Studying the Utility of Using Reed and Sawdust as Waste Materials to Produce Cementitious Building Units

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ABSTRACT

In this research, the possibility of using waste wooden materials (reed and sawdust) was studied to produce sustainable and thermal insulation lightweight building units , which has economic and environmental advantages. This study is intended to produce light weight building units with low thermal conductivity, so it can be used as partitions to improve the thermal insulation in buildings. Waste wooden materials were used as a partial replacement of natural sand, in different percentages (10, 20, 30, and 40) % . The mix proportions were (1:2.5) (cement: fine aggregate) with w/c of 0.4. The values of 28 days oven dry density ranged between (2060-1693) kg/m^3.The thermal conductivity decreased from (0.745 to 0.222) W/m. K .The percentages of decrease in 28 days compressive strength were (30.8, 36.8, 50 and 56.4) % .The flexural strength increased at low replacement of reed and sawdust content, and then it decreases with the increase of reed and sawdust content. At the end of the work, building units were produced from selected mix (natural sand with 30 % reed and sawdust) (MS30) .Two types of brick units were produced; the first type without coating reed or sawdust and the second type was coated with bituminous emulsion. The coating with bituminous emulsion increased the compressive by about (20.3) % and the water absorption was reduced by about (30.4) %. Efflorescence was almost negligible for both types of bricks.

Key words: reed, sawdust , thermal conductivity, cementitious building units

دراسة إمكانية الاستفادة من استخدام القصب ونشارة الخشب كمخلفات لانتاج وحدات بنائية

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الخلاصة

تم في هذا البحث دراسة إمكانية الاستفادة من المخلفات الخشبية (قصب ونشارة الخشب) لانتاج وحدات بنائية مستدامة وعازلة للحرارة وخفيفة الوزن والتي لها العديد من الفوائد الاقتصادية والبيئية. هذه الدراسة تهدف إلى إنتاج وحدات بنائية خفيفة الوزن مع توصيل حراري واطئ لكي يتم استخدامها في القواطع لتحسين العزل الحراري للابنية. تم استخدام المخلفات الخشبية كتعويض جزئي من الركام الناعم وبنسب مختلفة (10, 20 , 30 , 40) % .حيث تم استخدام نسب خلط (1:2.5) (سمنت : الركام الناعم) و نسبة ماء الى السمنت 0.4. قيم الكثافة المجففة بالفرن بعمر 28 يوم تراوحت بين (2060-1693) كغم /م^3.

إستخدام القصب والنشارة ساهم في تقليل الموصولية الحرارية وبذلك زيادة العزل الحراري بصورة جيدة فقد تناقصت الموصولية الحرارية من (0.745 الى 0.222) واط / م. كلفن . النقصان في مقاومة الانضغاط بعمر 28 يوم كان (30, 36, 50, 56)% . قيم معاير الكسر زادت عند نسب الاستبدال الواطئة للقصب ونشارة الخشب ومن ثم بدأت بالتناقص مع زيادة محتوى النشارة والقصب. في نهاية العمل تم إنتاج وحدات بنائية من خلطات مختارة وهي (الرمل الطبيعي مع نسبة 30 % قصب ونشارة) , تم إنتاج نوعين من الطابوق النوع الاول بدون طلاء القصب او النشارة بمادة مانعة للرطوبة والنوع الثاني تم طلاء القصب والنشاره بمادة مانعه للرطوبه وهي مستحلب قيري . استخدام المستحلب القيري ادى إلى زيادة مقاومة الانضغاط بمقدار 20.3 % وقلل الامتصاص بمقدار 30.4 % , أما التزهر فقد كان شبة معدوم لكلا النوعين من الطابوق.

الكلمات الرئيسية : قصب , نشارة خشب , موصولية حرارية , وحدات بنائية رابطة

1. INTRODUCTION

Iraq is located in the semitropical region which dominated by the semi-desert climate, where the summer season continuous for long period. Sun shines for more than 12 hours / day, which has a significant impact on the buildings. Temperature differences between the inside and the outside of the building are very high. Therefore the need for using air – conditioning became necessary to obtain the suitable temperature inside the building. Air – conditioners represent a fundamental load on the consumed electrical power ; statistics indicate that using air-conditioners represent (70%) of the entire electric power consumed ,**Al-Hadithi,1975 and ESCAWA , 2005.**The acceleration of social and urban renaissance in Iraq led to an increase in the number of houses built ; they increased in Baghdad city over the last three decades from 352870 in (1977) to 611022 in(2007) the ratio of increment was 73.2 % , while in whole Iraq , they increased from 470942 to 2391262 for the same period and the increment ratio was 62.6 %.This led to increasing the amount of produced energy to each person from 403.8 kw – hour /person in (1977) to 1115 kw- hour/ person in(2007),**Central Bureau of Statistic, 2007**. In 2014, there is a continues increase in buildings with time, which will have a great effect on economy. For reducing the load on electrical power generation, should taking into the account using thermal insulator materials inside the building. These materials have a low thermal conductivity to reduce the amount of heat passes through ceilings and Walls. This Keeps the building in suitable Temperature, without the need of using air – conditioning for a long period, **Rofa, 2011**. Many countries edited codes to make the use of thermal insulation mandatory in buildings. It was noticed from the previous researches that using thermal insulation in building reduces the consumed electricity by (30 – 40) %. Thermal insulation in buildings can be achieved by using materials with thermal insulation characteristics which include low density and high porosity.

