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Recycled Chopped Rice Straw- Cement Bricks: Mechanical, Fire Resistance & Economical Assessment

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Abstract: In Egypt burning of rice straw releases large amounts of air pollutants causing serious environmental problems. This paper addresses the recycling of chopped rice straw to produce light weight cement bricks. Different tests were performed to evaluate the rice straw brick (R-brick) with proposed mix proportions. Its weight is 25% lighter than the traditional ones. Indirect fire exposure tests were performed in accordance to the ASTM 119-00A standards to compare fire exposure behavior of the R-bricks to market cement bricks. One and two hours exposure tests were performed, with temperatures ranging between 300 and 800^{o}C. Both types of bricks did not suffer any significant loss in compressive strength when exposed to 300^{o}C for 1hour. A loss of 70% in compressive strength of the rice-straw cement brick was reported when exposed to 800^{o}C for 1 hour and 80% for 2 hours fire exposure. The economical investigation showed that the R-bricks under study cost 25% less than the standard cement brick. It was concluded that the proposed R-bricks provides an economical, light weight brick, with competing thermal insulation properties, while maintaining adequate mechanical properties, and fire resistance.

Key words: Composites, Chopped Rice Straw, Cement bricks, Recycling, Fire tests

INTRODUCTION

The Egyptian rice yield is one of the highest in the world (9.1 tons per hectare in 2001), a crop that leaves behind roughly 4.0 million tons of straw annually. The methods for disposing of the straw and stubble residue remaining in the fields after harvest are either burning or baling. Although some limited uses of rice straw such as animal feed or paper making are maintained, yet burning, the principal disposal method for most of the rice straw residue, is efficient, effective and cheap, even after being phased out in the Egyptian law of Environment number 4 -1994 [8]. As a result most farmers tend to burn the straw in open fields, boosting air pollution and serious human health problems due to the emission of carbon monoxide**.** [2]

Since the 1950's Egypt has adopted several low-cost housing strategies, in an effort to compensate for growing housing demands. At present, vast majority of housing units are reinforced concrete structures with either bricks or cement block infill, which are adopted materials from other climatic zones and countries with different types of natural resources. One of the most abandoned materials in Egypt is cellulous non-wood fibrous materials, such as rice straw. Instead of burning the straw, recycling it with a mixture of cement forms a sustainable low cost building material, which also reduces atmospheric pollution. In addition to these benefits, the resulting composite rice -straw bricks could act as a thermal insulator that can be used in building for the unpleasant Egyptian weather. The use of thermal insulation helps reduce energy costs, while improving indoor temperatures. [2]

Akmal (2006), conducted a preliminary simple laboratory study on preparing and examining rice straw-cement bricks to be used as a filling block in the traditional skeleton building technique.[6]

2. Research Significance & Problem Statement:

Recycling rice straw to be used in building process is one of the highly encouraged research areas that would yield great solutions to the major environmental problem resulting from burning this residue. Rare information is available on the effect of adding such material to different construction elements.

This paper investigates the effect of adding rice straw to the cement bricks used in construction. The objective of this research is to evaluate the effect of adding chopped rice straw on the mechanical properties and fire resistance of the cement bricks. An optimization study was performed between different mix proportions and the corresponding compressive strength. Thermal properties of the proposed bricks are studied

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to provide confidence in this new structural element. Accordingly, thermal conductivity of the bricks will be measured and fire endurance evaluation tests will be performed. Finally, an economical comparison between both types of bricks will be undertaken and reported for the mass production use in the local market.

3. Design Mixs for Rice Straw Bricks:

3.1 Mix Constituents:

1- Ordinary Portland cement (OPC) from local mark
2- Fine aggregate: siliceous sand with a maximum size of 5mm , well graded and free from impurities.
3- Coarse aggregate: free of impurities with nominal maximum of 10 mm and it was sieved to remove the particles smaller than 2 mm.
4- Chopped straw fibers with length ranging between 0.5 to 1.5cm4
5- Natural fresh drinking water free of impurities.

3.2 Design Mix Proportions:

The constituents considered in preparing and testing the mixes in this study are presented in Table (1).

Table 1: Mix proportions of Rice straw-Cement bricks/1000bricks

Type of Mix	Fine Aggregate (m^3)	Coarse Aggregate (m^3)	Chopped Rice Straw (Kg)	Cement (Kg)
Mix (A)	0.9	0.9	40	400
Mix (B)	0.85	0.4	70	400
Mix (C)	0.85	0.2	90	400

4. Sampling and Mechanical Testing of Rice-straw Cement Bricks:

4.1 Introduction

Brick manufacturing is based on the principle of mixing and densification of a straw-cement brick mix to make a regular shaped, uniform and high performance masonry unit. The technique used is the same as the production of traditional standard cement bricks using a mobile semi-mechanized egg-laying machine as shown in Fig (1), and the product is a standard brick with dimensions 25*12*6 cm.

