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(NTC 2015)



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## Physico mechanical properties of concrete mixes containing recycled Rice Straw and Blast-Furnace Slag

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### **ABSTRACT**

The aim of this study is to design concrete mixes, which is used in cement bricks and walls using recycled rice straw and blast-furnace slag. The studied factors are rice-straw content (3, 6, 9, 12, 15 % related to cement mass) for both rice straw (untreated and treated with NaOH with 1 % concentration). The main results show that; At 28 day, compressive, tensile and flexural-strength ranges of “20.56 – 3.7 and 17.03 – 3.44”, “2.65 – 1.17 and 2.52 – 1.03” and “6.49 – 1.66 and 3.04 – 0.84” MPa were obtained by using concrete mix with rice straw of 3 – 15 % for treated and untreated rice-straw respectively. Meanwhile, for concrete mix without rice straw (control) the strength values of 32.1, 2.78 and 5.9 MPa were obtained. The maximum absorption and porosity of 33.54 and 32.05 % respectively, were obtained for concrete specimens made by using untreated rice-straw of 15 %. Meanwhile, the minimum absorption and porosity values of 5.71 and 13.47 % respectively, were obtained by using concrete mix without rice straw. The real-density ranges of 1961 – 1444 and 1816 –



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1371 kg/m<sup>3</sup> were obtained by using concrete specimens made with rice straw content of 3 – 15 % for treated and untreated rice-straw ,respectively. Meanwhile, for concrete mix made without rice straw (control), the density is about 2243 kg/m<sup>3</sup>. The costs of 1000 brick unites were 550, 370, 360, 350, 340 and 330 L.E. for bricks containing 0, 3, 6, 9, 12 and 15 % rice straw, respectively.

### Key Words

Rice straw, Blast-furnace slag, Physico mechanical parameters

### INTRODUCTION

The urgent need to develop suitable and affordable housing is born as a consequence of the fact that over one billion people in the world, most of them are living in the developing nations, are either homeless or live in very poor housing. On the other hand, the sustain able world's economic growth and people's life improvement greatly depend on the use of alternative products in the architecture and construction, such as industrial wastes conventionally called “green materials” (BASIN news, 2001). Cement bonded boards (CBB) are well established in market place and widely applied in many developed countries. It combines the properties of two important materials: cement and any fibrous materials like wood or agricultural residues. It is a panel product made up of strands, flakes, chips, particles or fibers of wood or some agricultural residues bonded with ordinary Portland cement (Pererira *et al.*, 2006). Wood particles-cement composites was produced from a number of agro-forestry material including sawdust, construction waste, bagasse, coffee husk, maize husk, and furniture waste-wood among others (Kasai *et al.* 1998, Olorunnisola & Adefisan 2002, Ajayi 2002).



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Lignocelluloses materials are available on a worldwide basis and considered from renewable resources. These materials have low cost and energy because of producing them manually and by low technology (Frybort *et al.*, 2008). Composites made of cement and lignocelluloses materials have many advantages; better dimensional stability, better resistance to bio deterioration and fire, have no formaldehyde emission originating from the binder and can be used as means of recycling wood residues . On the other hand, these materials can be used to face the insufficient of wood fibers and the increasing in lumber prices (Pererira *et al.*, 2006). On the other hand, the manufacture of ordinary Portland cement (OPC) is a highly energy intensive and environment unfriendly process required about 4 GJ of energy per tone of the finished product in addition to produce 0.8 – 1.3 ton of CO<sub>2</sub> per ton of cement production. In addition, the contribution of Portland cement production worldwide to the greenhouse gas emission estimated to be about 1.35 billion ton annually or about 7 % of the total greenhouse gas emission to the earth atmosphere (Malhotra, 2002). In order to produce environmentally friendly concrete, Mehta (2002) suggested that to use of fewer natural resources, less energy and minimize carbon dioxide emissions. McCaffrey (2002) suggested that the amount of CO<sub>2</sub> emissions by cement industries could be reduce by decreasing the amount of calcite material in cement, by decreasing the amount of cement in concrete, and by decreasing the number of buildings using cement. Literature reveals that alternative binders in developing countries are called Fal-G binders, made from fly ash (as a source of pozzolan), lime and calcite gypsum (Garg *et al.*, 1996 and Tishmack *et al.*, 2001). The Egyptian rice yield is one of the highest in the world (3.7 tons per