The main criterion for the selection of thermal insulation materials is to have a low thermal conductivity, in addition to other properties such as their durability and endurance; it also prefers to have the capacity to absorb the sounds and vibrations

Taoukil et al, 2011, studied the thermal properties of a concrete lightened by wood aggregates from waste products of the carpentry work .They made a comparison between the properties of concretes lightened by sawdust and by wood shavings. They found that at equal mass percentage of wood aggregates, the concretes made from shavings present better thermal insulation than those obtained from sawdust.

Dawood, 2010, investigated the thermal conductivity of sawdust of different densities, (100,150,200,250) kg/m^3 without using a binder, then he studied the same densities of sawdust with binder (white glue) at different ratios (10, 25, 40) % from the weight of sample for each density. He found that the lowest thermal conductivity was 0.18W/m.K at a density of (100 kg/m^3) without a binder. While the highest value of thermal conductivity was 0.285 W/m.K at a density of (250kg/m^3) with 40% binder.

Saaed, 2013, treated sawdust before being used as an aggregate for making sawdust concrete. The treatment included boiling the sawdust in water containing hydrated lime in order to dissolve all soluble organic components. He used waterproofing materials to reduce water absorption of sawdust. Two types of waterproofing materials were used (cutback asphalt and classic varnish). The properties of sawdust concrete were highly improved; the increase of compressive strength was up to 50% for Moderate sawdust ratios. Flexural strength also increased; water absorption and thermal conductivity were highly reduced.

Al-Ubaidi, 2002, studied the properties of reed in concrete; she used two types of reeds (shredded reed of 4 cm length and sliced reed of 2 cm length) as coarse aggregate in different percentages (10, 20, 30 and 40) % by volume of total mix. The properties of 4 cm length shredded reed show better results than 2 cm length sliced reed .The 28 days air density was between (1360-1890)kg/m^3 for the 4cm shredded reed, while for 2 cm sliced reed ,the density was between(1302-1850)kg/m^3. Using reed as a coarse aggregate in concrete reduces the 28-days compressive strength from 24 to 0.4 MPa for shredded reed and 11.7 to 0.16 MPa for sliced reed. The thermal conductivity values were between (1.36-0.765) W/m.K for shredded reed and between (1.05-0.57) W/m.K for sliced reed.

Adullatif, 2009, investigated the durability of reed in cement media; he used (epoxy, SBR, PVD and liquid mastic) coatings to reduce the absorption of water and (sodium chloride, sodium sulfates and sodium nitrite) to reduce the alkaline of concrete. He found that epoxy paint is the best coating ; it reduced the absorption from 70 % to 26 % , while the liquid mastic reduced it by 30 % the reduction in SBR and PVA were (46.23, 52.15), respectively. The results of splitting and modulus of elasticity after immersion in lime for 90 days indicates that epoxy coating gives the highest splitting strength , but not higher than the reference mix (reed without coating and chemical treatment); the results also indicate that the treatment with sodium chloride is better than sodium nitrite and sodium sulfate.

2. MATERIALS

The materials used in this research are:

2.1 Cement

Ordinary Portland cement produced by Mass cement Factory was used in this work. It was stored in a dry and shaded place to avoid exposure to the atmospheric conditions like humidity. The chemical properties of the cement are shown in **Tables 1**; results show that the adopted cement conforms to the Iraqi specification **No.5/1984.**

2.2 Natural Sand

Natural sand from Al – Ekhadir region was used through this work. The grading , physical and chemical properties. **Table 2& 3** show the grading, chemical and physical properties of sand indicate that the used sand conforms to the Iraqi specification **No.45/1984.**

2.3 Sawdust

Sawdust was used as a partial replacement of fine aggregate to offer thermal insulation. It was brought from carpentry workshop, as shown in **Fig. 1.**

2.4 Reed

Local reeds from different river banks in Baghdad region are used in this work as shown in **Fig.2.** The reed crushed by a small hammer and cut with scissors to small particles as shown in **Fig. 3.**

2.5 High Range Water Reducers Admixtures

The superplactizer used was Top Flow (SP 603), (**Type F)**. It is a liquid admixture without any chloride content, basically consists of (Naphthalene Sulphonate) with other admixtures to produce high strength concrete , the products is designed to reduce the quantity of water without affecting on the initial setting time of the mix.

3. PRETREATMENT OF REED AND SAWDSUT

The pretreatment procedures for reed and sawdust used in this study and which are also used by other studies:

1- The reed and sawdust was washed under running water, to remove the barks and ash.

