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Application of Locally Available Natural Materials In Thermal Insulation

Noha Z. Hareedy, El-Sayed A. Nasr, Ehab F. Sadek,
Structural Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt

ملخص البحث

أجريت هذة الدراسة بهدف تطوير وتقييم أداء لوحات العزل الحرارى الجديدة المصنوعة من قش الأرز المتاح محلياً حيث تم تنفيذ برنامج عملى لتصنيع ألواح العزل الحرارى بأستخدام قش الارز ثم أختبار الخصائص الفيزيائية والميكانيكية للالواح المنتجة , كما تصف الدراسة عينات الاختبار وهى عبارة عن خليط من قش الأرز مع المونة الاسمنتية حيث تتكون هذة الدراسة من تطوير طريقة معالجة قش الأرز بأستخدام محلول هيدروكسيد الصوديوم لازاله المواد اللزجة الموجودة بقش الأرز بهدف تعزيز روابطة مع المونة الأسمنتية ثم تصنيع ألواح العزل الحرارى من قش الأرز ثم أختبار خصائص الألواح المنتجة من حيث الكثافة ومقاومة الضغط ومقاومة الانحناء ومعامل التوصيل الحرارى ومقاومة الحريق ، أما الجزء التحليلى من الدراسة فقد تألف من النتائج المقاسة لجميع العينات التى تم أختبارها فى المعمل وأستخدم فى ذلك بعض الاكواد الاوربية بجانب الكود المصرى .

ABSTRACT

Looking to the rice straw as an environmentally friendly and renewable material, rice straw thermal insulation boards are of considerable interest for energy saving purposes when it is used as building insulation material for walls or ceilings. Development and performance evaluation of new thermal insulation boards manufactured mainly from locally available rice straw and cement mortar is the main aim of this work. This study consists of developing a treatment method of rice straw aiming to enhance its bond with the surrounding mortar, manufacturing of thermal insulation boards from rice straw and investigating the physical and mechanical properties of the produced boards. The bonding efficiency between rice straw and mortar was analyzed through testing the compressive strength and flexural strength of boards with different rice straw contents and different types of additives to the mixtures used to enhance the boards properties. Thermal insulation properties and fire resistance of the produced boards have been investigated as well. The results indicated that the optimum physical and mechanical properties of boards are obtained with rice straw content of 20% and 30%.it was found that the thermal insulation boards had fairly low thermal conductivity, ranging from 0.21 to 0.25 W/ (m.K). The fire resistance of rice straw boards was found to be much better than the conventional industrial and commercial types of the thermal insulation boards.

KEYWORDS: Rice straw, Thermal Insulation, boards, thermal conductivity.

1. Introduction

Structural thermal insulation is necessary there are a number of key reasons to drastically reduce our consumption of fossil fuels. These include the need to limit the impact of the already apparent changes to our climate. Dwindling supplies of fossil fuels and the resulting increase in energy prices are further factors that need to be taken into consideration. Structural thermal insulation is necessary in order to prevent building damage resulting from the formation of moisture on the inside of external building components, guarantees sufficiently high surface temperatures on the inside of external building components during the winter, contributing to ensuring a feeling of comfort inside the building this allows for the same level of comfort to be achieved with lower room air temperatures and thus less energy consumption, reduces undesired heat input ,contributes to reducing energy consumption in summer and winter ,supports the preservation of resources and reduces the burden placed on the environment ,an support the durability of the building structure, contribute to the rectification of structural damage, facilitate a reduction in heating and cooling costs and ensure that the property's value remains stable [(1).].

Studies had been conducted by specialists in thermal insulation confirmed that the application of thermal insulation in buildings leads to excellent results in the comfort and savings in energy consumption.[(2)]

Materials based on natural fibers from renewable raw material resources are now becoming increasingly popular. Due to its low mass density and cell structure, they show very good thermal insulation properties, often better and more advantageous than synthetic fibers. A great advantage of the insulation based on natural fibers is not only a low value of thermal conductivity but also the natural character of input fibers. Another advantage is that it is a renewable material which does not place any significant strain on the environment. For example, when compared with mineral wool, the insulation based on natural fibers has comparable and sometimes even better thermal technical characteristics (e.g. heat capacity or the afore-mentioned thermal conductivity) [(3)].