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feddan in 2013). Thus, rice straw is a major agricultural by-product in Egypt, where its production in 2013 estimated to 4 million tons (FAO, 2014). The methods of disposing of the straw and stubble residue remaining in the fields after harvest are either burning or baling. There are some limited uses of rice straw such as animal feed or paper industry. Burning of rice straw is the principal disposal method that it is efficient, effective and cheap. Burning the straw in open fields, caused boosting air pollution and serious human health problems due to the emission of carbon monoxide (Allam *et al.*, 2011) 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 (Allam *et al.*, 2011). Morsy (2011) found that the compressive strength for rice straw - fly ash cementitious mixture ranged between 3.8 MPa at 20 % rice straw content and 30 MPa at 5% rice straw content. Rice straw cementitious composite flexural strength increased by increasing the straw content up to 7.5 % for 10, 20 and 30 mm rice straw particle. In addition, flexural strength increased when flake length increased at the same fiber content. The rice straw cementitious mixture could be classified as carrying material for making bricks with straw content up to 10 %. This study proposes the use of rice straw as a lignocelluloses material to improve and develop



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slag -lignocelluloses-composites building materials as a means to positively impact on the shelter conditions of Egypt and the resource poor countries of the developing world. In addition to these benefits, the straw could act as a thermal insulation material for the hot climate of Egypt. In addition, the use of thermal insulation helps in saving energy, and creating a pleasant indoor air temperature. The aims of this study are:

- (1) Study the effect of rice-straw ratio on physical, mechanical and thermal properties of bricks.
- (2) Study the effect of rice-straw chemical treatment by sodium hydroxide on physical and mechanical properties of bricks.
- (3) Study the effect of slag binding-material on physical and mechanical properties of bricks.

## 2. EXPERIMENTAL

### 2.1. Materials

The main experiments were carried out through Company Good Mix for Ready Mix Concrete, 6Th of October City, Giza Governorate during the period from 2012 to 2014.

The materials used in this study include water, rice straw, binding materials and chemicals. Potable water with PH value of 7.0 confirming to IS 456-2000 was used for making concrete and curing of the specimens. The silica-fume powder used was complying with the requirements of ASTM C 1240, with an average  $\text{SiO}_2$  content of 92.85 % . The cement was locally produced according to Egyptian Standards ES 4756 that complies with the EN197. Cement type of «CEM I», 52.5 N and grade with commercial name of "Misr- BeniSuef" was used in the experimental study. Granulated blast furnace slag used in experimental research was produced from Helwan Iron and



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Steel Company. The slag was ground to size of 150 - 200 microns. Gypsum from Sinai Company was used. Local limestone was used in tested concrete mixes. Crushed limestone filler retained on the sieve No. 200 was used with specific gravity of 2.61 kg/cm<sup>3</sup>. Table 1 illustrates the chemical composition of these raw materials. Fine aggregate (sand) with 100 percent passing sieve No. 3/8 and a minimum of 80 percent sieve passing the No. 4 sieve was used in the preparation of concrete mixes. Course aggregates having a minimum of 20 percent retained on sieve No. 4. Agricultural residues used in experiments was rice straw with addition of 3, 6, 9, 12, and 15 % related to the weight cement. According to (ASTM-D1109-84), the treatment of agricultural residues was carried out by soaking in 1 % sodium hydroxide for 24 hours then filtered through 2 mm screen. The ratio between agricultural residues and soaking solution was 1:10 by weight. After filtration, rice straw was washed till the water became clear. Then the treated rice straw was dried in an oven at 105 ± 2°C and packed in polyethylene bags until using the time of utilization. Chemical additives are also used in this study, these are: (i) A commercially available super-plasticizer (SPR from NOVO CHEM Company) was used to enhance the workability of fresh concrete for the selected proportions of ingredients (ASTM C494 as Type G) and (ii) sodium hydroxide. All the materials were stored in the concrete laboratory at 25° C in closed containers or bags to ensure that the conditions were kept constant throughout the test period.