2- The reed or sawdust was soaked in boiling water; lime was added to the boiling water of about 20 % from the weight of reed or sawdust for an hour to reduce the harmful soluble carbohydrates, tannins, waxes and resins in wood.

3- The reed or sawdust removed from the boiling water and exposed to the atmosphere for 2 days to be air dried.

4- Before using the reed or sawdust, it was soaked in water with salt of about 10 gm/L, to protect the reed and sawdust from fungi.

4. THE EXPERIMENTAL PROGRAM

The experimental program consists of using reference mix of proportion (1:2.5) by weight (cement: fine aggregate), the cement used was about 550 kg/m^3 and sawdust and reed were used together in different percentages (10,20, 30 and 40) % as a partial replacement from the volume of fine aggregate. The (w/c) ratio is adjusted to produce mixes with a flow of 100$\pm$10 mm, several trail mixes were done in order to determine the suitable dosage of superplacrizer for each mix to maintain the determined flow. The details of mix designations are shown in **Table 4.** All the tests were done at University of Baghdad laboratory, expect the thermal conductivity test was done at Building Research Directorate / Ministry of Science and Technology.

4.1. Mixing Procedure

According to **ASTM 305-99**, the following sequences used for mixing sand and fine brick aggregate mortars:

1- Reed and sawdust were added gradually to the fine aggregate and mixed together properly until they formerly distributed through the fine aggregate.

2- Cement was mixed with the fine aggregate until they are thoroughly blended.

3- The superplacticizer was added to the mixing water, and squeezed in the graduated cylinder to ensure that the superplactizer spread homogeneously through water.
4- The water and superplactizer was added to the mass and mix until the mixture is homogenous in appearance and has the desired consistency.

4.2. Casting and Compaction

After mixing, the mix was poured immediately into the molds by means of scoop, and was compacted in one layer by vibrating table. The top surface was trowelled to obtain smooth surface.

4.3. Curing

After casting, the specimens were covered by nylon sheets to prevent the evaporation of water from the surface for (24$\pm$2) hours. After that period, the specimens were demolded and cured in water until the age of testing. All specimens were cured in water until the age of testing except the length change specimens were cured in water for seven days and then they were kept in a dry place inside the laboratory. The laboratory temperature was about 25-30 ^{0}C.

4.4 Hardened Tests

4.4.1 28 Days Oven Dry Density

The oven dry density was conducted in accordance with **B.S EN12390-7: 2009,** on (50 mm) cubes. The specimens were cured until the age of 28 days. After that, the specimens were dried in ventilated oven at 105 $\pm$ 5 ^{0}C until constant mass is achieved. Then the specimen was cool near room temperature. The density is calculated as follows:

Ƥ = m / v

Where:
Ƥ: oven dry density (kg/m^3).
m:the mass of oven dry specimen (kg).
v: the volume of specimen calculated from its dimensions (m^3).

4.4.2 Compressive Strength Test

Compressive strength test was conducted on a (50) mm cubes according to **ASTM C 109C 109/C 109M – 02, by** using 650 KN capacity, digital testing Machine. The test was conducted at ages of (7, 28 and 90) days .The average of three specimens were adopted at each age. The compressive strength computed as follows:
Fcu = P / A
Where
Fcu : compressive strength (N/mm^2).
P: The applied load (N).
A: The surface area of the cube (mm).

4.4.3 Flexural Strength Test

The flexural strength was conducted by using (160x40x40) mm prisms according to **ASTM C 348-02**.The prisms were subjected to single point loading. The specimens were tested at ages of

(7, 28 and 90) days. The average of three specimens was tested at each age. The flexural strength was tested by using 650 KN capacity tester machine. The following equation was used to estimate the flexural strength, where the failure occurred in the middle point:
Sf = 0.0028p
Where:
SF: flexural strength, MPa.
P: total maximum load, N.

4.4.4 Thermal Conductivity Test

The thermal conductivity conducted using wood moulds of (300x300x50) mm was tested in accordance with **ASTM C177.**The type of thermal conductivity apparatus is (Linseis HFM 300) It is made in Germany and is shown in figure (3.10) .It is used to measure the thermal conductivity and overall coefficient of heat transfer (U-value). The test sample is placed between plates, operating the apparatus until the thermal equilibrium happens. The time taken to reach the thermal equilibrium depends on the type of material, thickness and the temperature difference between the upper and lower plate. The specimens should be completely dry.

5. RESULTS AND DISSCUSIONS

5.1 The 28 Days Oven Dry Density

The 28 days oven dry densities of natural sand mixes are shown in **Table 5** and **Fig. 4.**The results indicate that the 28 days oven dry densities decrease with the increase in reed and sawdust content. This is due to low density, and high porosity of reed and sawdust; this will contribute in producing air voids inside the structure of the matrix, and hence reducing the density. At 28, days the oven dry density for sand mixes ranged between (1976 – 1693) kg/m^3 for (10, 20, 30 and 40) % of reed and sawdust content respectively, and 2060 kg/m^3 for the reference mix. The percentages of decrease in unit weight compared with reference mix were (4.07, 7.57, 11.4 and 17.8) %, respectively.