Egypt is located in the north-east of the continent of Africa, it is bordered from the north by the Mediterranean, the Red Sea from the east, and at latitude 22-32 north [(4)]**.** Climate in Egypt is generally dry climate where the temperature rises as we move to the south. Temperatures are regularly equal from east to west with a decrease of up to 1 to 3 c^o on the coastal cities. [(5)]

In Egypt heat is transferred from outside the building to inside in summer and this trend is reflected in winter as a result of the temperature difference between inside and outside Therefore, Egypt started using the thermal insulation system to reduce the problem of temperature difference and this industry has developed widely in recent times and has varied forms and types due to the increase in energy demand. The electrical energy consumed to cool the building in Egypt is estimated to be about 66% of full power in needed in the summer. [(5)]

It is well known that rice straws have been used as building insulation material for a long time due to their hollow structure, low density and outstanding characteristics of heat insulation.It has been reported that the typical thermal conductivity values for cellulose insulation materials are between 40 and 50 w/ mk [(6).] Therefore, to improve the thermal insulation properties of the exterior building facades ,some researches have focused on the thermal insulation benefits of incorporating the rice straw in some building materials by means of some advanced manufacturing technologies [(7,8).]

Rice straw is available in vast quantities in the rice paddy growing countries as Egypt.it is considered as an agricultural waste and presents a serious problem in disposal and environmental pollution. Therefore, the use of straws in building will not only solve the problem of straw as a waste, but also will help in building houses having significantly low impact on the environment without sacrificing most of comforts [(7,8)]

the objectives of the current research is to develop and manufacture thermal insulations boards based on the locally available rice straw using a relatively simple technology and then investigating the main physical and mechanical properties of the manufactured boards .

2. Experimental program

The experiments were divided into two successive parts of study. It could be described in table (1), Where the first part was used a large particles of rice straw and the second part was used a small particles of rice straw.

Table (1): experimental program

mix	cement	fly ash	lime	gypsum	sand	rice straw				cacl2
						0	10%	20%	30%	6%
Part (1)										
1	cement							20%		6%
2	cement				sand			20%		6%
3	cement			gypsum				20%		6%
4	cement		lime					20%		6%
5	cement	fly ash						20%		6%
6	cement	fly ash	lime	gypsum	sand			20%		6%
7	cement		lime		sand			20%		6%
Part (2)										
8	cement		lime		sand	0%				6%
9	cement		lime		sand		10%			6%
10	cement		lime		sand			20%		6%
11	cement		lime		sand				30%	6%

Treated dry rice straw is mixed in container with Ordinary Portland cement (OPC) with ratio 20% from cement weight. Calcium chloride ratio 6% from cement weight were added as a hydration accelerator to the mixture by dissolving it in tap water .The amount of water was calculated using equation (1) was presented by (Hachimi *et al.*, 1990). [9]

$$WC = 0.35\,C + 1.7\,(WS - M) \qquad (1)$$

Where:

WC: The amount of water (g),
C: Weight of cement (g),
WS: Weight of straw (g),
M: Weight of moisture in the straw (g).

On the other hand, the next steps aimed to develop a green composite from rice straw, which can be used for making thermal insulation boards will by preparing six mixtures to achieve the desired objective, and the four materials (sand, gypsum, lime and fly ash) were added to increase the strength properties. After that formed in steel molds (185 mm /185 mm / 185 mm), (150mm/150mm/75mm) and wood molds (300mm/300mm/50mm) Figure (1) molds used in this study. compacted with a tamping bar and covered with steel sheet to make smooth surface. After that, the specimens were cured in wet burlap. After that compressive strength, flexural strength and bulk density was measured after 28 days, then we choose the best mix from the previous six mixtures. Different rice straw content ratios 0, 10, 20 and 30 % were mixed separately with best mixture to determine thermal conductivity, compressive strength, flexural strength, density and fire resistance.