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**Table 1: The Chemical analysis of raw materials**

Oxides	OPC	Slag	SF	Gypsum	Limestone
SiO <sub>2</sub>	20.47	35.55	92.85	0.23	1.34
CaO	63.52	36.53	0.39	32.7	55.13
Al <sub>2</sub> O <sub>3</sub>	4.99	11.53	0.61	0.08	0.69
Mg O	2.32	6.7	1.58	0.46	0.13
N <sub>2</sub> O	0.16		0.5	0.03	
MnO		3.6			
K <sub>2</sub> O	0.12		0.87		
Fe <sub>2</sub> O <sub>3</sub>	3.54	0.39	0.94	0.05	0.12
SO <sub>3</sub>	3.04			43.68	1.7
BaO		3.00			
Free Lime	1.17				40.56
S		1.31			
Losses	0.45				

### 3.2 Methods of investigation:

Gradation of all-in aggregate was carried out according to (BS 882) standard, with 35 % of sand, 32.5 % of size number 1 and 32.5 % of size number 2. Curing of all concrete specimens was carried out according to ASTM C 192 standard of. After 24 hours of tee casting the specimens were removed from the moulds and immediately submerged in clean fresh water and kept there until taken out just prior to testing. The curing temperature of the water in the





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curing tank should be maintained at 20-25°C. Concrete specimens made of all mixes was designed according to BS5328:1981 standard. Concrete mix design consists in selecting and proportioning the constituents to give the required strength, workability and durability. A total of six concrete mixtures were prepared. The first is a reference concrete mix (control mix), the remaining five mixtures were prepared with agricultural residues of 3, 6, 9, 12, and 15 % , limestone filler of 0.5 % , gypsum of 0.5 % , silica fume of 10 % and slag of 50 % as replacement for cement respectively. Water / cement ratio is constant at 0.55 for all concrete mix.

### 3.2.1. methods of Physical Studies

Real density was measured according the standard of (BS1881:Part114 methods for determination of density of hardened concrete) - (ISO 6275). Density was measured based on the oven dry weight and volume of the specimens .Each real density result was the average of three specimens. Real densities were calculated by using the equation:

$$\rho_s = \frac{W_d}{V}$$

Where:  $\rho_s$  is the real density; (g/mm<sup>3</sup>),  $W_d$  is the weight of the specimens; (g) and  $V$  is the volume of the specimens; (mm<sup>3</sup>).

Water absorption and shrinkage were determined according to the standard of ASTM (D- 1037) The percentage of total absorption was calculated by using the following equation;





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$$\text{Absorption (\%)} = \mathbf{Abs} = \frac{(W_2 - W_1)}{(W_1)} \times 100$$

Where:  $W_1$  is the average weight of dry specimen's; (g).  $W_2$  is the average weight of wet specimen's; (g).

Then the amount of water absorbed and shrinkage increase after 24-hours of water soak was calculated as a percentage of the original weight and thickness of test specimens. While, the porosity was calculated after 28 days from soaking in water by using the following equation:

$$\mathbf{P} = \frac{(w_a - w_d)}{(w_a - w_w)} \times 100$$

Where:  $P(\%)$  is the saturated porosity.  $W_a$  is the Specimen weight in air of saturated sample; (g).  $W_d$  is the specimen drying weight; (g) after 24 h in oven at  $105 \pm 5^\circ\text{C}$  and  $W_w$  is the specimen weight in water; (g).

Porosity is defined as the volume of voids in a solid material expressed as a percentage of the total volume. This method was used to measure cement based materials porosity successfully (Papadakis et al, 1992; Cabrera et al, 1988; Rossignolo and Agnesini, 2004; Gonen and Yazicioglu, 2007).

### 3.2.2. Methods of Mechanical Studies:

The compressive strength of concrete was determined according Standard of BS. 1881:1983 part 108-111 with dimensions of (150 ×150×150 mm). The compression test machine was Chinese made, model of jys-2000A, Class 1,



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measure range of 0 – 2000 kN, accuracy of 0.1 N. The test was carried out after ages of 3, 7, 28 and 56 days. The average for three specimens were taken. The compressive strength is calculated using following equation:

$$CS = \frac{P}{(B \cdot L)}$$

Where: **CS** is the compressive strength; (MPa), **P** is the maximum load; (N), **L** is the length of sample; (mm) and **B** is the width of sample; (mm).