5.2 Compressive Strength

The compressive strength test results of natural sand mixes are shown in **Table 6** .The compressive strength of all cubic specimens decreases with the increase in sawdust and reed content. This is due to the inclusion of reed and sawdust to the matrix, which considered weak when compared with natural sand aggregates. The strength development with time of natural sand mixes are shown in **Fig. 5**. **Fig. 6** shows a relationship between the 28 days compressive strength and oven dry density for sand mixes. It is indicated that the density is a major factor affecting on compressive strength.

5.3 Flexural Strength

The flexural strength test results are shown in **Table 7** .The results show an increase in flexural strength for (MS10, MS20) mixes by about (26, 30) %, respectively compared with the reference mix. Then the flexural strength decrease with the increase of reed and sawdust content for (MS30, MS40) mixes. **Fig. 7** shows the effect of reed and sawdust content on the 28 days flexural strength. The decrease in flexural strength with the increase in reed and sawdust content it is attributed to the increase of air voids content and is due to non homogeneity of the matrix; also the cement paste – aggregate bond becomes weaker. The development of flexural strength with time is shown in **Fig. 8.** Most of the flexural strength is gained at 28 days then the rate of increment decreases with time. This is because of the rate of hydration and the properties of reed and sawdust, which are affected when exposed to water for long period.

5.4 Thermal Conductivity

The main purpose for producing such a type of light weight mortar is to improve the thermal insulation. **Table 8** and **Fig. 9** show the thermal conductivity test results .it is found that when reed and sawdust content increases, the thermal conductivity decreases compared with the reference mix and hence the thermal insulation is improved. Reed and sawdust are classified as fibrous insulating materials; they have a high porosity, which can be considered as hollow bodies filled with gases that can resist the heat flow. They have good thermal insulation and characterized by their lightness. The range of thermal conductivity for natural sand mixes at the sawdust content %, by volume) respectively, compared with 0.745 for reference age of 28 days is between (0.222-0.524) W/m.K for 10% to 40% (reed and sawdust content %, by volume).

5.5 Thermal Insulation Building Units

From the previous discussion of the results, it is intended to select the suitable mixes to produce building units. They can be used in multiple applications, due to their low weight and good thermal insulation, such as boards, panels and building units.

Several considerations were taken when choosing the optimization mix, such as the thermal conductivity and compressive strength. It was decided to select MS30 mixes to produce bricks. **Table 9** summarizes the tests results of bricks units for MS30 mix. The produced products with dimensions of (240x120x55) mm as shown in **Fig. 10.**

5.5.1 Test Results for Thermal Insulating Bricks

5.5.1.1 Compressive Strength

Table 9 shows the compressive strength results of bricks. The compressive strength for MS30 without coating was (19.3) MPa. The compressive strength with coating was (24.1) MPa According to IQS 25 /1988 the two types of bricks can be classified as (class A) brick.

5.5.1.2 Water Absorption

The results for water absorption are listed in **Table 9** .Reed and sawdust has high water absorption. According to IQS 25/1988[(13)], the max water absorption is 24 %. The absorption is reduced by coating the sawdust and reed with bituminous emulsion. For bricks made with natural sand without coating the absorption was 16.4%, while with coating it was 11.6% .The reduction in absorption is 29.2%.

5.5.1.3 Efflorescence

Table 9 shows that bricks made with sand were with almost negligible efflorescence, while the building units made with fine brick aggregate were with very light efflorescence of 5% from the total area of faces of bricks .

6. CONCLUSIONS

1- It is possible to produce aggregate from reed and sawdust of different grading to be used in producing lightweight mortar. Local waste materials such as reed and sawdust can be used in construction after pretreatment. The reusing of waste materials in concrete helps in reducing the disposing of waste materials, and thus will preserve the environment.

2-The inclusion of sawdust and reed in mortar decreased the compressive strength significantly. The percentage of decrease at 28 days was (30.8, 36.8, 50 and 56.4) % for (10, 20, 30 and 40) % reed and sawdust content as a replacement by volume of natural sand, respectively.

3-The flexural strength increased for 10 and 20 % reed and sawdust content while using higher percentages of replacement (30 and 40) % sawdust and reed content causes a reduction in flexural strength up to (8.3, 23.4) %.

4- The addition of reed and sawdust reduced the thermal conductivity of the mixes by about (0.524, 0.410, 0.334 and 0.222) W/m.K compared with (0.745) W/m.K the thermal conductivity of reference mix of natural sand mixes.

5- Two types of bricks (240x120x50) mm without bituminous emulsion coating and with coating were produced. The compressive strength of natural sand mixes with and without coating were (24.1, 19.2) MPa, respectively. It can be concluded that using recycled materials (reed, sawdust) provide good thermal insulation and could be used as building units to construct partitions in framed structure.