Figure(1):molds used in this study

On the other hand, two sizes from treated rice straw were prepared: small particles (10mm) and large particles (30mm) were made by cutting straw with scissors. The different sizes were mixed separately with best mixture (OPC+sand+lime) with ratio 20% rice straw. This is to study the difference between the two sizes and their effect on Mechanical and physical properties. Figure (2): straw particles used in the study.

10mm 30mm

Figure (2):straw particles used in the study

2.1 Materials

The materials used in this study included rice straw was harvested in an agricultural field of Qaliubiya in Egypt (γ_b =0.159g/cm^3), water used in all study was normal tap water (γ_b =1g/cm^3), sand (γ_b =2.674 g/cm^3,fine models =8.8%), fly ash (γ_b =2.3g/cm^3), three different types of binders materials (Ordinary Portland cement grade 42.5, local gypsum and lime which used in Egypt and powder chemicals (sodium hydroxide, calcium chloride).

2.2. Methods

2.2.1 Rice straw preparation

Rice straw was chipped into particles with lengths of 30-50mm. According to (ASTM-D1109-84) [(10),] treated rice straw was prepared by soaking it in 1 % sodium hydroxide for 24 hours then filtered through 2 mm screen. The ratio between rice straw and soaking solution was 1:10 by weight, respectively. After filtration, rice straw washed with tap water until washing water became clear. Treated rice straw was dried in an oven at 105 ± 2 C^o and packed in polyethylene bags until using the time of utilization.

Sodium hydroxide (NaOH) treatment of rice straw was effective for removing the extractives (lignin and hemicellulose) which increasing the roughness of the surfaces. The removal of surface impurities could be resulting in stronger composites consistent due to enhanced chemical bonding and mechanical interlocking between the straw and cementitious matrix.

2.2.2 Manufacturing of rice straw cementitious board

Rice straw ratio (by weight) is varied from mixture to another for production the best boards. The straw mixing ratios (0%, 10%, 20%and 30%) respectively Treated rice straw was dry mixed in a container with best mixture (OPC+sand+lime) using mixer. After that water containing $CaCl_2$ was added to the dry mixture and mixed until having a homogeneous salary. Water amount was calculated according to Equation (1), whereas $CaCl_2$ was added with 6% from the cement weight. The blend was poured in a different molds shape related to the test type. Then, compacted with a tamping bar. For each test three specimens were prepared then covered with steel sheet. After that, specimens were cured in burlap until tested at day 28 for compressive strength, flexural strength, thermal conductivity, density, water Absorption and fire resistance.

2.3 *Experimental tests*

2.3.*1 Mechanical and physical properties*

The unit weight test was carried out using specimens with dimensions 15.8/15.8/15.8 cm according of the standard BS 1881 part: 114 [(11)]. Samples were tested at 28 days. Density was measured based on the oven dry weight with volume of the sample. Three replicate samples were used for each test.

Straw particles bulk density was determined by filling a one liter plastic tank with oven dried straw particles. Then straw particles bulk density was calculated using the following equation (2): $\gamma_b = \{w_1 - w_2\} / 1000$ (2)

Where: γ_b: Bulk density of straw particles (g/cm3), W_1: Weight of the plastic tank with straw particles (g), W_2: Weight of empty tank (g).

Compressive strength test of cubic specimens 15.8/15.8/15.8cm according to the standard BS 1881 part: 115 [(12)] was performed using servo hydraulic testing machine with maximum load of 200 ton. Figure (3) Compressive test machine

Figure (3): Compressive test machine

Flexural specimens have a rectangular shape measuring approximately 15/15/75cm.the flexural test was carried out according to the standard ISO 4013 [13]. Maximum load reading was taken and MOR calculated using the three points bending test. Figure (4) Flexural test machine and shape of crack