Fig. 1: Semi-Mechanized egg-laying machine

4.2 Samples Casting & Curing:

Coarse and fine aggregates were batched by volume using wooden boxes with the desired volume. Cement was added by weight using only whole bags of 50 kg to ensure uniform proportions of mix. The chopped rice straw was added to the mixture according to the previously mentioned quantities. The dry mixes were batched outdoors in rotating power-driven resolving mixer of 100 liters capacity before adding water.Then the bricks were molded and vibrated using 'egg-laying' mobile machines and then de-molded immediately after compaction The samples were carried away on pallets to the curing place and they were regularly sprayed with water twice a day for a period of 7 days to gain sufficient strength. Visual inspection revealed non-consistency of mix C as it was weak and breakable by hand. Accordingly; bricks of mix C were excluded.

4 .3 Mechanical Testing:

For each mix of the rice-straw cement bricks A and B, 3 samples were tested in the laboratory. Also 3 samples of a standard commercial cement brick were tested to compare the compression stress of each brick. The dimensions of bricks for each sample tested were measured precisely and an average of 6 * 12 * 25 cm dimensions were obtained

4.3.1 Compression Test Apparatus:

The Shumadsu 1000 KN universal tension- compression machine (Fig 2**)** was used in testing the bricks for compression. The machine is equipped with a data analyzing output unit for output data recording.

Fig. 2: The Shumadzu machine used for testing the rice straw-cement bricks

4.3.2 Testing Procedure:

Initially, the 3 rice-straw bricks mixes under testing were prepared and compared with standard pure cement commercial bricks as shown in Fig. 3.

Fig. 3: Color and texture of different samples.

Bricks were placed flat on the platen of the testing machine. A 0.5 mm/sec rate of loading was applied on each specimen until failure. The compression testing results for all mixes are summarized in Table (2). These results were compared to the values specified by the Egyptian Code of Practice ECOP 204-2005.[7]

Table 2: Compression Test Results

MIX	Specimen No.	Max. load (Ton)	Max. Stress (Kg/Cm^2)
	1	35	114.4
MIX A	2	36	116.7
	3	35	113.6
	1	30	97.8
MIX B	2	22	72.5
	3	15	49
	1	54	177.9
Commercial Sample	2	63	204.3
	3	55	177.6

The maximum compression loads applied on the bricks showed wide variance. The specimens of mix (B) containing 70 kg/1000 brick of chopped rice straw , showed non homogeneity in its maximum compressive stress values 97.8, 72.5 and 49.0 kg/cm^2 for samples 1,2 and 3 respectively. This can be due to the partial loss of bond among the mix components as a result of the excessive amount of chopped straw existing in the mix. These scattered values didn't give confidence in this mix although within the specified values (70 kg/cm^2 for commercial cement bricks used as load bearing walls and 25kg/cm^2 for bricks used as fillers in skeleton type buildings) stated by the Egyptian Code of Practice ECOP 204-2005 [7]. The maximum compressive stress values for specimens of mix (A) increased by decreasing the chopped rice straw content to 40 kg/ 1000 bricks using the same quantity of cement with almost the same amount of fine aggregate . The maximum compressive stress values for mix (A) were 114.4, 116.7 and 113.6 kg/cm^2 for samples 1, 2 and 3 respectively showing homogeneity in its results. These values exceeded the values specified by the Egyptian Code of Practice ECOP 204-2005. Compared to the values obtained in Garas et al [3] which reached stresses of 36.6kg/cm^2, these results are considered relatively higher for the same mix proportions produced by a different supplier. This could be due to the lack of quality control measures and inadequate curing time. Standard commercial samples obtained from the local market were considered to be very homogeneous with maximum compressive stress values of 177.9, 204.3 and 177.6 kg/cm^2 for samples 1, 2 and 3 respectively.

Accordingly, rice straw cement bricks of mix A (40 Kg straw/1000 bricks) with the highest compressive strength of all mixes (115kg/cm^2 in average) was chosen for mass production purposes. Consequently, all further comparative tests were conducted between this brick and the standard commercial cement brick.

5. Characterization of Rice Straw Brick (R) Versus Commercial Cement Brick (C):

5.1. Chemical Analysis:

A chemical analysis of the 2 types of bricks under investigation (Table 3) was performed to study the effect of its constituents on the mechanical behavior of the bricks.

