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Abstract. The generation of new building materials responds to the reduction of energy consumption and regulation of building interior temperatures as strategy to improve energy efficiency in materials engineering and architecture. This research focuses on the study of the rice husk incidence on the physical, mechanical and thermal properties of H10 block manufactured in the metropolitan area of San José de Cúcuta, Colombia. The methodology consists in 4 stages: In first instance, raw material characterization to identify chemical, structural and morphological components of clay and rice husk. Then, H10 blocks manufacturing in 2 clay mixtures, fired at 900 °C, 1000 °C and 1100 °C. Likewise, tests of manufactured samples to analyze its physical and mechanical properties. Parallel to the manufacturing process, transfer and heat fluxes simulations to evaluate surface temperatures and energy concentration of H10 block. In conclusion, rice husk acts as a technological nutrient added to clay mixture and strengthens thermal and insulating capacity of blocks. Nevertheless, the presence of rice husk in clay mixtures increases water absorption capacity of the products, as the percentage of husk increases. And therefore, the compressive strength decreases, which is a factor to consider for the constructive application of H10 block.

1. Introduction

Rice industry in Colombia produces about 400,000 tons of rice per year and 20% corresponds to organic waste of difficult biodegradation and digestion due to its high silicon content, commonly known as rice husk. Therefore, rice husk cannot be reused in food industry, which limits its applications to fields of construction, fuel, gas, beds for poultry, compost, among others [1].

Nevertheless, potentials of this agricultural by-product transcend its thermal insulation capacity, thanks to its porous structure and low conductivity [1,2]. This means competitive advantages at a productive, biochemical and physical level as an alternative for the improvement of ceramic and cementitious materials [2]. It is proven that implementation of the rice husk in the bricks manufacture process reduces the environmental impact, mitigates surfaces heating and transforms mechanical properties according to the production process [3-6]. For this reason, it is credited with the term of technological nutrient [6].

According to the environmental need to generate new materials from the reuse of industrial waste, this paper focuses on the study of mechanical and thermal properties H10 blocks manufactured at laboratory scale in mixtures of clay and rice husk, at the "Centro de Investigación de Materiales Cerámicos (CIMAC)", San José de Cúcuta, Colombia. As a first step, chemical, structural and morphological characterization of clay and rice husk is carried out. Before, laboratory tests of linear shrinkage, water absorption and compressive strength is performed on the manufactured samples. And transfer and heat flows simulations are carried through with H10 block design in clay and rice husk. Finally, the results obtained in comparison with constructive regulations were discussed to conclude the main ideas of the investigation.

2. Methodology

The study begins with raw materials characterization used for the manufacture of ceramic pieces, clay and rice husk. For this, techniques as X-ray diffraction (XRD), X-ray fluorescence (XRF) and scanning electron microscopes (SEM) are used to identify the structural, chemical and morphological components of each material. The formulated ceramic pastes vary according to the percentages of rice husk concentration and the particle size thereof. In Table 1, the mixtures are labeled with 5% and 10% of husks, sieved in 16, 80 and 200 meshes; ceramic paste in 100% clay will be used as a reference to establish a point of comparison with the new mixtures.

Table 1. Formulation of ceramic pastes according to rice husk concentration.

Concentration	Grain size (micrometers)		
	< Mesh 16	< Mesh 80	< Mesh 200
5%	M CRHa-5	M CRHb-5	M CRHc-5
10%	M CRHa-10	M CRHb-10	M CRHc-10

H10 blocks were manufactured by extrusion, at laboratory scale in the CIMAC. The wet samples were kept at rest 24 hours after their manufacture; then, the samples were subjected to temperatures of 110 °C in a drying oven Franco Gabrielli Technology brand for 24 hours. Finally, the samples were cooked in a muffle oven at three temperatures: 900 °C, 1000 °C and 1100 °C. Once manufacturing process was completed, laboratory tests of linear shrinkage, water absorption and compression resistance were performed on the extruded samples, according to Colombian technical standard: Methods for sampling and testing of masonry units and other clay products NTC 4017 in the CIMAC [7].