Figure (4): Flexural test machine and shape of crack

2.3.2 Thermal conductivity

The test was made from best mixture of this study to investigate the effect of straw content in the thermal conductivity of cementitious composites. Thermal conductivity measures the ability of a material to conduct heat, and is defined as the quantity of heat (Q) transmitted through a unit thickness (L) in a direction normal to a surface of unit area (A) due to a unit temperature gradient (ΔT) under steady state conditions and when the heat transfer is dependent only on the temperature gradient. If a flat sample is placed between two flat isothermal plates maintained at two different temperatures, and a uniform one-dimensional temperature field has been stabilized, the temperature field in the sample should be uniform within all the sample's volume (size of the plates is supposed to be much larger than thickness of the sample). The temperature gradient can be determined by measurements of the temperature difference between hot and cold plates ($\Delta T = T_{hot} - T_{cold}$) and thickness of the sample Δx, because in this case average temperature gradient dT/dx is equal to -ΔT/Δx. This test was carried out on samples of 30*30*5cm using Laser Comp instrument and according to ASTM C-518 [14]. This test can be described as follows; the sample is placed between two plates, the first one is a flat electrical heating plate and the other one is flat electrical cooling plate. Figure (5) shows the details of thermal conductivity apparatus used in this study. All the information about the sample is recorded and the test started. It may be 6 to 8 hours till the condition of steady state reach. Through this time the software store the temperature of the hot plate and the cooled plate and the heat flux through the samples. Finally the thermal conductivity was calculated using the following Equation (3);

$$K = \Phi \Delta x / \Delta T \qquad (3)$$

Where;

Φ is heat flux (W/m^2) flowing through the sample, **K** is its thermal conductivity (W m^{-1} K^{-1}), **Δx** is the sample thickness (m), **ΔT** is the difference in temperature between the hot and cold surfaces of specimen (C^o).

Figure(5):thermal conductivity test machine

2. 3.3 Fire resistance

The test was made from best mixture of this study to investigate the effect of straw content on the fire resistance of cementitious composites. The samples are a mortar reinforced with 20% and 30% rice straw respectively with dimensions of (30*30*5) cm. The fire resistance tests were conducted in accordance with the standard specification NFPA 251. Measurements are taken by exposing the sample from one side to specific temperatures at certain times and then measuring the temperature of the other side of the sample. Figure (6) Fire resistance apparatus used in this study. One face of the sample was subjected to time-temperature curve as described in the standard specification NFPA 251 [15] and the temperature of the other face of the sample was recorded every 1 minute all over the test period. The test was ended when the temperature of the unexposed of the sample reached 140 ^{0}c above the ambient temperature.

Figure (6) :Fire resistance apparatus used in this study

3. Results and discussion

3.1 The result from first mixture of the experimental program

The densities, compressive strength and flexure strength of the rice straw–cementitious composites were produced from the first seven mixtures to get the best mixture described in table (2)

Table (2): densities, compressive strength and flexure strength results

Specimens	Mixtures with (20%rice straw +6%$Cacl_2$)	Density (g/cm^3)	Compressive strength (kg/cm^2)	flexure strength (kg/cm^2)
1	Cement	1.2	23.1	4.23
2	cement+sand (1:3)	1.58	28.57	10.53
3	cement+gypsum(7%)	1.3	30.31	13.68
4	cement+lime(3.5%)	1.28	52.07	11.21
5	cement+fly ash(70%)	1.45	20.7	3.55
6	cement+lime(3.5%)+gyps(7%)+ sand+fly ash(70%)	1.08	21.9	6.53
7	cement+lime (3.5%)+sand	1.48	42.73	20.20

From the previous table, compare the seven mixtures to choose the best mixture and determine the strength of the cohesion by knowing the properties of compressive strength and flexure strength
It has been observed that the best mixtures are number (7) (cement+sand+lime).

