other purposes can require similarities with the environmental materials, on the aesthetic formed structure. So, the color parameters of mortars were determined and are presented in Table 1. The differences in color are analyzed as ΔL (brightness), Δa (red-green parameter), and Δb (yellow-blue parameter) respectively, calculated as the difference between the sample without SMS and the samples with different volumetric percent of replaced sand.

Table 1. Chromatic parameters of raw materials and mortars

Sample	L_x^*	a_x^*	b_x^*	Sample	L_x^*	a_x^*	b_x^*
SMS	84.73	3.10	13.03	1.2.0	68.12	-0.4	5.76

Sand	66.10	1.79	15.74	1.2.5	63.86	-0.54	8.73
Cement	63.62	-0.45	7.14	1.2.10	57.93	-0.76	11.46
				1.2.20	55.60	-0.79	12.43
				1.2.40	51.64	-0.86	13.78
1.1.0	70.55	-0.53	5.01	1.4.0	62.06	-0.63	8.99
1.1.5	69.45	-0.59	6.57	1.4.5	60.41	-0.91	9.40
1.1.10	68.64	-0.61	7.13	1.4.10	57.97	-0.68	12.61
1.1.20	64.49	-0.68	8.20	1.4.20	57.20	-0.52	14.79
1.1.40	60.32	-0.73	9.35	1.4.40	56.43	-0.51	15.15

Starting from the raw materials color, greenish grey for cement, grey brown for sand, and a light ochre tint for SMS, the chromatic parameters show their influence on the mortars' shades. Increasing the cement proportion decreases the dry samples' lightness. Although the spent mushrooms substrate is characterized by a higher value of L_x^* , as compared to the control specimens of each set of mortars, ΔL_x has lower values with increasing the SMS content. A possible explanation can be related to SMS particles covering with cement that impart its color characteristics. For the samples with 1:4 cement:sand, ΔL_x has lower values probably due to upper SMS amount from mortars' compositions.

Regarding the red-green parameter, it can be observed also the cement influence, the powder giving the greenish shade to all the samples, with or without SMS embedded. Comparing the SMS mortars, it can be observed that the yellowness is higher with increasing the percent of SMS added into the composition, imparted by sand and grounded spent mushrooms substrate. If the differences between the walls or ceramic parts and the applied mortar are considered important, then, the composition of the material and the proportion of components must be analyzed in order to obtain the smallest color discrepancy.

The present study uses the rebound hammer method as a non-destructive method to evaluate the construction materials, including mortars and concrete. The technique consists in measuring the rebound of a spring-loaded mass, the rebound distance being correlated with the compressive strength and surface properties, with benefits especially on using on site. The aim of using this technique is to evaluate the strength and compare the mortar and concrete quality.

The compressive strength was determined by measuring the rebound number (Q) and correlating the rebound energy with the compressive strength.

The strength variation with the percent of replaced sand, is mentioned in Figure 3.

As previous researches found [6, 11, 12, 23], compressive strength of mortars containing spent mushroom substrate or sawdust as sand replacement demonstrate their low-to-medium strength characteristic.

In our case, although the values seem to be moderate, the technique is applied to compare the strength variation with the ratio between sand and cement and with the volumetric percent of replaced sand. As can be observed, the dry mortar samples lose strength by increasing sand content. The values are lower than the ones found in other studies when fine and coarse aggregates were contained into mortars' composition that could ensure higher strength of dried mortars.