Thermal validation of H10 block was performed by transfer and heat fluxes simulations in the ANSYS R16 software; data provided to perform this procedure correspond to materials conductivity [8] and environmental and atmospheric conditions of a specific environment, in this case the city of San José de Cúcuta, Colombia, in September [9], as show the Table 2.

Table 2. Data provided for transfer and heat flows simulations.

Terms	Values
Conductivity	k M A = 0.691 W/m•°C k M ACAb 5% = 0.462 W/m•°C
Average maximum temperature	33 °C
Average maximum solar radiation	796.80 W•h/m^2
Time	12:00-13:00 hours = 1 hour
Qsolar	796.80 W/m^2
Average wind speed	4 m/s

3. Results and discussion

3.1. Characterization of raw material

The characterization of the raw materials contemplates the analysis of the structural, chemical and morphological components of the clay and the rice husk through techniques of XRD, XRF and SEM. The importance of the characterization of clay and rice husk is to identify those components that determine the physical, mechanical and thermal properties of the product to be manufactured. In addition, to know the potentials of the material in the first instance and to foresees possible pathologies and deficiencies drink.

The structural characterization of clay was obtained by X-ray diffraction. Next, Figure 1 shows the presence of corundum, quartz, kaolinite, hematite, muscovite, anatase and potassium feldspar (microcline) in the sample. Likewise, quartz stands out as the predominant phase and kaolinite and muscovite with less relevance [8,10]. The presence of potassium feldspar (microcline) improves the vitrification process in the firing of products manufactured by extrusion [11].

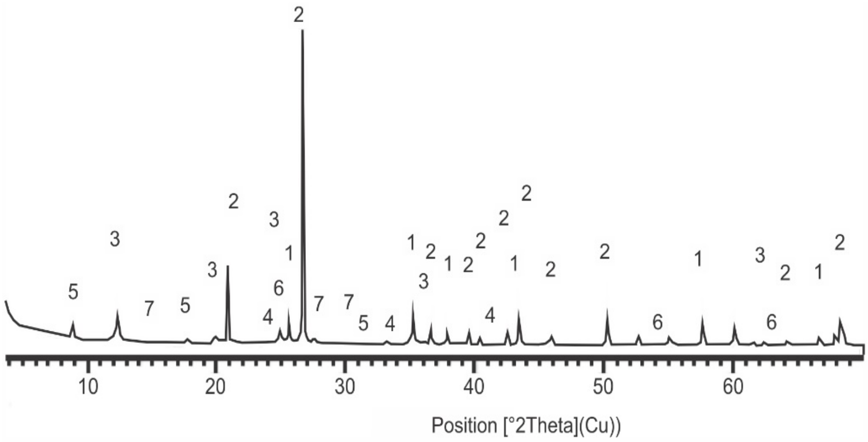

Figure 1. XRD pattern of clay. (1) corundum; (2) quartz; (3) kaolinite; (4) hematite; (5) muscovite; (6) anatase; (7) potassium feldspar (microcline).

On the other hand, chemical components resulting from the XRF agree with structural characterization of clay, since silicon concentration is related to the quartz present in the crystalline phase of the XRD. In this sense, other elements such as iron and potassium are associated with feldspar while magnesium and calcium with muscovite and limestone.

Finally, morphological characterization shows a grain size variation between 200 µm and 1 µm through micrographs. According to Figure 2, the brightest areas (site 3) correspond to the presence of heavy elements such as iron in oxidized phases. Sulfur is present at a site 5 in small quantities, the presence of this element may pose risks aesthetically with efflorescence.