3.2 *Rice straw density and dry density of rice straw cementitious board*

Straw density was measured from equation (2) equaled 0.159 g /cm^3. The densities of the rice straw–cementitious composites were produced by using the best mixture (cement+sand+lime) with small particles of rice straw at different straw content (0, 10, 20 and 30 wt%) are shown in Figure (7). The values obtained ranged between 2.04 g/cm^3 at 0% and 1.39 g/cm^3 at 30%. Generally, the higher the straw content, the lower the composite density. A possible reason for this is that the lower content are likely to be better bonded with the cementitious matrix than with higher, thereby minimizing the presence of air voids. Table (3): all results of density with different quantities of rice straw.

Table (3): density results

Straw content,wt %	density (g/cm^3)
0	2.04
10	1.85
20	1.66
30	1.39

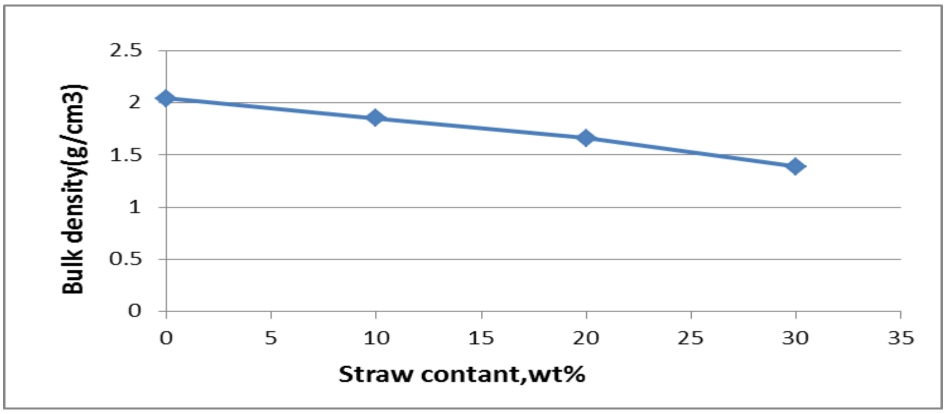

Figure (7): Effects of straw content on composites density

3.3 Compressive strength

The compressive strength of the composites with respect to the straw particle content at 28 days is presented in Figure (8). The results show that the increase of the straw content decreases the compressive strength of the composites. The compressive strength of the composites ranges from 34.5 to 119.3 kg/cm^2. Compressive strength value decrease from 119.3 kg/cm^2 for net cementitious paste (ratio 0%), to 73.2, 56.5 and 34.5 kg/cm^2 for 10, 20 and 30 % straw content. However, higher fiber content increases porosity of the composite material and results in a loss of compressive strength. Also, the decrease in the compressive strength is attributing to the physical properties of the straw particles, since they are less stiff than the cement matrix. Under loading, cracks are initiated around the particles, which accelerate the failure of the cement matrix. Table (4): all results of compressive strength with different quantities of rice straw.

Table (4): compressive strength results

Straw content,wt %	Compressive strength (kg/cm^2)
0	119.3
10	73.2
20	56.5
30	34.5

Figure (8): Effects of straw content on compressive strength

3.4 Flexural strength

The variation in 28 day flexural strength as a function of the straw content is shown in Figure (9). The flexural strength of the composites increases with an increasing straw content up to 10 %.Value of flexural strength increases from 8.67 kg/cm^2 for net cementitious mixture, to 21.73, 16.27 and 10.4 kg/cm^2 for 10, 20 and 30 % straw content. Flexural strength decrease with an increasing straw content. Table (5): all results of Flexural strength with different quantities of rice straw.

Table (5): Flexural strength results

Straw content,wt %	Flexure strength (kg/cm^2)
0	8.67
10	21.73
20	16.27
30	10.4

Figure (9): Effect of straw content on flexural strength

3.5 Thermal conductivity

As a thermal-insulating material, the thermal conductivity is one of the most important properties that should be investigated. The thermal conductivity of fibrous insulation materials is affected by a number of basic factors: straw content and temperature. In general, thermal conductivity increases with rising temperature.