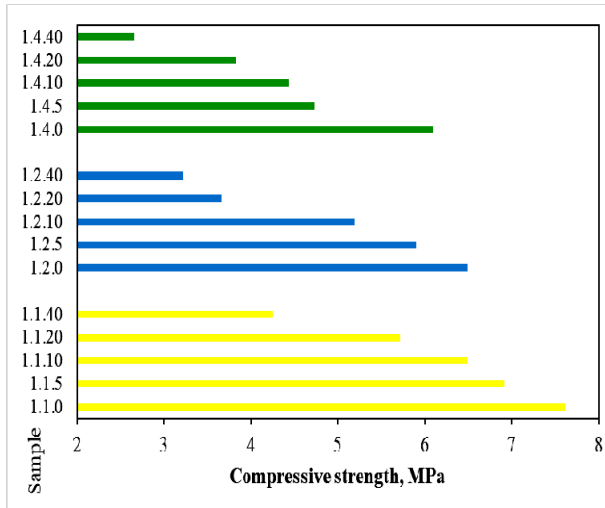


Figure 3. The mechanical strength of mortar specimens

The control samples present a low decrease strength when increasing the sand percent. Higher compressive strength is recorded for 1:1 sample died for 28 days. Also, the smaller changes in strength when replacing sand with SMS are recorded for this set of samples. For specimens where cement:sand is 1:4, the amount of SMS is also superior and it could affect the moisture retaining into mortar's structure. The water presence is important in ensuring proper strength, internal moisture can hydrate the cement that imparts the main part of mortar strength [12, 24]. The cement hydration occurs slower in the presence of wood extractive.

All the three sets of samples present a less significant decrease of strength at lower dosages of SMS added into the mortars' compositions. At 5% SMS, 1:1 and 1:2 specimens had a strength decrease of about 9%, while for 10 % SMS, the values are with 14-19% lower. When 20% of sand is replaced, the strength is with a quarter smaller for samples with equal cement and sand percent and reaches 43% decrease for 1:2 set. The mortars with 1:4 cement to sand ratio presented the higher decrease in strength as the recorded values were lower with 23%, 27%, and 37% respectively as the SMS amount was increased. For all the 40% samples, independent of the sand fraction, the compressive strength resulted after the hammer test presented a drop of 45-55% as compared to the control samples.

According to literature [24, 25], the decrease in strength may be due to pores formed then the fine particles of

spent mushroom substrate reach fiber saturation point and it reduces in size. Also, the smaller densities of SMS samples can be responsible of the strength decrease. Regarding the mortars' composition, modifying the sand percent can lead to a fragile interface between cement and sand, besides the weak bond between aggregates and SMS [11].

The peeling test is a method to analyze the adhesion between components and surface cohesion characteristics of materials, including mortars. In situ strengthening of sample' layers can be evaluated by this simple and reliable testing method. The technique uses a 3M adhesive tape, pressed with constant force and removed from the surface for 10 times, in the same place on the surface to minimize the error given by the materials detached from the subsurface layers [26]. The amount of material detached from the surface is analyzed. In figure 4 and Table 2, it can be seen an increase in the amount of detached material directly proportional to the percentage of SMS in the mortar' composition.

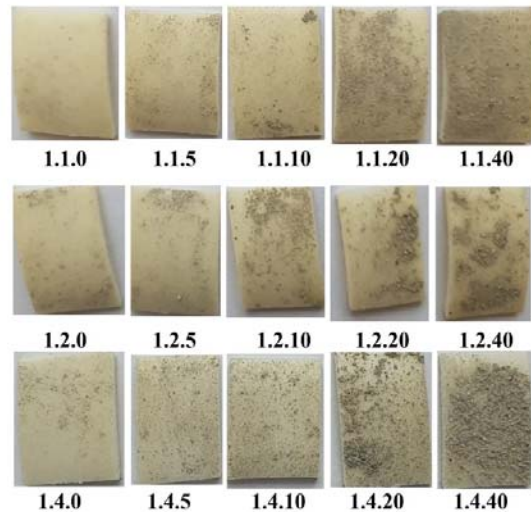


Figure 4. Results of the exfoliation test of the mortar samples

Table 2. Results of the peeling test

Sample	Detached material, mg	Sample	Detached material, mg	Sample	Detached material, mg
1.1.0	1.5	1.2.0	2.6	1.4.0	2.7
1.1.5	2.4	1.2.5	3.4	1.4.5	4.9
1.1.10	3.2	1.2.10	4.2	1.4.10	8.4
1.1.20	5.4	1.2.20	5.7	1.4.20	10.9
1.1.40	7.6	1.2.40	8.4	1.4.40	25.8

The peeling results are in accordance with the strength of tested mortars. The cohesion between spent mushroom substrate and mineral part formed by cement and sand is

weakened with SMS amount increase and this is reflected very well into the extent of detached material.

The peeling test shows similar cohesion between components for 1:1 and 1:2 sets of samples, with smaller increase of detached material amount until 20% replaced sand with the wood filler and higher amount for 40% sample. For 1:4 cement:sand specimens, the quantity of detached material is significant higher as compared to control and the other two sets of samples. In this case, the increased volume occupied by SMS weakens the in situ and surface resistance to mechanical stress.

