CHARACTERISTICS IMPROVEMENT OF BUILDING MATERIALS FABRICATED FROM AGRICULTURAL RESIDUES*

KHAIRY[1], M.F.A; MOSALLAM[2], M.A. and EL-BESSOUMY[3], R.R.

ABSTRACT

For improving the qualities of the straw brick (as control), three waste materials and sand were used to replace partially the straw. The waste materials are rubber, glass and mix of rubber and glass. The replacement ratios were 15, 30 and 45 % by weight basis. After carrying out the replacements, the bricks were tested for each of the following characteristic: bulk density, water absorption percentage, compressive stress, thermal conductivity and acoustical insulation percentage. Generally the resulted bricks were superior for the previously mentioned characteristics than the control brick. Replacing sand into the straw brick (control) resulted in less water absorption; less thermal conductivity and more acoustical insulation percentage while replacing a mix of glass and rubber resulted in more compressive stress in comparison with the control brick.

INTRODUCTION

Revolution in the agricultural sector has resulted in substantial increases in the quantities of agricultural by-products and wastes of different types. Most of these wastes are not adequately managed and utilized. Accumulating of unmanaged wastes especially in developing countries has resulted in an increasing environmental concern. They are mostly disposed of by incineration or used as fuel, although their calorific value is much lower than that of coal. Little work has been carried out to develop utilization of these wastes in the production of building materials.

* Research taken from PhD thesis, Dept. of Ag. Eng., Fac. of Ag. (Cairo), Al–Azhar U.
(1) Prof. Of Ag. Eng. Dept. of Ag. Eng., Fac. of Ag. (Cairo), Al–Azhar U.
(2) Ass. Prof. Of Ag. Eng. Dept. of Ag. Eng., Fac. of Ag. (Cairo), Al–Azhar U.
(3) Ass. Lect. Of Ag. Eng. Dept. of Ag. Eng., Fac. of Ag. (Cairo), Al–Azhar U. (PhD's Author).

Since a large demand has been placed on building material industry especially in the last decade owing to the increasing population that causes a chronic shortage of building materials, the civil engineers have been challenged to convert the industrial wastes to useful building and construction materials.