The thermal conductivity of composites with respect to straw particle content is presented in Figure (10).the straw content from 0 wt% to 30 wt%, thermal conductivity decreases from 1 w/mk to 0.21 w/mk .Generally, the results show that an increase of the straw content decreases the thermal conductivity of the composites. Table (6): all results of thermal conductivity with different quantities of rice straw.

Table (6): thermal conductivity results

Straw content,wt %	Thermal conductivity (w/m.k)
0	1
10	0.44
20	0.25
30	0.21

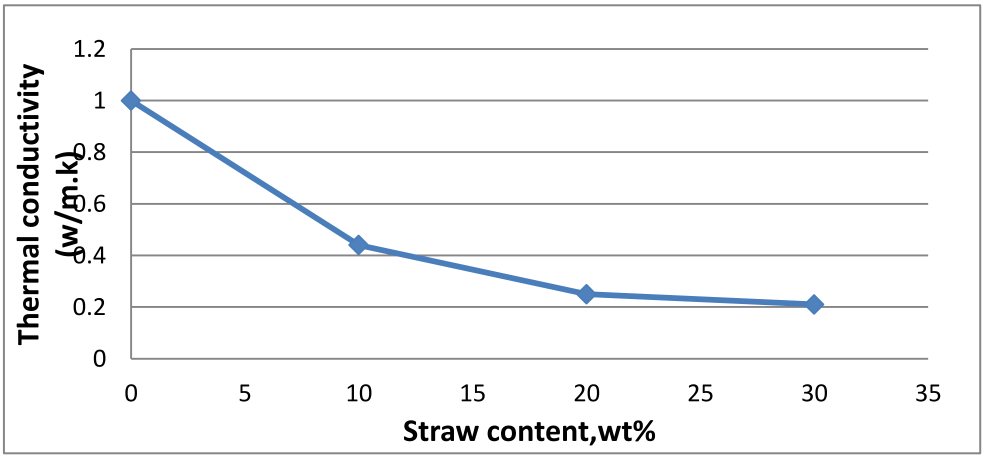

Figure (10): Effect of straw content on composite thermal conductivity

3.6 *Fire resistance*

The fire resistance of the composites with respect to the straw particle content is presented in Figure (11). The results show that an increase of the straw content decreases the time of the composites fire resistance. Shows temperature-time curve in accordance to NFPA 251 of the tested samples.

The straw content from 20 wt % to 30 wt% ,time of fire resistance decreases from 70 minutes to 42 minutes. Table (7): all results of fire resistance with different quantities of rice straw.

Table (7): fire resistance results

property	Sample	Result
Fire resistance	20 % rice straw	70 minutes
	30 % rice straw	42 minutes