The stereomicroscopic images made on each mortar sample have revealed a porous aspect of specimens. In case of control samples, the increase of sand amount into the composition leads to voids and interface gaps formation. By adding SMS into each set of mortars, the microstructure is further changed, with the appearance of some holes with different dimensions.

For 1:1 set of mortar compositions, visible changes are observed on higher SMS content, but only a reduced number of voids are present into mortar structure. The voids increase from 5.05-10.1 μm to 14.2-16.1 μm from 0 to 40% replaced sand with SMS. The compact structure, with less defects, can be correlated with the good compressive strength demonstrated for samples with up to 20% SMS.

For 1:2 specimens, more voids appear and the higher content of SMS can be better observed into the structure. The shrinkage below fiber saturation point of the spent mushroom substrate powder and the weaker interface between SMS and the inorganic materials lead to this porous microstructure. The number of voids and their size increase from 7.98-20.2 μm to 5.96-24.7 μm with the SMS dosage. The most important changes in mortars' porosity seems to occur in 1:4 set of samples, when pore with dimensions up to 42.3 μm are formed at higher content of organic powder, in accordance to strength value and low bulk density, the most reduced as compared to control. The data are were also previous observed in other studies, where sawdust or spent mushroom substrate in concrete mixtures also after 28 days of water curing lead to voids, interface gapes and openings into the microstructure [6, 12].

By changing the porous structure of the mortar, the hydrophilicity of the material also changes. For this, mortar samples with and without SMS into the composition, were tested to determine the water absorption and the results are shown in Figure 5. A high SMS content, of 40%, led to a very high brittleness of the samples in contact with water, so that these samples disintegrated during testing. As expected, as the porosity of samples increase with SMS content, the hydrophilicity of mortars increases proportionally.

Mortars without SMS powder have higher water absorption with increasing the sand proportion, with 2.19% for 1:2 and 11.95% for 1:4 compared to equal percentages of sand and cement. This could be explained

based on the porous structure of the samples that makes the specimens more hydrophobic, Table 3.

As the percentage of SMS increase in all the mortar compositions, most of the water absorbed in the sample is retained by the wood powder and the hydration process is hampered and decreases the compression strength, as presented in Figure 3.

A higher value of water absorption can be due, on the one hand, to the different porosity of the mortar samples, and on the other hand to the hydrophilic nature of the sawdust used as a substrate for the growth of mushrooms.

Table 3. Stereo microscopic images of mortars, evidencing the pores whose dimensions were calculated using the ImageJ software

Cement: sand / SMS	1:1	1:2	1:4
0			
5			
10			
20			
40			

The frost resistance is the ability of a material to withstand freezing or thawing cycles. It is also a characteristic dependent on the material's density and porosity. A higher freeze-thaw resistance is observed in denser materials.

Mortar resistance over time, by changing environmental factors, is an extremely important characteristic for

choosing a material and an appropriate application for each type of mortar. Extreme variations in temperature, respectively freezing-thawing, determined the appearance of cracks and other defects which can lead to mortar's degradation, even to the total destruction of the structure. For this, specimens from each mortar sample, with and without embedded SMS, were subjected to 20 freeze-thaw cycles, with monitoring the signs of degradation and the determination of the gelivity coefficient, gravimetrically (mass thawed sample at the end of the test-mass saturated sample at the beginning of the test)/dry mass initial sample. The results are highlighted in Table 4.

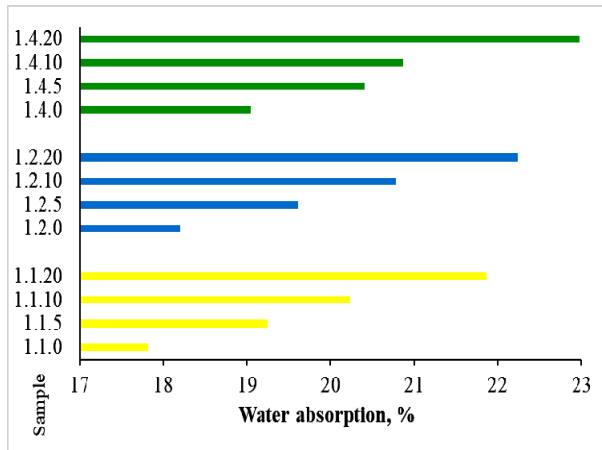


Figure 5. The water absorption values of mortar specimens

Table 4. Freeze-thaw test results

Sample	Gelivity coefficient, %
1.1.0	0.54
1.1.5	0.86
1.1.10	1.16
1.2.0	1.06
1.2.5	1.08
1.2.10	1.32
1.4.0	1.38
1.4.5	1.69
1.4.10	2.05