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Table 1. Chemical composition and main compounds of ordinary Portland cement used in this research.

Oxide composition	Abbreviation	Content %	Limits of Iraqi specification No.5/1984
Lime	CaO	61	-
silica	SiO_2	19.84	-
Alumina	Al_2O_3	5.28	-
Iron oxide	Fe_2O_3	4.2	-
Magnesia	MgO	2.48	5.0% max
Sulfate	SO_3	2.49	2.8% max if C3A > 5
Loss on ignition	L.O.I	3.8	4 % max
Insoluble residue	I.R	1.13	1.5 % max
Lime saturation factor	L.S.F	0.92	0.66-1.02
Main compounds (Bogue's equations).			
Triccalcium silicate	C_3S	48.97	-
Dicalcium silicate	C_2S	20.01	-
Tricalcium aluminate	C_3A	6.88	-
Tetracalcium Alumino -ferrite	C_4AF	12.78	-

Table 2. Sieve analysis of natural sand.

Sieve size (mm)	Cumulative passing %	Limits of Iraqi specification No.45/1984 (cumulative passing %(zone 2)
10	100	100
4.75	94	90-100
2.36	79.4	75-100
1.18	65.4	55-90
0.6	51.5	35-59
0.3	19	8-30
0.15	3.7	0-10

Table 3. Physical and chemical properties of natural sand.

Properties	**Test results**	**Limits of Iraqi specification No.45/1984**
Specific gravity	2.7	-
Absorption %	1.66	-
Dry rodded unit weight kg/m^3	1550	-
Fineness modulus	2.81	-
sulfate content	0.25	0.5 (max value)

Table 4. Details of mix designation of sand mixes.

Series No	Details	Mix designation	Reed and sawdust content as a partial replacement of natural sand, by volume %	HRWRA % by weight of cement	Cement Kg/m^3	Natural sand Kg/m^3
1	Natural Sand mixes	MS0	-	1	550	1375
2		MS10	5reed+5sawdust	1	550	1239
3		MS20	10 reed+10 sawdust	1.2	550	1101
4		MS30	15 reed+15 sawdust	1.35	550	964
5		MS40	20 reed+20 sawdust	1.4	550	826

Table 5. The 28 days oven dry density for reference mix and various types of mixes.

Details	Mix designation	Reed and sawdust content %	Fresh density kg/m^3	28 days oven dry density kg/m^3
Natural Sand mixes	MS0	-	2242	2060
	MS10	5 reed+5 sawdust	2218	1976
	MS20	10 reed+10 sawdust	2186	1904
	MS30	15 reed+15 sawdust	2140	1824
	MS40	20 reed +20 sawdust	2090	1693

Table 6. Compressive strength test results for reference mixes and various types of mixes**.**

Details	Mix designation	Reed and sawdust content %	Compressive strength MPa At different ages		
			7days	28days	90days
Sand mixes	MS0	-	32.02	40.00	45.00
	MS10	5 reed+5 sawdust	21.12	27.68	35.13
	MS20	10 reed+10 sawdust	16.12	25.28	31.66
	MS30	15 reed+15 sawdust	13.96	20.84	29.5
	MS40	20 reed +20 sawdust	11.62	17.44	25.76

Table 7. Flexural strength test results of reference mixes and various types of mixes.

Details	Mix designation	Reed and sawdust content %	Flexural strength MPa at different ages		
			7days	28days	90days
Sand mixes	MS0	-	4..05	4.32	4.97
	MS10	5 reed+5 sawdust	4.13	5.21	5.52
	MS20	10 reed+10 sawdust	5.10	5.44	5.96
	MS30	15 reed+15 sawdust	3.24	3.96	4.36
	MS40	20 reed +20 sawdust	2.88	3.50	3.85

Table 8. The Thermal conductivity test results and 28 days oven dry density of reference mixes and various types of mixes.

Details	Mix designation	Reed and sawdust content %	28 days oven dry density kg/m^3	Thermal conductivity W/m.K
Natural Sand mixes	MS0	-	2060	0.745
	MS10	5 reed+5 sawdust	1976	0.524
	MS20	10 reed+10 sawdust	1904	0.410
	MS30	15 reed+15 sawdust	1824	0.334
	MS40	20 reed +20 sawdust	1704	0.222

Table 9. The mechanical and physical properties of building units.

Test	MS30 without coating	MS30 with coating	LIMITS OF IQS 25 /1988			
			Limitations for 10 bricks		Limitations for one brick	
			Class A	Class B	Class A	Class B
Average compressive strength (MPa)	19.6	24.1	Min 18	Min 13	Min 16	Min 11
Average absorption	16.4	11.4	Max 20 %	Max 24 %	Max 22 %	Max 26 %
Efflorescence	Very light	Very light	Class A : Light Class B : Moderate			

Figure 1. Sawdust particles.

Figure 2. Reed.

Figure 3. Reed particles.