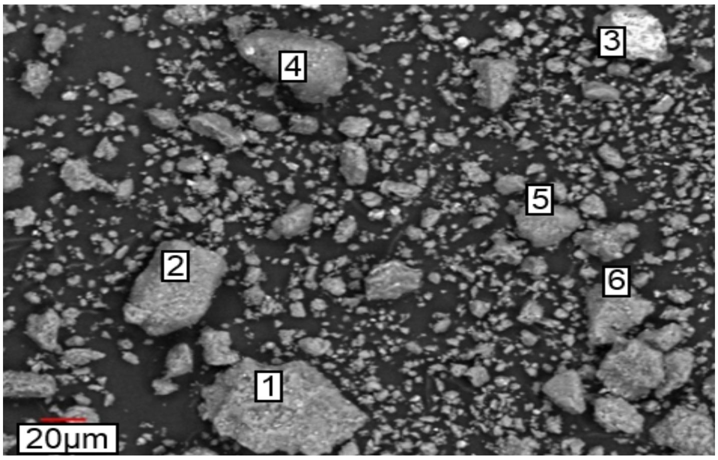

Figure 2. Photomicrograph of the clay sample [8].

According to the structural characterization of the rice husk, Table 3 shows the low concentration of quartz in the crystalline phase; therefore, it is defined as an amorphous material. Chemical composition concludes a high silicon content in the inorganic phase, which makes rice husk an optimal material for construction due to its difficult biodegradation [6]; nevertheless, the XRF records a high percentage of loss on ignition (LOI), about 84%, as show the Table 3.

Morphological characterization classifies husk as fibrous material of lamellar structure due to the shape of the grains, which vary between 300 and 700 microns. The above are points to consider regarding the calcination of the material in the brick firing processes; this material behavior means two main factors: generation of pores or vacuum chambers functioning as insulation and possible damages in the resistance of the finished product (block) [6].

Table 3. Structural and chemical composition of rice husk.

	Phase		Name	Quantitative (% weight)
Structural composition	Crystalline	SiO_2	Quartz	0.2
	Total crystalline			0.2
	Amorphous and others			99.8
	Element	Quantitative (% weight)	Oxide	Quantitative (% weight)
Chemical composition	Si	7.27	SiO_2	15.56
	K	0.23	K_2O	0.28
	Al	0.11	Al_2O_3	0.20
	P	0.07	P_2O_5	0.15
	Ca	0.06	CaO	0.09
	Mg	0.05	MgO	0.09
	Fe	0.04	Fe_2O_3	0.06
	Mn	0.01	SO_3	0.03
	S	0.01	MnO	0.02
	-	-	LOI	83.50

3.2. *Products physical ceramic properties*

Figure 3 shows extruded samples of H10 block at laboratory scale in mixture with 95% of clay and 5% of rice husk sieved in 80 mesh in wet condition. In this part of the manufacturing, the samples rest during 24 hours at room temperature and fulfill its first drying step to subsequently introduce them into the drying oven.

Figure 3. H10 blocks manufactured at laboratory scale in the CIMAC. Wet condition in M CRHb-5.

Physical ceramic properties of products correspond to linear shrinkage, water absorption and compressive strength capabilities of H10 blocks manufactured at laboratory scale in CIMAC facilities (Figure 3). Next, Table 4 compiles the drying and firing shrinkage percentages at the 3 temperatures evaluated; rice husk concentration and particle size are factors that alter linear shrinkage values in dry and cooked condition of most samples. To be more specific, the higher the concentration of the nutrient and particle size is lower the percentage of linear shrinkage. Nevertheless, there is one last important factor in the alteration of shrinkage values that only affect samples in cooked condition: firing temperature, since the temperature increase structural vitrified clay composition and therefore increases the contraction. These findings are consistent with other experts in the field author's study [6,12,13].

Table 4. Linear shrinkage drying and firing of the samples.