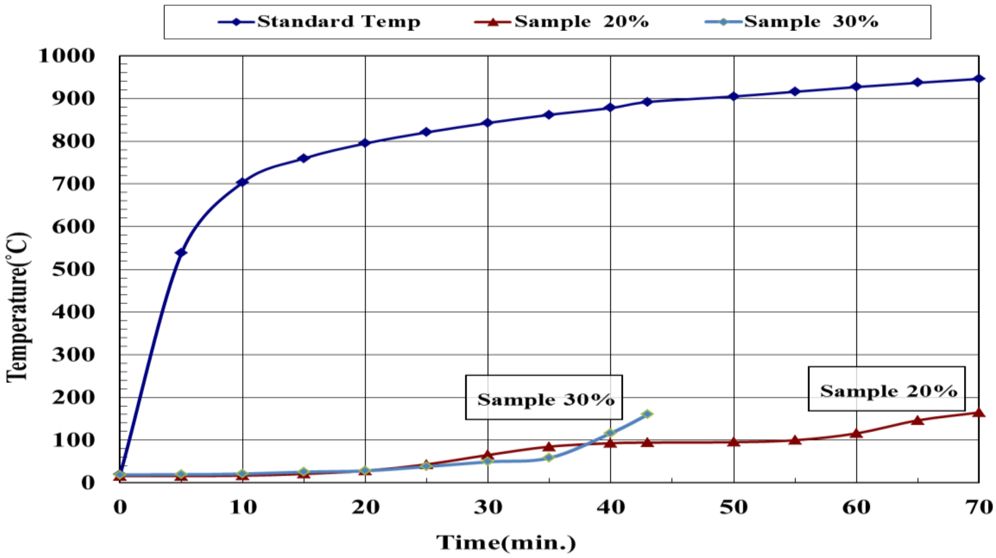

Figure (11): Effect of straw content on composite fire resistance

3.7 *Effect of particle size on properties*

The densities of the rice straw–cementitious composites produced using two particles sizes 10mm and 30mm at straw content 20 wt% are shown in Figure (12), the 10 mm straw particles produced are relatively denser composites than the 30 mm particles. The smaller particles are likely to be better bonded with the cementitious matrix than with bigger particles. Also, compressive strength decrease with an increase of the straw particles size at the same level of straw content. Also, flexural strength increase with an increasing the critical length of the straw particles. Table (8): all results of Effect of particle size on properties.

Table (8): Effect of particle size on properties

mixture	Size	Bulk density (g/cm^3)	Compressive strength(kg/cm^2)	Flexure strength (kg/cm^2)
Best mixture (cement+ lime + sand + 20% rice straw)	10 mm	1.66	56.50	16.27
	30 mm	1.48	42.73	20.20

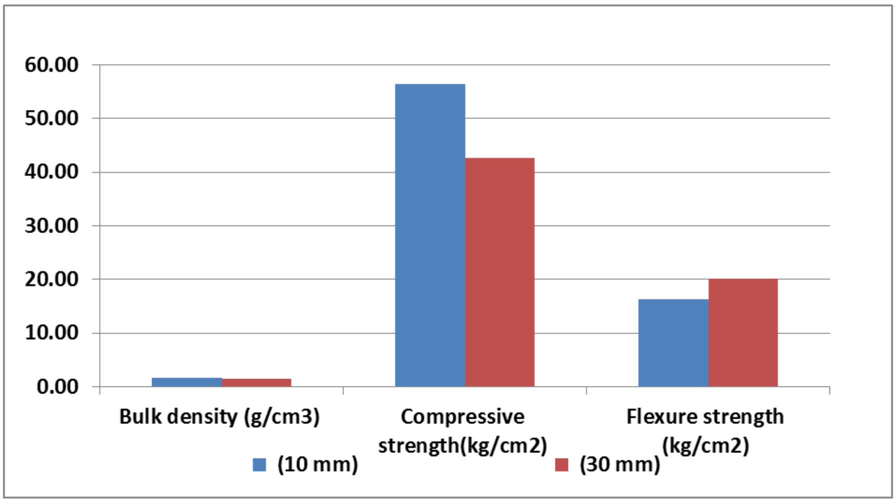

Figure (12) : Effect of particle size on properties

4. Conclusions

NaOH treatment of rice straw is very effective due to its role in removing viscous surface which could be resulting in stronger composites consistent so enhanced chemical bonding and mechanical interlocking between the straw and cementitious matrix**.** Also, the addition of 6% CaCl2 to treated straw cement composites results in the highest increase in compressive strength. NaOH treated rice straw with an addition of $CaCl_2$ has the best adhesion between straw fiber and cement matrix. Small straw particles results in a high compressive strength, also compressive strength is higher than the composites with big straw particles.

The inclusion of rice straw fibers to the cementitious matrix reduces the density, compressive strength, and thermal conductivity with an increasing of the straw content in the composites. Rice straw cementitious composites which are made with smallest rice straw particles have a higher density, compressive strength than the composites made with bigger straw particles. Straw particles fibers to the cementitious matrix increases the flexural strength up to 10 % straw content. They are also given good fire resistance

Therefore, the presented paper shows that straw-cement blocks as building materials have two main advantages: 1) a thermal insulation effects for energy conservation and 2) a cheap recyclable building material compared to traditional bricks or blocks. Overall, the findings of the study show that the new straw-cementitious blocks represent good low-cost sustainable building material for low-cost housing projects in Egypt.

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