One of the most abandoned materials in Egypt is cellulous non-wood fibrous materials, such as rice straw. The total annual Egyptian crop residues are about 30 Tg, about 3 Tg of which is rice straw **(FAO,2005)**. In fact, rice straw is so abandoned that the Egyptian government allowed straw burning at agricultural fields. In the fall of 1999, an autumnal black cloud appeared above several Egyptian cities, with a thick bitter-smelling fog, due to the straw burning. Consequently, instead of burning the straw, recycling it with a mixture of cement forms a sustainable low-cost building material, which also reduces atmospheric pollution (**Kazragis, 2005).** In addition to these benefits, the straw could act as a thermal insulation material for the unpleasant Egyptian weather. The use of thermal insulation helps reduce energy costs, while creating pleasant indoor temperatures. Egypt is probably one of the first countries in the world to use straw as a building material. By 4000 B.C., Egyptians used sun dried bricks mad out of clay and straw in building entire villages. Even today, clay with straw is used as building housing material in Egyptian rural areas **(Mansour *et al.*, 2007**). Mixing cement with one or more of the agricultural residues for brick making is a promising role in utilizing crop residues with some modification of the brick characteristics. The concept is new and not many research publications could be found in the literature. There are drawbacks for building materials which fabricated from agricultural residues as increasing water absorption percentage, insects (as pests, termites, and mice) and decreasing compression stress. Therefore, the main aim of this research is to investigate possibility of improving some of building materials characteristics which fabricated from agricultural residues. **Staniforth (1979), Alaa El-Din *et al.* (1983) and Suliman and El-Zahaby (1998)** mentioned that the crops residues are materials that remain after the edible grain, seed, fruit, or primary fibers has been removed from plant. **Hermansson (1993)** said that the mix of 30% straw and 70% cement was put into 400×400×100 mm (16" x16"x4") molds and compressed by a load of 5 kN/m^2. The slabs were stripped after 48 hours and put in a kiln at 50°C (122°F) for additional 48 hours. In the last step, the blocks were put in a basket tunnel to dry. **Mansour *et al.* (2007)** said that the final list materials needed for the unit blocks production is: straw, Portland cement, water, and a chemical solution for neutralization, acceleration, and adhesion of the straw with the cement. Cement-straw sample block units have been prepared to demonstrate the production methodology. The treated and dried straw should be mixed with cement in several steps. The first step was preparation of slurry, which was a liquid mixture of water, cement and accelerating material, with ratio of 1:2:0.1 respectively. After preparation of slurry, the treated and dried straw had to be added with straw-cement ratio of 1:3. Finally, the straw and cement should be mixed well to obtain a homogenous material. **Turgut (2008)** said that the compressive strengths of the masonry blocks containing 25 %, 50 %, and 75 % waste glass powder (WGP) of cement weight were 6.2 %, 11.6 % and 21.1 % higher than that of the control masonry block, respectively. Flexural strength of the masonry blocks containing 25 %, 50 %, and 75 % WGP of cement weight were 18.6 %, 41.2 % and 77.3 % higher than that of the control masonry block, respectively. **Shayan (2004)** added that the glass powder in concrete improved some durability properties of concrete. **Corinaldesi *et al.* (2005)** said that no reaction is detected with particle glass size up to 100 µm indicating the feasibility of the waste glass reuse as fine aggregate in mortars and concrete. **Yang *et al.*(2004)** investigated that the possibility of using waste tires and rice straws as composite materials, and the potential applications for which these material could be used after recycling. Waste tires have hardness and elasticity properties superior to those of rubber, good resistance to weathering, can be used for preventing impact damage, and for construction materials, because of their low specific gravity which is lower than that of most construction materials. Moreover, it is possible to use tires in almost any environmental conditions and in any climate, due to their ability to withstand both hot and cold, and their anti-caustic and anti-rot properties They added that the rice straw-waste tire particle composite boards had better flexural properties than wood particleboard, insulation board, fiberboard, plywood and various other construction materials. The sound absorption coefficients of the composite boards were higher, in the middle and high frequency range, than those of commercial wood-based materials **Sukontasukkul (2009)** mentioned that the crumb rubber from used tires, produced in a local recycling plant, was used to replace fine aggregate at ratios of 10%, 20% and 30%. The mix proportion for the control specimen (no crumb rubber) was set at 1.00:0.47:1.64:1.55 (cement: water: fine aggregate: coarse aggregate). The strength of concrete mixed with crumb rubber is quite low (as compared to plain concrete) and tend to decrease with increasing rubber content. The test result showed that, the bulk density of concrete mixed with crumb rubber was found to decrease gradually with the rubber content compared to normal concrete. By replacing conventional fine aggregate with crumb rubber at 10-30%, the unit-weight of concrete can be reduced from 14% up to 28% depending on the type and the content of the crumb rubber. The replacing rate of 10%, both compressive and flexural strengths were found to decrease by 35% and 28%, respectively. At 20%, the strength of crumb rubber was decreased to only about 22-28% of that of plain concrete. The CR concrete exhibits superior thermal and sound properties than plain concrete as measured by the decrease in thermal conductivity coefficient (k) and the increase in sound absorption coefficient (α) and noise reduction coefficient (NRC).