Ceramic mixture	Drying shrinkage %	Firing shrinkage%		
		900 °C	1000 °C	1100 °C
M C	8.24	0.08	0.78	3.12
M CRHa-5	4.74	0.35	0.67	2.13
M CRHb-5	5.43	0.65	1.70	4.56
M CRHc-5	5.39	0.46	0.29	3.62
M CRHa-10	4.36	0.51	0.21	3.30
M CRHb-10	5.10	0.32	0.18	1.11
M CRHc-10	7.79	0.28	0.22	1.90

Similarly, Table 5 compiles water absorption and compressive strength results at 900 °C, 1000 °C and 1100 °C of the manufactured samples. Water absorption values register an increase, as the concentration of the rice husk in the mixture is increased; moreover, it decreases with increasing firing temperature. The particle size varies water absorption, samples with 10% of the additive decreases when husk particle size is smaller in the mixtures. The grain size varies the water absorption, the absorption of samples with 10% of the additive decreases when particle size becomes smaller in the mixtures. It follows that, the increase absorption in mixtures with this nutrient is due to the calcination of the material LOI firing processes bricks.

Table 5. Mechanical properties of H10 blocks manufactured of clay and rice husk.

	Sample	Temperature (°C)		
		900	1000	1100
Water absorption (%)	M C	11.97	11.18	6.85
	M CRHa-5	18.76	18.62	16.32
	M CRHb-5	14.81	14.03	9.73
	M CRHc-5	18.03	18.82	19.72
	M CRHa-10	25.50	23.68	17.09
	M CRHb-10	24.39	24.02	19.26
	M CRHc-10	21.32	21.89	19.56
Compressive strength (Kg•f/cm^2)	M C	35.58	36.45	38.39
	M CRHa-5	18.80	17.68	18.70
	M CRHb-5	25.20	22.21	29.09
	M CRHc-5	14.16	14.89	12.55
	M CRHa-10	25.98	25.67	28.81
	M CRHb-10	16.29	14.36	17.52
	M CRHc-10	17.31	18.50	17.41

Resistance to compression increases with increasing firing temperature of the samples (Table 5); M C stands out for its mechanical property, because it is the only mixture that fulfills with NTC 4205 for structural masonry units [14]; thus, as mentioned [6], rice husk concentration determines the compressive strength, which was affected in the mixtures with greater presence of the nutrient; nevertheless, M CRHb-5 and M CRHb-10 meet the minimum values for non-structural uses of masonry units. In contrast, remaining mixtures including rice husk breach with the current regulations, which implies an exclusive defect in samples with organic material concentrations for technical validation of future products.

Considering the results, it is evident an inverse relationship between water absorption and compressive strength. That is, the increase in absorptive capacity decreases mechanical properties of resistance to compression.

3.3. *Thermal properties*

Thermal conductivity is the last factor evaluated in the rice husk incidence in H10 block. Likewise, polystyrene and pore-forming agents, mixture with rice husk decreases its conductivity as its concentration increases, which means thermal improvement [15,16]. Figure 4 shows energy behavior profiles of H10 block in M C and M CRHb-5 according to the heat transfer (Figure 4(a), Figure 4(b)), and heat fluxes (Figure 4(c), Figure 4(d)). The importance of this aspect lies in the contributions to new materials generation focused on improving energy efficiency from building.

Table 6 compiles inner and outer surfaces temperatures and maximum values and minimum heat fluxes of H10 blocks with clay and M CRHb-5. According to the results, rice husk addition contributes to decrease 1.74 °C in the inner surface temperature of the piece. Besides, energy concentration decreases by 27.8%. These values are related to water absorption and weight loss of units, due to increasing the pore volume decreases weight loss and hence material conductivity, according to the revised sources [6].