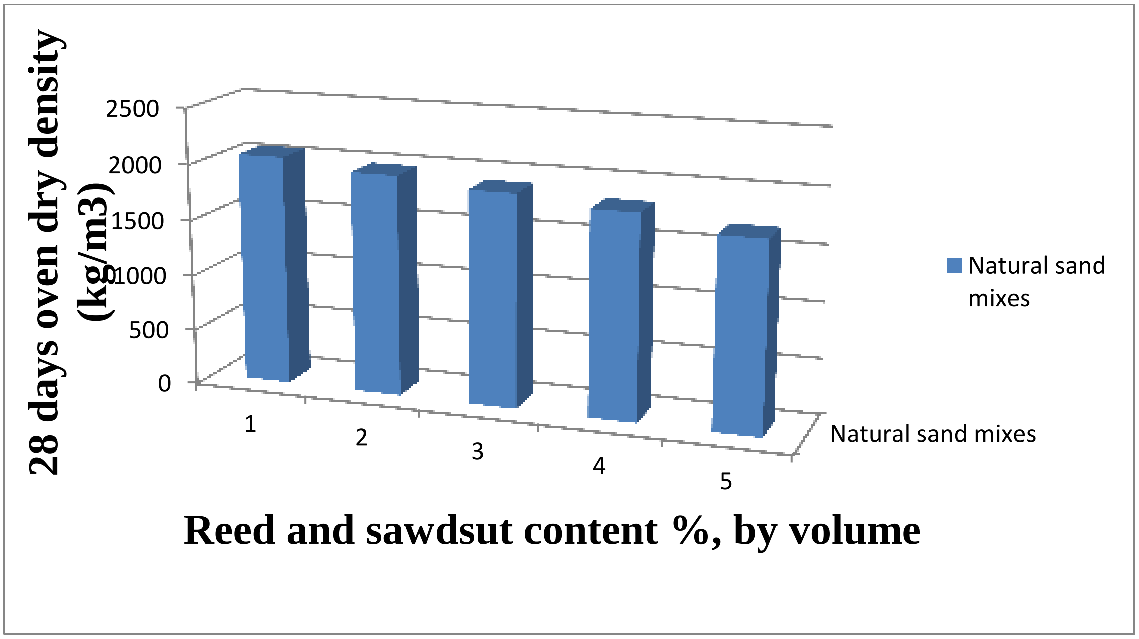

Figure 4. The 28 days oven dry density of natural sand mixes with various percentages of replacement of reed and sawdust.

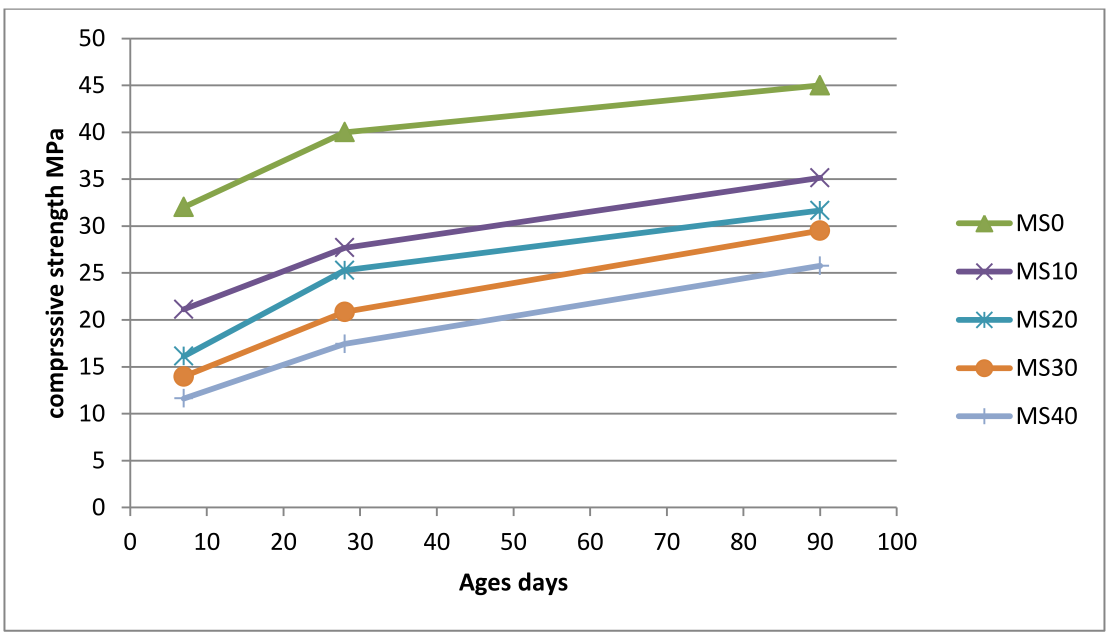

Figure 5. Effect of reed and sawdust content on the compressive strength of natural sand mixes at different ages.