The flexural strength was measured by using prism with dimensions of 100 × 100 × 400 mm. This test was determined according to ASTM C 496-86 Standard. Prisms were cast, demolded and cured in a similar way as the compressive strength. The average of strength for three specimens were taken. The flexural strength is calculated by the following equation:

$$FS = \frac{3PL}{(2WT)^2}$$

Where: **FS** is the flexural strength ;N/mm (MPa), **P** is the maximum load; (N), **L** is the length of sample; (mm), **W** is the width of sample; (mm) and **T** is the thickness of sample; (mm).

Indirect tensile test was measured in according to ASTM C 496-96 standard. This test method measures the splitting tensile strength of concrete by the application of a diameter compressive force on a cylindrical concrete specimen placed with its axis horizontal between the platens of a testing



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machine. The splitting tensile strength of the specimen was calculated according the following equation:

$$T = \frac{2P}{\pi Id}$$

Where: **T** is the splitting tensile strength, (MPa), **P** is the maximum applied load indicated by the testing machine; (N), **l** is the length of cylindrical specimen; (mm) and **d** is the diameter of cylindrical specimen; (mm).

### 3. RESULTS AND DISCUSSION

Fig. 1 shows the effect of rice-straw percentage treated and untreated on absorption, porosity, real density and shrinkage of the hardened concrete. The results show that the absorption and porosity increases with increasing rice-straw percentage for treated and untreated rice-straw. Meanwhile, the real density and shrinkage decreases with increasing rice-straw content of 3 to 15% treated and untreated rice-straw. The maximum value of absorption and porosity of 33.54 and 32.05 % respectively, were obtained by using untreated rice-straw of 15 % content. Meanwhile, the minimum value of absorption and porosity of 5.71 and 13.47 % respectively ,were obtained by using concrete mix without rice straw. The absorption and porosity values increased by 81.3 and 54.2 % respectively ,when rice-straw content of concrete increased from zero to 15 %. Also, the absorption and porosity values increased by 15.3 and 17.8 % for concrete specimens made by using untreated rice-straw compared with those made with treated rice-straw. The increase of absorption by increasing rice-straw content in concrete is due mainly to the increase in



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porosity of concrete containing rice straw as compared with the concrete made with neat cement. As the straw content increases, the ability of the composite to absorb water increases. This may be explained by the fact that straw, like other lignocelluloses, is hygroscopic, with a relatively high affinity for water. Also, the increase of absorption for concrete specimens containing untreated rice-straw is due to the increase of porosity as compared with those containing treated rice-straw. Meanwhile, the minimum porosity of 13.47 % was obtained by using concrete mix made without rice straw. The maximum shrinkage of 32.05 % was obtained for concrete made by using untreated rice-straw of 15 %. The shrinkage was increased by 88.1 % by increasing rice-straw content from 3 to 15 %. Also, the shrinkage was increased by 43.3 % by using rice straw as untreated rice straw compared with treated rice-straw. At 28 days of hardness, real-density ranges 1961 – 1444 and 1816 – 1371 kg/m<sup>3</sup> were obtained by using concrete mix made with rice straw of 3 – 15 % for treated and untreated rice-straw, respectively. Meanwhile, the real density of 2243 kg/m<sup>3</sup> was obtained by using concrete mix without rice straw (control).

Figure 2 shows the effect of rice-straw percentage treated and untreated and treatment on compressive, tensile and flexural strength of hardened concrete. The compressive, tensile and flexural strengths of the hardened concrete decrease with increasing rice-straw percentage and age for concrete specimens containing treated and untreated rice-straw. After 28 days of hardened the values of , compressive, tensile and flexural-strength ranges are “20.56 – 3.7 and 17.03