MATERIALS AND METHODS

As a reference, a straw brick (control) was formed from cement, water and straw at ratios, 1.4: 0.7: 0.6 by weight respectively. Cement used in this study is Egyptian Portland cement**.** Tape water was used. The straw used in this study was rice straw. The used straw screened through a sieve of 2 mm diameter. The ground glass used in this study, recycled from the glass waste. The grinding process achieved manually to get the required quantity. The ground glass screened by using a sieve to the desired size. The ground glass size was about ≤ 2 mm. The used crumb rubber was obtained by grinding recycled vehicle tires into small particles. Rubber pieces were fed into the cutting wheel of the grinding machine repeatedly until the desired size had been achieved. The size of the crumb rubber obtained is about 1 mm. The used fine sand was obtained by screened by using sieve of 2 mm. The used sand screened by using a sieve to the desired size. The used fine sand size was about ≤ 2 mm. The mold used in forming the experimental samples is mad of mild steel and is of dimensions 25x 12x 10 cm and thickness of 0.7cm. The hydraulic press used in manufacturing sample is of maximum pressing load of 260 bar made by SICMI sa.s., Trecasali (Parma), Italy. A digital sound level meter used to measure acoustical insulation percentage is of range 50 dB to 126 dB mad by China. The compartment inside which the samples is put for testing acoustical insulation percentage is mad of foam with dimensions of $680 \times 350 \times 350$ mm. the thermal conductivity used in this study is manufactured according to Lee's method **(Noakes *et al.*, 1953)**. Thirteen different types (control and three ratios of replacement of each of rubber, glass, mix and sand) of mixtures are prepared in the laboratory. All types of mixtures are prepared for producing bricks samples. (GRS), the abbreviation refers to the first letters of the statement: Ground Rubber Straw. The abbreviation refers to the used materials and its condition. The control mixture contains water, cement and ground rice straw (GRS) with ratio of 0.7:1.4:0.6 respectively. The water and cement proportion in all mixtures are taken as constant to determine the effect of various ground glass waste (GGW), ground rubber waste (GRW) ,sand , both of (GGW) & (GRW) and (GRS) combinations. The replacement ratios between each of GGW, GRS, both of GGW & GRW, sand and GRS are taken in weight basis. The following measurements were made at each brick sample after about 4 weeks: 1- bulk density 2- water absorption 3-compressive stress 4- thermal conductivity 5- acoustical insulation 6- expansion ratio. Before measuring brick Samples, the moisture content "MC" is determine for all types of mixture. For each type of the thirteen different types, eight replicates were manufactured. Testing the manufactured samples was carried after four weeks from the time of press. The sequence and number of replicates used for each type for testing was as follows: firstly the bulk density was determined for the eight replicates of each type. Then for three of the eight replicates, water absorption percentage was carried out. This test consumed the three replicates out of the five remaining replicates; three replicates were tested for acoustical insulation percentage. The same replicates used for acoustic test were consumed under thermal conductivity test. Out of the 2 remaining replicates, one replicate was cut into three pieces and these three pieces were used for thermal conductivity test. The remaining replicate was consider as a stock

RESULTS AND DISCUSSION

Effect of the replaced materials:

For the purpose of investigating the effect of replacing each of the materials; rubber, glass, mix of rubber and glass, under range of replacement of 15-45% on the tested characteristics compared to the control straw brick, the mean value for the three ratios for each matter was estimated and compared to the correspond value of the control. Table (1) shows the mean values of bulk density (g/cm^3) for different mixtures. The maximum mean value of bulk density was 1.14 g/cm^3 for CSS, the abbreviation refers to the first letters of the statement: Cement, Straw and Sand. The abbreviation refers to the produced brick by replacing Sand into the control brick. The minimum mean value of bulk density before pressing was 0.84g/cm^3 for CS, the abbreviation refers to the first letters of the statement: Cement and straw. The abbreviation refers to the produced control brick. Table (2) shows the mean values of compression stress (N/cm^2) for different mixtures. The maximum mean value of compression stress was 419.18 N/cm^2 for CSM (Cement, Straw and mix of glass and rubber) mixtures.

Table (1): The mean values of bulk density (g/cm^3) for different mixture

Type of mixture	Bulk density (g/cm^3)
CS	0.84
CSG	1.03
CSR	0.92
CSS	1.14
CSM	1.10

Table (2): The mean values of compression stress (N/cm²) for different mixtures.