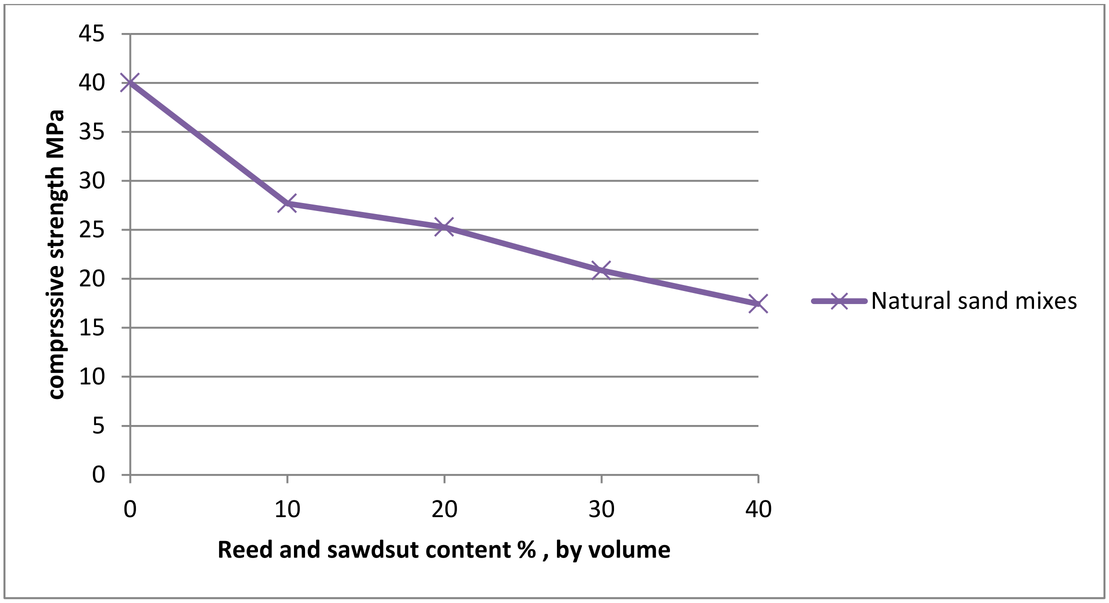

Figure 6. Effect of various percentages of reed and sawdust content on the 28 days compressive strength.

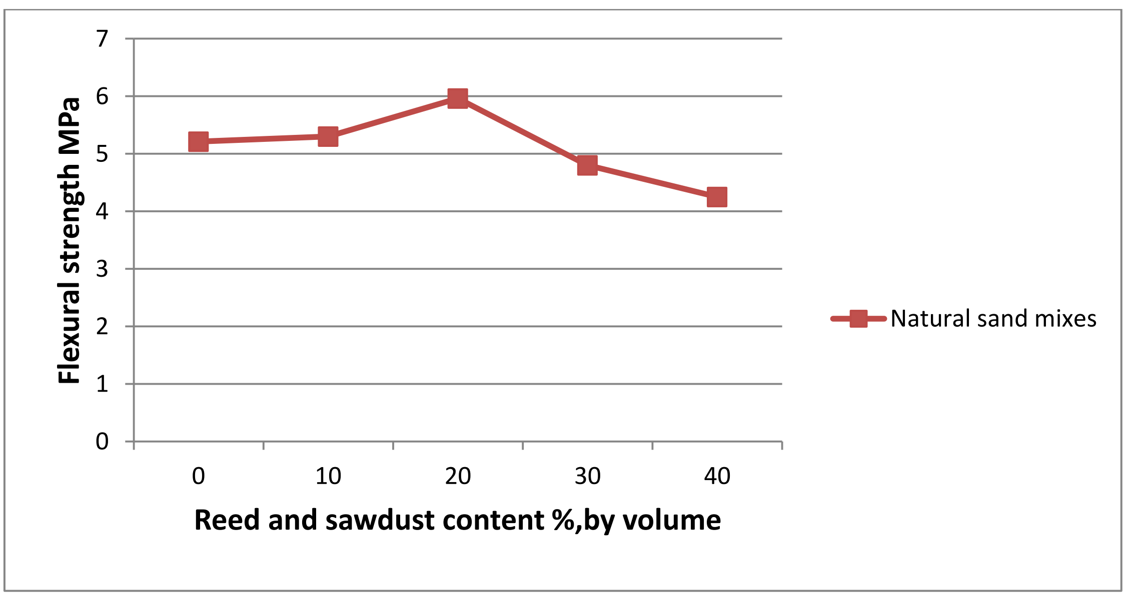

Figure 7. Effect of various percentages of reed and sawdust content on the 28 days flexural strength.