Table 3: Chemical Analysis of Rice Straw and Cement bricks percent by weight

Constituents	Rice Straw-brick	Cement-Brick
SiO_2	20.47	23.87
Al_2o_3	2.07	2.48
Fe_2O_3 ^{tot}	1.90	2.37
TiO_2	0.30	0.31
NiO	---	0.03
Mno	---	0.07
Mgo	8.40	6.79
Cao	33.57	35.15
SrO	0.07	0.09
Na_2O	0.24	0.39
BaO	0.51	0.46
K_2O	0.52	0.54
ZrO_2	0.03	0.03
Rb_2O	0.07	0.05
Y_2O_3	0.01	0.01
P_2O_5	0.03	0.06
SO_3	0.75	1.22
Cl	0.07	0.16
LOI	31.00	25.94

Calcium oxide showed to be the highest component in both bricks (the major constituent in the Portland cement) followed by the silicon dioxide which is the main constituent of sand , although slightly higher in the cement brick. This can be due to replacing a percentage of fine aggregates in rice straw bricks by chopped

rice straw particles. The Loss Of Ignition (LOI) value was one of the governing items in the constituent percentage for both types of bricks. Its value for the rice straw brick is 5% more than in the cement brick which was previously expected due to the presence of the chopped rice straw. This study proved that adding chopped rice straw as a natural material to the cement brick constituents does not include any strange components (rather than the original ones of the cement brick) that might result in a negative effect on the properties of the new rice straw brick.

5.2 Fire Resistance Test:

5.2.1 Instrumentation and Test Setup:

A custom built furnace of internal dimensions 60*85*165 cm (length *width * height respectively) was used to perform the fire testing. The maximum temperature that can be reached by the electric furnace is 1200º C. The temperature –time rate curve for the furnace was adjusted to follow the ASTM 119-00a [1] standard fire test curve (Fig 4). Detailed information about instrumentation can be found in previous work by Elkady [4,5].

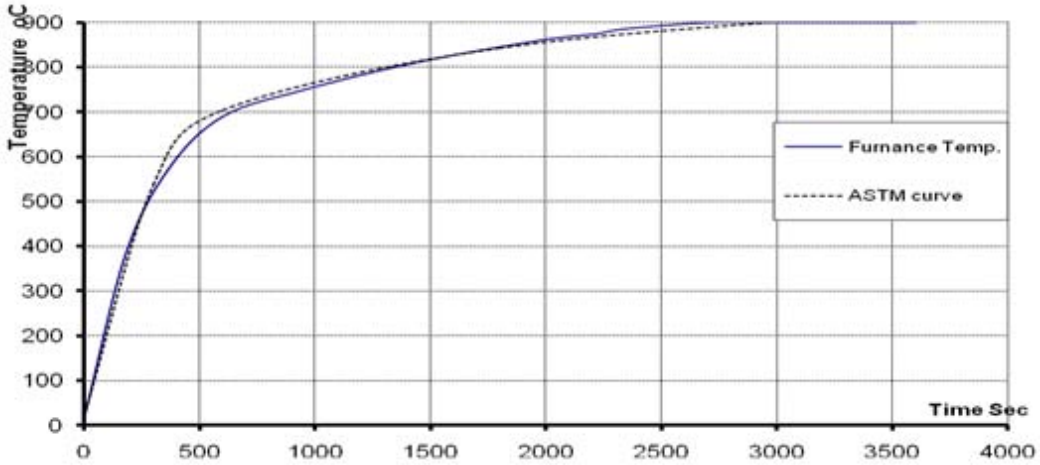

Fig. 4: Furnace Time-temperature curve, versus ASTM 119 fire test curve

To insure uniformity of temperature distribution, 4 K-type thermocouples were mounted inside the furnace. Targeted temperature is programmed on the control unit attached to the thermocouples.

The one hour exposure tests were conducted at 6 temperature levels: 300,400, 500, 600, 700 and 800 º C. Each test was conducted on a set of three samples that was exposed to the assigned temperature for one full hour.

The test was conducted simultaneously on both types of bricks: cement and rice straw bricks.

The second group (2hour exposure) was exposed to elevated temperatures up to 700 º C.

5.2.2 Fire Tests Results and Discussion:

Figure 5 displays the reduction in compressive strength of the tested bricks due to one hour of fire exposure. Both types of bricks did not suffer any significant loss of strength at 300º C. Starting from 400 to 800ºC, loss in strength of a maximum of 25% is noticed in cement bricks while the loss in the rice straw bricks strength graduated till reaching about 70% of its original strength when exposed to 800 degrees for one hour.

The two hours fire exposure test (Fig.6) revealed a maximum loss of about 50% in the cement brick compressive strength compared to 80% loss in rice straw bricks under 700º C.

5.3 Economical Study:

Cost is a major parameter in any industry. One of the main elements of construction industry is brick manufacturing and its cost. Also utilization benefits of a brick add indirect savings for comparative purposes.

Table 4 shows that the manufacturing cost of both types of bricks indicates savings up to 25% of the total direct cost /1000bricks. This direct saving in costs is added to the environmental profit of recycling rice straw which is traditionally burnt by farmers in open fields, boosting air pollution and serious human health problems. Besides, rice straw material is known for its high insulation properties which could add another indirect saving value by minimizing energy consumption.