Type of mixture	Compression stress "σ" (N/cm²)
CS	125.81
CSG	271.28
CSR	96.31
CSS	302.59
CSM	419.18

The minimum mean value of compression stress was 96.31 N/cm² for CSR (Cement, Straw and Rubber) mixture. Table (3) shows the mean values of thermal conductivity "K" (w/m.c°) for different mixtures. The obtained data indicated that the maximum mean value of thermal conductivity "K" was 0.0455 w/m.c° for CSR mixture. The minimum mean value of thermal conductivity "K" was 0.0217 w/m.c° for CSS mixture.

Table (3): The mean values of thermal conductivity "K" (w/m.c°) for different mixtures.

Type of mixture	Thermal conductivity "K" (w/m.c°)
CS	0.0440
CSG	0.0349
CSR	0.0455
CSS	0.0217
CSM	0.0318

Table (4) shows the mean values of acoustical insulation percentage (%) for different mixtures. The obtained data indicated that the maximum mean value of acoustical insulation percentage (%) was 15.53 % for CS mixture. The minimum mean value of acoustical insulation percentage (%) was 9.09 % for CSR mixture.

Table (4): The mean values of acoustical insulation percentage (%) for different mixtures.

Type of mixture	**Acoustical Insulation percentage " %"**
CS	15.53
CSG	10.61
CSR	9.09
CSS	13.64
CSM	12.88

Table (5) shows the mean values of water absorption percentage (%) for different mixtures. The obtained data indicated that the maximum mean value of water absorption percentage (%) was 111.3 % for CS mixture. The minimum mean value of water absorption percentage (%) was 66.58 % for CSS mixture.

Table (5): The mean values of water absorption percentage (%) for different mixtures.

Type of mixture	**Water Absorption percentage " %"**
CS	111.30
CSG	75.17
CSR	81.96
CSS	66.58
CSM	71.86

Effect of the ratios of each replaced materials:

Fig.(1) shows the relationship between bulk density "B.d" and replacement ratio (%) by weight basis for CS, CSG, CSR, CSS, and CSM mixtures. The obtained data indicated that the bulk density increases with the increasing of replacement ratio (%). These results were expected because of the replacement ration effect. The maximum value of bulk density was 1.26 g/cm^3 for CSS mixture at 45 % replacement ratio. The minimum value of bulk density under pressing was 0.84 g/cm^3 for CS mixture. From the graph it is obvious that bulk density increases as replacement ratios increases. Generally the lower bulk density obtained is for GRW while the higher bulk density for sand. Fig.(2) shows the relationship between compression stress (N/cm^2) and replacement ratio (%) by weight basis for CS, CSG, CSR, CSS, and CSM mixtures. The obtained data indicated that generally the compression stress (N/cm^2) increases for CSM, CSS, CSG and CSR respectively. At any replacement ratio, CSR mixture had lower values than the other mixtures. From 0-15 % replacement ratio, the compression stress is increasing for CSG, CSR, CSS, and CSM mixtures.