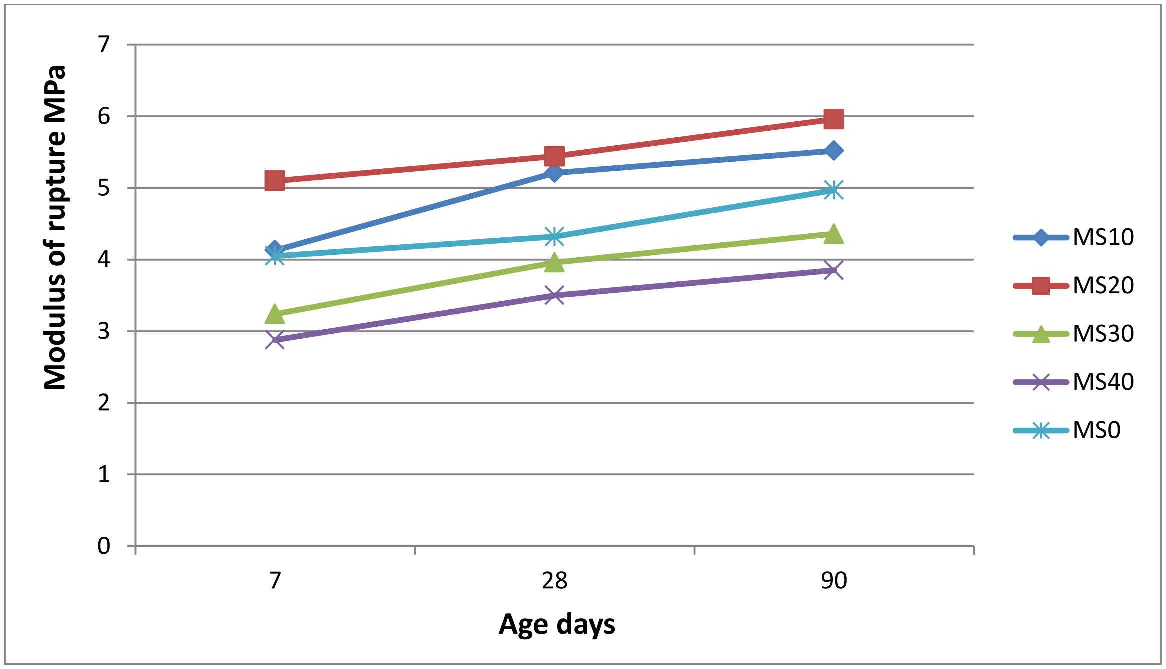

Figure 8. Relationship between the age of test and the flexural strength of natural sand mixes.

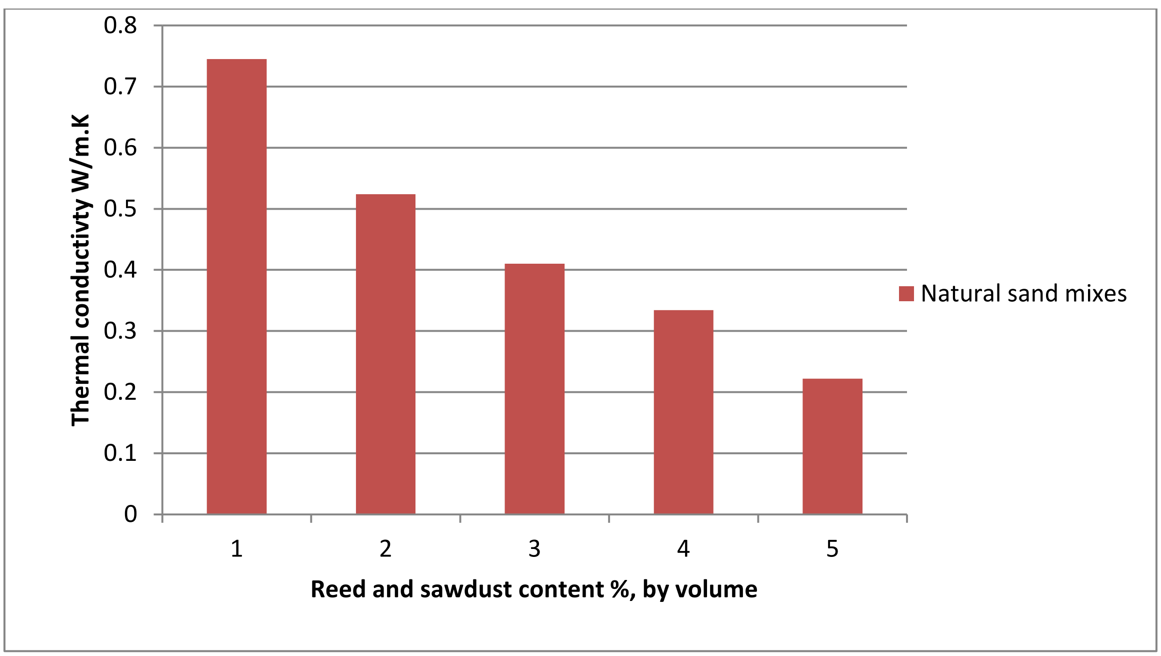

Figure 9. Effect of various reed and sawdust content on the thermal conductivity of natural sand mixes.

Figure 10. Brick units.