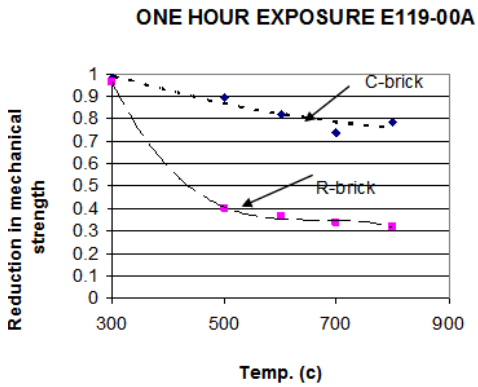

Fig. 5: One hour fire exposure test results for R and C-bricks

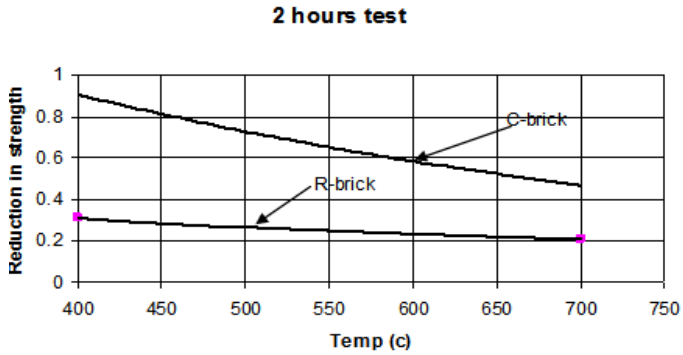

Fig. 6: Two hours fire exposure tests results for R and C-bricks

Table 4: Comparison between Commercial cement and Rice-straw brick

Brick Type	Average Compressive Stress Kg/cm2	Price /1000 Bricks L.E
Commercial Standard Brick	186	500
Rice straw-cement brick	115	380

6. Conclusion:

- This research presents an intensive evaluation of recycling chopped rice straw to be used in the manufacture of cement bricks.
- The optimized chosen mix of constituents 0.9 m^3 fine aggregate, 0.9 m^3 coarse aggregate, 40 kg chopped rice straw and 400kg cement/1000 brick resulted in producing a rice straw brick of density 25% less than the commercial cement brick.
- As for cost saving, using rice straw brick resulted in 25% reduction in the production cost/1000brick.
- Chemical analysis was performed on the constituents of the rice straw cement brick and the commercial cement brick, no strange materials were reported.
- The fire exposure tests of chopped rice straw cement brick compared to local market cement bricks : The results indicated that the loss in the compressive strength of both types of bricks under study increased by the increase of temperature, and the period of fire exposure.
- In order to use the rice straw brick in load bearing walls, the fire temperature should not exceed 400^o C to reach stress up to to70kg/cm^2, while in case of using it as filler in skeleton type buildings, it can maintain temperatures even more than 800 ^{o}C for 1 hour fire exposure to comply with the Egyptian Codes of practice.
- The rice straw brick is unable to be used as a load bearing wall if exposed to 2 hours fire exposure due to the dramatic loss in its compressive strength.
- Reduction in strength due to fire exposure up to 300^o C for 1 hour did not have significant effect on the compressive strength of both types of bricks.
- It was concluded that the proposed rice straw bricks provides an economical, light weight brick, with competing thermal insulation properties, while maintaining adequate mechanical properties, and fire resistance.

REFERENCES

ASTM E119-00a, standard test methods for fire tests of building construction and materials, ASTM international, west Conshohocken, Penn. Doi: 10.1520/E119-00.

Mansour, A., J. Srebric and B.J. Burley, 2007. Development of Straw-cement Composite Sustainable Building Material for Low-cost Housing in Egypt, J. Appl. Sci. Res., 3(11): 1571-1580.

Garas, G., H. El Kady and A. El Alfy, 2010. " Developing A New Combined Structural Roofing System Of Domes And Vaults Supported By Cementitious Straw Bricks", ARPN Journal of Engineering and Applied Sciences, under publication.

Elkady, H., 2010. Effect of High Temperature on CFRP Retroffitted Columns, Protected with Different Coatings ", Structural Fire Engineering Journal, 1(2): 89-100.

Elkady, H. and A. Hassan, 2010. "Protection of reinforced concrete beams retrofitted by carbon fibre-reinforced polymer composites against elevated temperatures ", Canadian journal of civil engineering, pp: 1171-1178.

Tamer, R., 2006. Recycling of rice straw in the manufacture of building materials: A Study of Manufacturing Building Bricks. Modern University - Department of Architecture(in Arabic).

The Egyptian Code of Practice ECOP, 204-2005. Ministry of housing and urban communities, 2005.

The Egyptian law of Environment number 4 -1994.