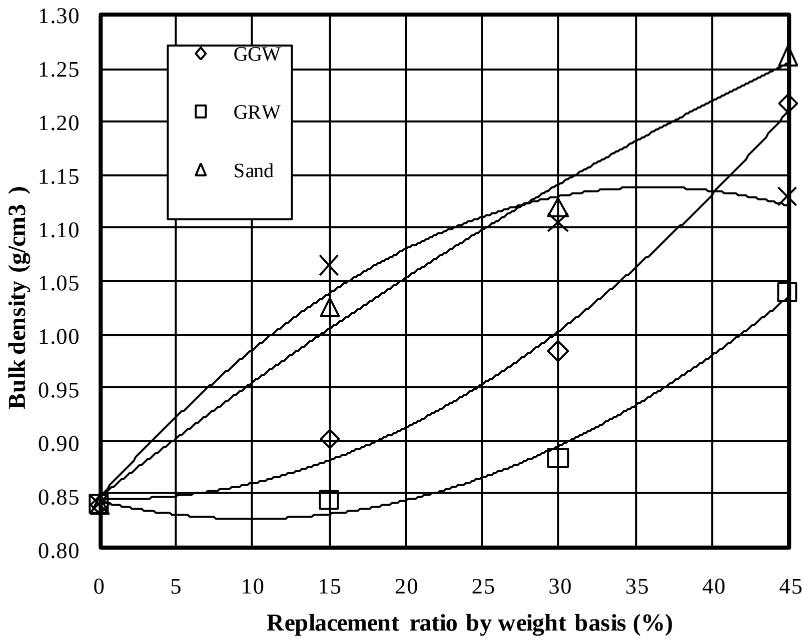

Fig.(1): Relationship between bulk density and the replacement ratios by weight basis for the four tested materials.

The maximum value was 520.86 N/cm² for CSM mixture at replacement ratio of 15 %, the minimum value was 152.93 N/cm² for CSR mixture at replacement ratio of 15 %. From 15-30 % replacement ratio, the compression stress is increasing for CSS and CSG mixtures respectively.
The maximum value was 320.92 N/cm² for CSS mixture at replacement ratio of 30 %, the minimum value was 235.25 N/cm² for CSG mixture at replacement ratio of 30 %. The compression stress is decreasing by increasing the replacement ratio % from 15-30%. The compression stress had the higher values for CSM, CSS and CSG mixtures respectively until replacement ration of about 41.5% the reverse is happed. The compression stress is increasing by increasing rate for CSG mixture and increasing by decreasing rate for CSS mixture. From these results the mixture CSM which contains mix of both GGW and GRW better than the mixture contains only each one and the mixture contains the sand. The mixture CSS contains sand is better than the mixture contain GGW and the mixture contains the GRW. Fig. (3) Illustrates the relationship between thermal conductivity "K" (w/m.c°) and replacement ratio (%) by weight basis for CS, CSG, CSR, CSS, and CSM mixtures.

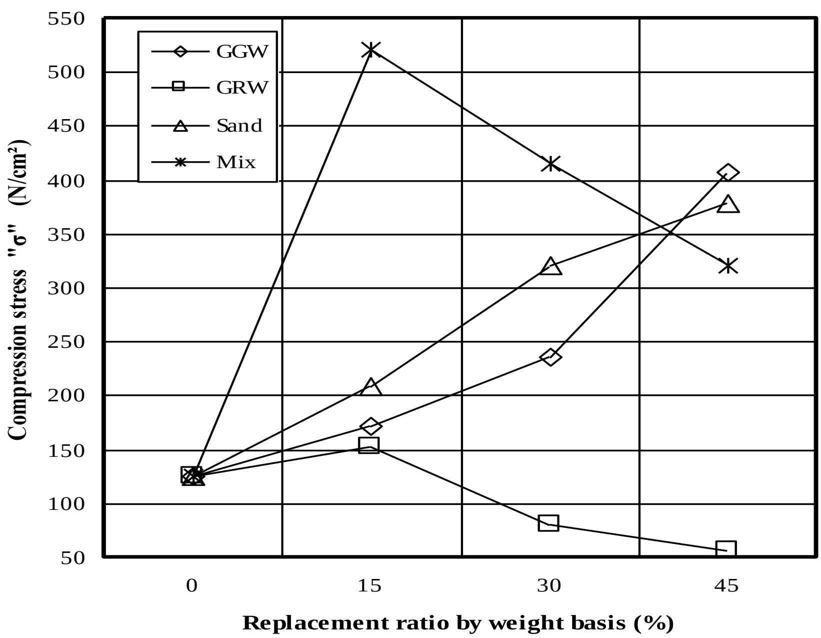

Fig.(2): Relationship between compressive stress and the replacement ratios by weight basis for the four tested materials.