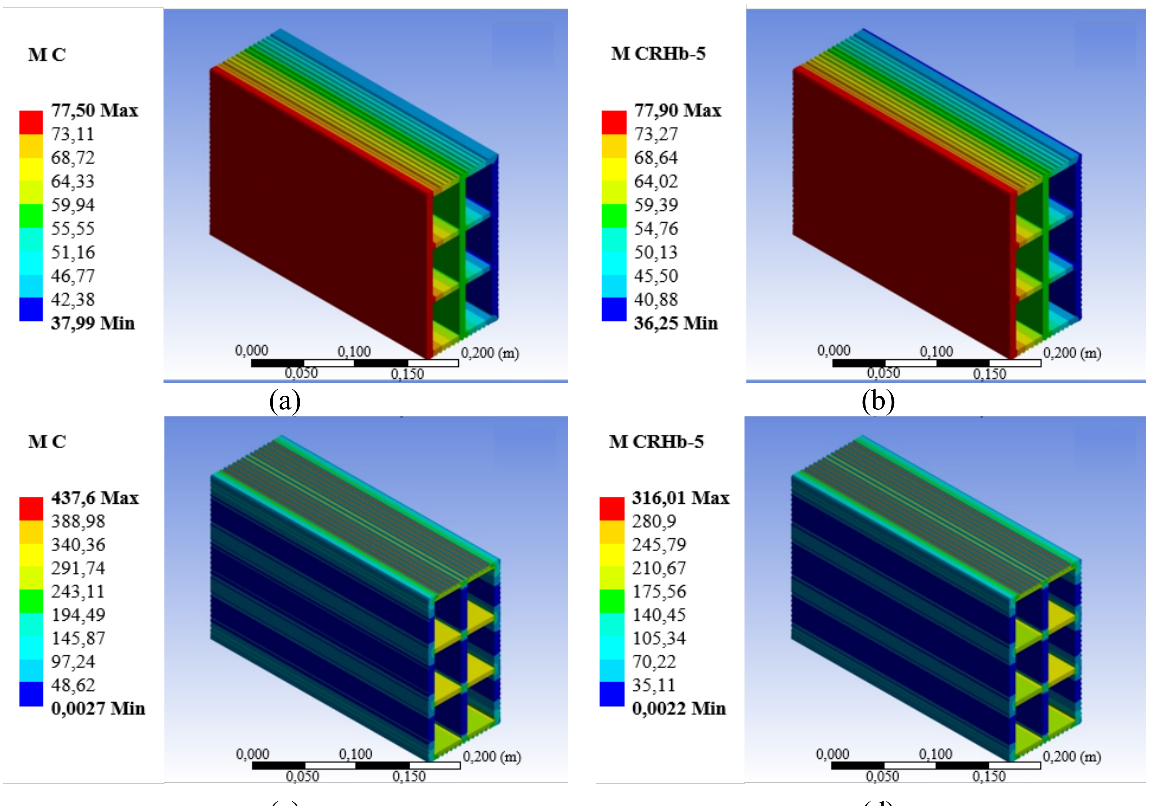

Figure 4. Temperature distribution (a) M C, (b) M CRHb-5; heat fluxes (c) M C, (d) M CRHb-5.

Table 6. Thermal properties of H10 blocks in M C and M CRHb-5.

Material	Temperature (°C)		Heat fluxes (W/m^2)	
	External	Internal	Maximum	Minimum
M C	77.50	37.99	437.60	0.002
M CRHb-5	77.91	36.25	316.01	0.002

4. Conclusions

The study about an organic industrial waste incidence on the properties of a building material yields very interesting results in the characterization of H10 block, a traditional product of the ceramic industry of Norte de Santander, Colombia. The most important inference is the relationship between the linear shrinkage, absorption and resistance capacity and heat transfer. Additionally, analysis of the chemical, structural and morphological composition characterizes raw material identifies possible pathologies such as weakening of mechanical properties and deficit in aesthetic quality of the products (efflorescence).

The presence of rice husk improves energy efficiency of H10 blocks by almost 30% according to the maximum levels of heat fluxes, which implies a reduction in the transfer of temperatures of internal surfaces of almost 2 °C. Despite this, compressive strength deterioration of 25% and 70% in some of the samples evaluated is clear. Although these data can be alarming, mixtures such as M CRH-5 and M CRHa-10 accomplish the standard for non-structural masonry units.

To summarize, rice husk consideration as nutrient technology improves thermal comfort through the decreasing of the interior surface temperature, mainly in warm tropical regions like San José de Cúcuta, Colombia. Therefore, new buildings should must consider material conductivity of their facades. Besides, it is recommended to deepen research on approaches to optimization of compressive strength to consolidate its marketing and constructive application in buildings.

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