The test was achieved only for the samples with maximum 10%SMS, at higher dosage of wood powder the specimens disintegrate at the first 1-5 cycles of freezing and thawing.

Replacing a small amount of sand with SMS leads to an improvement in behavior during the test. Samples with a small amount of ground spent substrate did not show significant structural changes after the 20 freeze-thaw cycles. The SMS usage limit for adequate resistance appears to be 10% SMS. The gelivity coefficient is small, confirming the stability of the tested mortar samples at freeze-thaw cycles.

The analysis of the production cost of different mortar compositions containing 5-40% SMS is presented in table 5. The economy index was quantified by dividing the compressive strength determined for each individual sample by the total cost of 100 kg of mortar [12]. For the total cost, the two main inorganic components were considered, not considering the price of SMS and water.

The price of the used lignocellulosic component should not influence the total cost of the mortar because it is a waste and only the advantages of reusing it instead of burning or storing it in the environment should be considered, benefits for environmental conservation and by reducing the consumption of natural raw materials and CO2 emissions.

Table 5. Economy index for different lightweight mortar compositions

Sample	Cement-sand, kg/100kg	Cement-sand cost, Euro/100 kg mortar	Total cost, Euro/100 kg mortar	Compressive strength, MPa	Economy index
1.1.0	50-50	8.25-5.2	13.45	8.38	0.623
1.1.5	50-47.5	8.25-4.94	13.19	7.62	0.578
1.1.10	50-45	8.25-4.68	12.93	6.92	0.535
1.1.20	50-40	8.25-4.16	12.41	6.5	0.524
1.1.40	50-30	8.25-3.12	11.37	5.72	0.503
1.2.0	33.33-66.67	5.5-6.93	12.43	6.5	0.523
1.2.5	33.33-63.33	5.5-6.59	12.09	5.9	0.488
1.2.10	33.33-60	5.5-6.24	11.74	5.2	0.443
1.2.20	33.33-53.33	5.5-5.55	11.05	3.66	0.331
1.2.40	33.33-40	5.5-4.16	9.66	3.22	0.333
1.4.0	29-71	4.79-7.38	12.17	6.1	0.501
1.4.5	29-67	4.79-6.97	11.75	4.72	0.402
1.4.10	29-64	4.79-6.66	11.44	4.43	0.387
1.4.20	29-58	4.79-6.03	10.82	3.82	0.353
1.4.40	29-42	4.79-4.37	9.15	2.66	0.291

The economy index is dependent on the cement:sand composition. Its variation for 1:1 samples is small, but the compression strength must be correlated to other properties of mortars, according to the targeted application. The maximum percent of replaced sand with

SMS powder seems to be 10% for 1:2 set of samples, and 5-10% for 1:4 specimens.

Further studies on recycling spent mushroom substrate in sand-based construction materials must target also a detailed life cycle assessment of SMS in order to obtain a complete understanding of the environmental evaluation.

4. CONCLUSIONS

The present study aimed to optimize the characteristics of medium-light mortars both by replacing sand with spent mushroom substrate, and by varying the cement to sand ratio, in order to obtain mortars with different applications in the construction field, which do not require high strength properties. The use of this wood waste offers opportunities to obtain materials with a lower density that can reduce the load placed on the building structure/foundation, with possible soundproofing or insulation properties.

The mechanical strength of obtained mortars were found to be dependent of the composition, especially by the amount of grounded substrate added instead of the fine aggregate. The hydrophobic properties were influenced by the quantity of replaced sand. Although the economy index is higher, the best properties are achieved for 1:1 cement to sand ratio, with up to 15% replaced fine aggregate with SMS.

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