The obtained data indicated that generally the thermal conductivity "K (w/m.c°) increases with increasing replacement ratio (from 15 %) for CSR, CSG, CSM and CSS respectively, the maximum value of thermal conductivity "K was 0.0621 w/m.c° for CSM mixture at 45% replacement ratio. The minimum value of thermal conductivity was 0.0115 w/m.c° for CSM mixture at 15% replacement ratio.

The thermal conductivity "K (w/m.c°) decreased from 0-15% replacement ratio for CSR, CSG, CSS and CSM respectively. From replacement ratio of 22.5 - 45%, CSS mixture had lower values than the other mixtures and this is mean that the sand better in thermal insulation than the other, from 15-22.5 % replacement ratio the CSM had the lower values in thermal conductivity "K (w/m.c°) and this is mean that the mix of GGW and GRW is better than the sand in this range. From 22.5-45% replacement ratio, the increasing rate for CSS mixture is lower than the increasing rate for the CSM mixture and this mean that the sand is better than mix of GGW&GRW in thermal insulation at this range too.

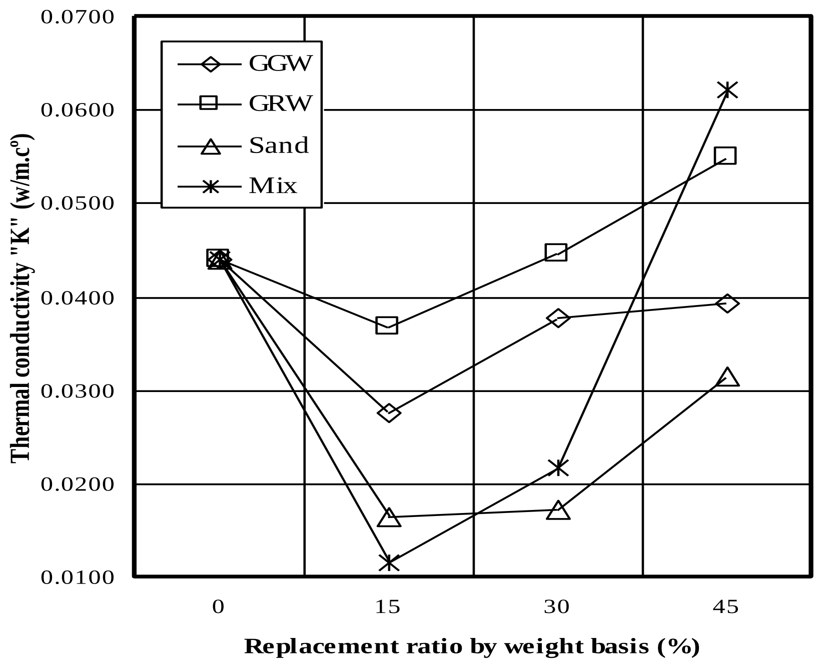

Fig.(3): Relationship between thermal conductivity and the replacement ratios by weight basis for the four tested materials.

The CSG mixture had lower values in thermal conductivity than CSR and this mean that the GGW better than GRW in thermal insulation, the thermal conductivity is increasing by decreasing rate for CSG mixture while the thermal conductivity is increasing by increasing rate for CSR mixture.

Fig. (4) Shows that the relationship between acoustical insulation percentage (%) and replacement ratio (%) by weight basis for CS, CSG, CSR, CSS, and CSM mixtures.

The obtained data indicated that generally the acoustical insulation percentage (%) decreases with increasing replacement ratio for CSR, CSG, CSM and CSS respectively, the maximum value of acoustical insulation percentage (%) was 15.53 % for CS (control) mixture. The minimum value of acoustical insulation percentage (%) was 8.33 % for CSR mixture at 45% replacement ratio.