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– 3.44”, “2.65 – 1.17 and 2.52 – 1.03” and “6.49 – 1.66 and 3.04 – 0.84” MPa were obtained for the hardened concrete containing rice straw content of 3 – 15 % for treated and untreated rice-straw respectively. Meanwhile, compressive, tensile and flexural-strengths values of 32.1, 2.78 and 5.9 MPa were obtained for concrete specimens made without rice straw additions (control). The values of compressive, tensile, flexural strengths of concrete containing treated rice-straw were increased by 6.4, 6.0 and 6.7 % respectively as compared with those of concrete containing untreated rice-straw concrete at 28 days of curing. The Egyptian standard specification number 1349 - 1991 indicates that the compressive strength of cement-sand bricks should be not less than 7 MPa for carrying bricks and not less than 2.5 MPa for non-carrying bricks. Based on this fact, all concrete containing treated rice-straw content up to 9 % by weight of cement are recommended for utilization as carrying bricks. Also, concrete having rice-straw content of 12 – 15 %t were accepted as non-carrying bricks. The decrease of compressive, tensile and flexural strengths by increasing of rice-straw content in concrete mixes is mainly due to decrease in the consistency of concrete because of decrease of cement percent. However, higher fiber content increases porosity of the composite material and resulted in the loss of compressive, tensile and flexural strengths values. Other possible reasons for the increase in porosity at higher levels of straw addition include the higher amount of water required for the sand mix consistency and poor compaction (Karade 2003). Also, the decrease in the compressive, tensile and flexural strengths are



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attributed to the physical properties of rice straw particles, since they are less stiff than the cement matrix. Meanwhile, the increase of compressive, tensile and flexural strengths of treated rice-straw concrete is due to the increase of silica content above the surface area of untreated rice-straw, which activates the pozzolanic reaction with the cement. Free lime liberated during the hydration of cement. The decrease of real density of cement bricks by increasing rice-straw content is due to the decrease of rice-straw density compared as with those of concrete containing cement density. In addition, the increase in the density values of concrete containing treated rice-straw as compared with concrete containing untreated rice-straw is due to the increase porosity of of the latter .

### 4.3 Costs.

The results show that the costs of bricks units decreased by increasing treated rice-straw content from zero to 15 %. The costs of 1000-bricks units were 550, 370, 360, 350, 340 and 330 L.E. for brick contents 0, 3, 6, 9, 12 and 15 % rice straw, respectively; the cost of 1000 bricks decreased by 40 % by increasing rice-straw content from 0 to 15 %.

### 5. Conclusion

From the results of this study, the following conclusion can be driven:

- At 28 days of curing , compressive, tensile and flexural-strength values are ranged “20.56 – 3.7 and 17.03 – 3.44”, “2.65 – 1.17 and 2.52 – 1.03” and “6.49 – 1.66 and 3.04 – 0.84” MPa were obtained for concrete mix



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made with rice straw content of 3 – 15 % for treated and untreated rice-straw, respectively.

- . The Egyptian standard specification number 1349 - 1991 indicates that the compressive strength of cement-sand bricks should not be less than 7 MPa for carrying bricks and not less than 2.5 MPa for non-carrying bricks. Based on this fact, all concrete mixes containing up to up to 9 % rice straw are accepted as carrying bricks; also, concrete mixes having rice-straw contents of 12 – 15 % were accepted as non-carrying bricks.
- The costs of 1000 bricks unit were 550, 370, 360, 350, 340 and 330 for 0, 3, 6, 9, 12 and 15 % rice straw respectively

## Thermal Conductivity

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 ( $\Delta T$ ) under steady state conditions and when the heat transfer is dependent only on the temperature gradient. This test was carried out on samples of 30\*30\*3cm using Laser Comp instrument and according to ASTM C-518. It may be 5 to 6 hours until the condition of steady state reach. The thermal conductivity was calculated using the following Equation;

$$K = \Phi \Delta x / \Delta T$$





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Where:  $\Phi$  is heat flux ( $W/m^2$ ) flowing through the sample,  $K$  is its thermal conductivity ( $W m^{-1} K^{-1}$ ),  $\Delta x$  is the sample thickness (m),  $\Delta T$  is the difference in temperature between the hot and cold surfaces of specimen ( $^{\circ}C$ ). Figur (3) show the thermal conductivity of concrete containing different percent of treated rice waste. The thermal conductivity measured of these samples were varied between 0.83 and 0.3316 W/mK for samples without rice straw and with rice straw content of 3 to 15 % .