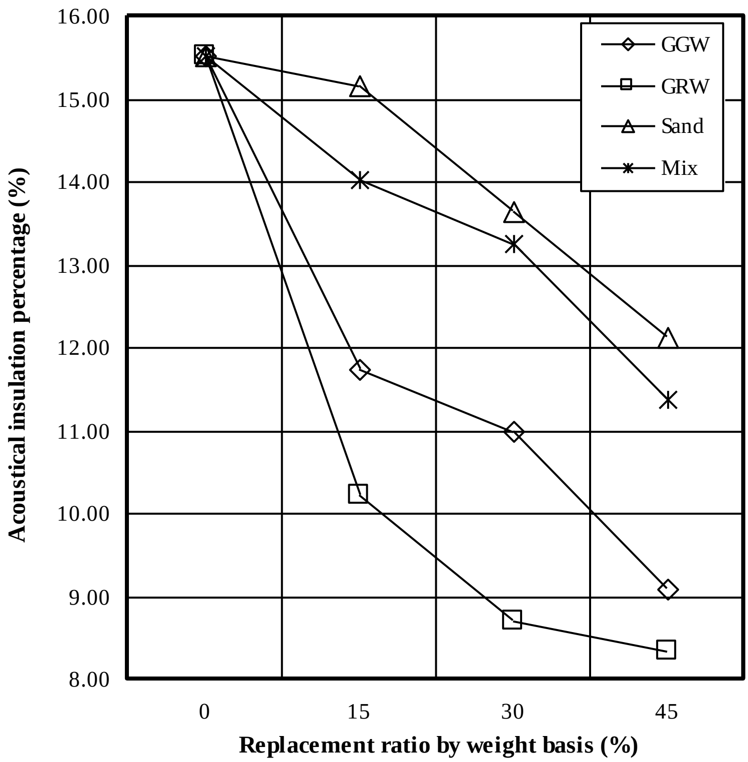

Fig.(4): Relationship between acoustical insulation percentage and the replacement ratios by weight basis for the four tested materials.

The data indicated that the CSS mixture (contains sand) had the higher values of acoustical insulation percentage than the others mixtures except CS mixture (control), the values of acoustical insulation percentage of CSS mixture were 15.15, 13.64, and 12.12 % at replacement ratios of 15, 30, and 45 % respectively. The CSM mixture had nearest values to the CSS mixture. From the previous the sand is better in acoustical insulation percentage %. The data showed that the CSG mixture (contain GGW) better than CSR mixture (contain GRW), at replacement ratio of 45%, the acoustical insulation values of CSG mixture and CSR mixture were nearest each other.

Fig. (5) Illustrates that the relationship between water absorption percentage (%) and time (min) at different replacement ratios of 0, 15, 30 and 45 % by weight basis for CSG, CSR, CSM, and CSS mixtures respectively as shown in figure (5). The obtained data indicated that generally the water absorption percentage (%) increases with increasing time at any replacement ratio for CS, CSR, CSG, CSM and CSS mixtures respectively, the maximum value of water absorption percentage (%) was 111.30 % for CS (control) mixture after 120 min at replacement of 0 %. The minimum value of water absorption percentage (%) was 48.78 % for CSG mixture after 30 min at 45% replacement ratio. The obtained data showed that generally, the water absorption percentage (%) decreases with increasing of replacement ratio (%) 45, 30, 15 and 0 % respectively for CSS, CSM, CSG and CSR respectively. The lower values of water absorption percentage (%) were at replacement ratio of 45 % for CSG, CSS and CSM mixtures respectively than the other replacement ratio %. The lower values of water absorption percentage (%) were at replacement ratio of 30 % for CSS and CSM respectively than the other mixtures. From the previous results, at replacement ratio of 15 % the CSS mixture (contains sand) better than the other mixtures; at replacement ratio of 30 % the CSS mixture (contains sand) better than the other mixtures, at replacement ratio of 45 % the CSG mixture (GGW) better than the other mixtures.