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◆ Treated ▲ Untreated

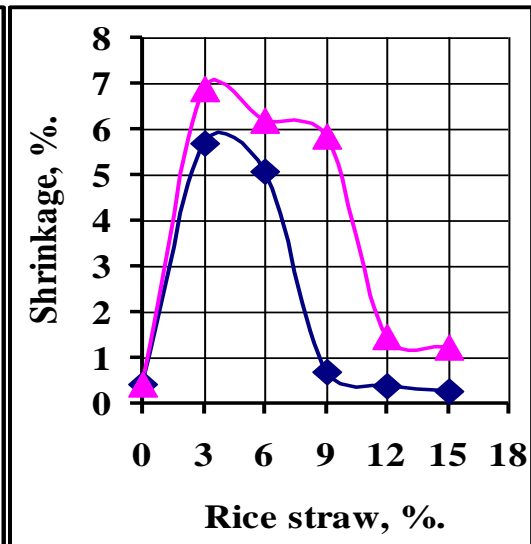
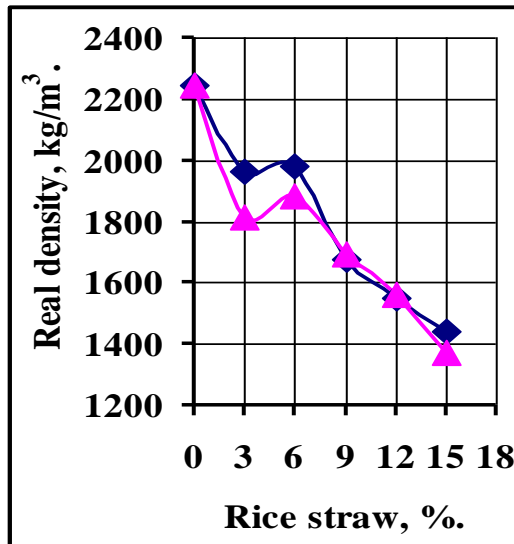
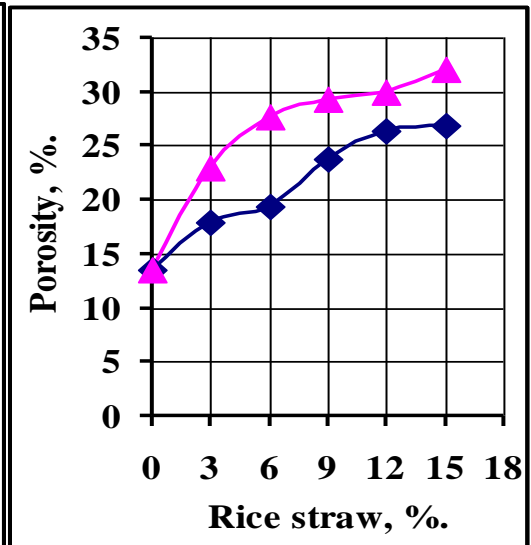
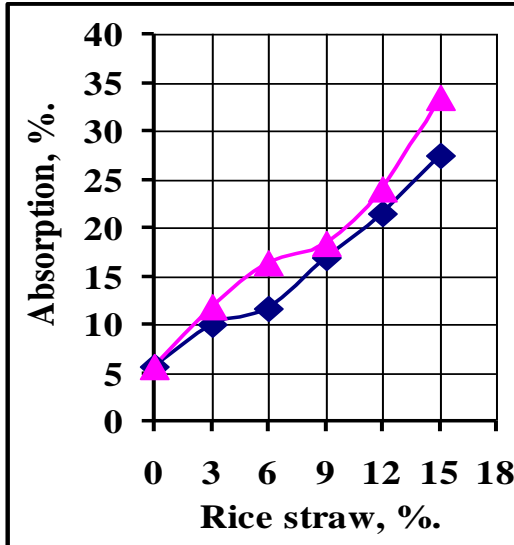


Fig 1: Effect of rice-straw percentage and treatment on: (a) absorption, (b) porosity, (c) real density and (d) shrinkage of hardened concrete.