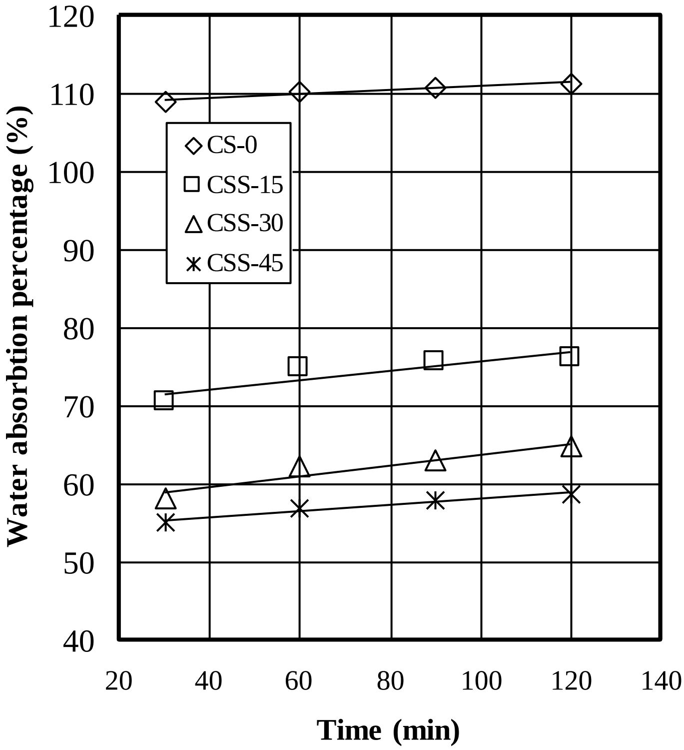

Fig.(5): Relationship between water absorption percentage and the time for the four tested materials.

CONCOLOUSION

The four used materials at the three ratios of each have in general better characteristics than the control straw brick. The replacement of sand gives better characteristics of water absorption, thermal conductivity and acoustical insulation while a mix of rubber and glass give the higher compressive stress. Generally the mixture replacement of rubber and sand was better in tests characteristics than each of them.

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الملخص العربى

تحسين خصائص مواد البناء المصنعه من المخلفات الزراعيه*

محمد فايد عبد الفتاح خيرى[١] محمود أحمد مسلم[٢]

رزق ربيع كامل البسومى[٣]

لتحسين خواص طوبة القش (كطوبة قياسية) تم احلال جزئى لثلاث مخلفات والرمل محل القش. المخلفات هى المطاط ,الزجاج وخليط منهما. نسب الإحلال لكل من المواد السابقه هى ١٥, ٣٠ و ٤٠ % على اساس الوزن. بعد عمل الإحلالات فإن الطوب الناتج تم إختباره للصفات التالية: الكثافة الظاهرية, نسبه امتصاص الماء, الإجهاد الضاغط, الموصلية الحرارية و العزل الصوتى. عموما كان الطوب الناتج عن الإحلال افضل فى المواصفات السابق ذكرها مقارنة بالطوبة القياسيه. الإحلال الجزئى للرمل محل قش الطوبه القياسية نتج عنه امتصاص افضل للماء, موصليه حرايه اقل وعزل صوتى اكبر بينما إحلال خليط المطاط والقش نتج عنه زياده فى تحمل اجهاد الضغط مقارنة بالطوبه القياسية. خليط المطاط والفش يحسن من الخواص السابق ذكرها عن إحلال أيا من المطاط أو القش.

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* بحث ماخوذ من رساله دكتوراه– قسم الهندسه الزراعية – كلية الزراعة بالقاهره – جامعة الازهر.

(١) أستاذ الهندسة الزراعية – قسم الهندسه الزراعية – كلية الزراعة بالقاهره– جامعة الازهر.
(٢) أستاذ الهندسه الزراعيه المساعد– قسم الهندسة الزراعية – كلية الزراعة بالقاهره – جامعة الازهر.
(٣) مدرس مساعد الهندسة الزراعية – قسم الهندسه الزراعية – كلية الزراعة بالقاهره – جامعة الازهر.