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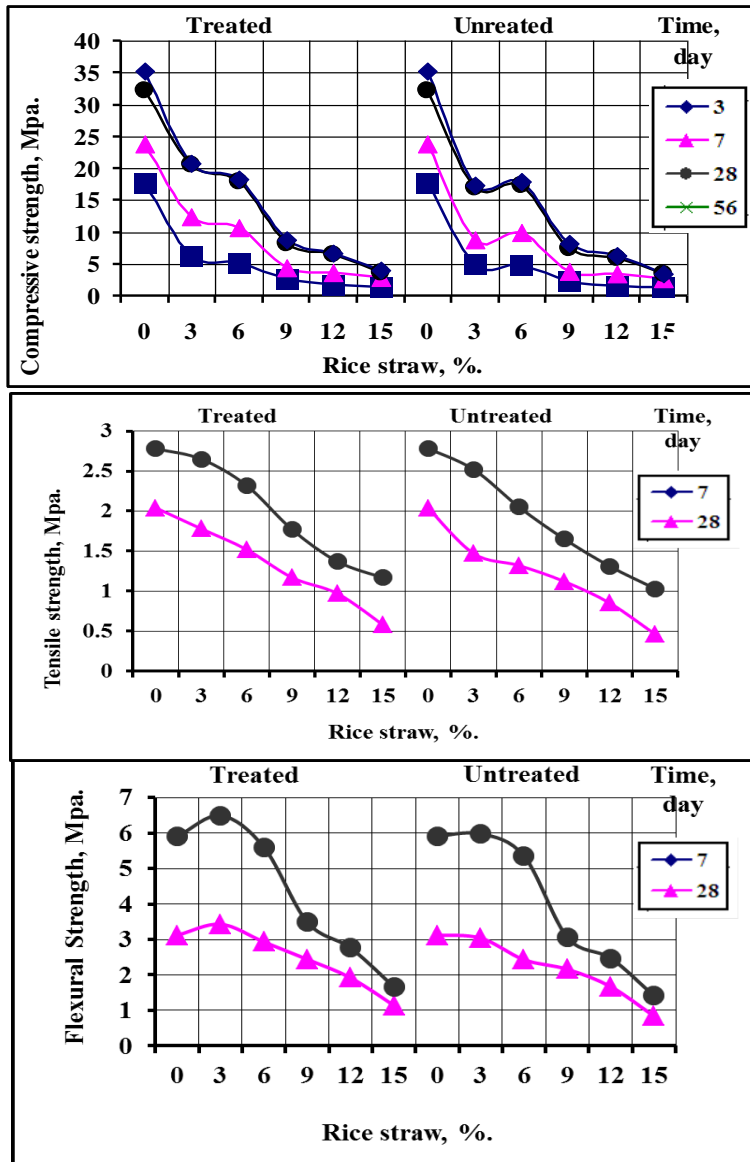


Fig. 2: Effect of rice-straw treated and untreated percentage on compressive, tensile and flexural strengths of hardened concrete



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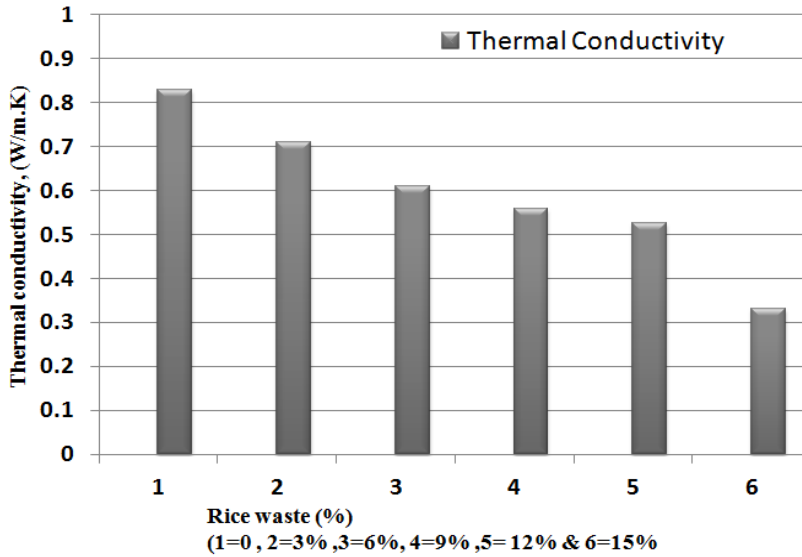


Fig.3: The thermal conductivity of concrete containing different percent of treated rice waste.