POTENTIAL ENRICHMENT OF PHYSICAL PROPERTIES OF GYPSUM ADDING PALM TREE ASH AND SAW DUST

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ABSTRACT: Natural architecture uses locally produced materials to assure the strength of the construction elements. Palm tree is widely planted in the Gulf countries and its annual abounded residues constitutes a greater environmental burden of being neglected and rarely used or recycled in efficient ways. The paper discusses the potential changes in the physical properties of pure gypsum cubes when utilizing additives such as the ash and saw dust of palm tree residues. The additives are added in various proportions by weight. Four groups of different laboratory tests are conducted on four different groups of cubic samples made of pure gypsum powder, admixture of gypsum and palm tree ash, and admixture of gypsum and palm tree saw dust. Results showed that both sawdust and ash of palm tree have significantly enhanced the physical properties of gypsum cubes tested in this paper, weight, porosity, and compressive strength.

Keywords: Ash; Building Materials; Gypsum; Palm Tree; Properties; Saw Dust.

فرص تحسين الخصائص الفيزيائية للجبس بإضافة رماد و نشارة أشجار النخيل

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الملخص: تستخدم الهندسة المعمارية الطبيعية المواد المنتجة محليا لضمان قوة عناصر البناء. وتُزرع شجرة النخيل على نطاق واسع في دول الخليج كما تشكل بقاياها السنوية الكبيرة عبئًا بيئيًّا كبير، ونادراً ما تُستعمل أو يُعاد تدويرها بطرق فعالة. تناقش هذه الورقة البحثية التغيرات المحتملة في الخواص الفيزيائية لمكعبات الجبس النقي عند استخدام مواد مضافة مثل الرماد ونشارة بقايا أشجار النخيل. تم خلط المواد المضافة بنسب مختلفة حسب الوزن، كما أجريت أربع مجموعات من الاختبارات المعملية على أربع مجموعات مختلفة من عينات مكعبة مصنوعة من مسحوق الجبس النقي (مجموعتين) ، ومزيج من الجبس ورماد شجرة النخيل (مجموعة) ، ومزيج من الجبس ونشارة شجرة النخيل (مجموعة). أظهرت النتائج أن كلا من نشارة الخشب ورماد شجرة النخيل قد عززتا بشكل كبير الخواص الفيزيائية لمكعبات الجبس المختبرة في هذه الورقة من حيث الوزن والمسامية وقوة الانضغاط.

الكلمات المفتاحية: خصائص الجبس؛ رماد اشجار النجيل؛ مواد البناء؛ نشارة الخشب.

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1. INTRODUCTION

Gypsum is an important building material that has many commonly known uses, such as gypsum boards and paints. Gypsum is at the forefront of basic materials used in building and construction (EG 2017). It has many important characteristics such as: fire resistance, sound absorption, heat insulation, considerable bending strength, light weight, low cost, long life, fast solidification and ease of composition (Kami and Kami 1995). Current necessities for gypsum compounds for execution or mortaring comprise organized setting time, workability, sag resistance, compressive and flexural strength, ideal bond to bricks and concrete, waterproofing, and better thermal and acoustic. These advances are accomplished by the diligence of some chemical admixtures and mineral additives; among them are superplasticizers, water-soluble polymers and the admixtures responsible for retarding and air-entraining (Arikan and Sobolev, 2002). In the last few years, considerable interest has been demonstrated in the investigation of date palm waste products as reinforcing and insulating materials to raise the mechanical properties of building materials. Consequently, much literature has been published on gypsum and the effects of some additives on its associated properties. This paper is conducted to investigate the properties of gypsum cubic blocks by adding the sawdust and ash separately to gypsum powder.

2. RELATED WORK

Danso *el al.* (2015) investigated the characteristics of mud blocks stabilized with leftover agricultural fibers, and performed the tests of density, shrinkage, water absorption, compressive and tensile strength, corrosion and wearing. The results revealed general enhancement in the physical, mechanical and durability properties of the blocks with the 0.5 wt. % fiber content. Sharma *el al.* (2016) presented an effort to develop the low durability of clay blocks by reinforcing it with the rural natural waste materials of Grewia Optiva and Pinus Roxburghii. The results showed an increase by 72 % to 68 % in the durability of the blocks reinforced with fibers of Grewia Optiva and Pinus Roxburghii. Sharma *el al.* (2015a) investigated improving the compressive strength of adobe using natural fibers of Grewia Optivia and Pinus Roxburghii. The reinforcement with these fibers resulted in an increase in the compressive strength by about 94–200 % and 73–137 % for Grewia Optivia and Pinus Roxburghii respectively. Sharma *el al.* (2015b) investigated enhancing soil sustainability and stabilizing it with natural fibers of Pinus roxburghii and Grewia optiva. Results revealed an increase in the compressive strength by 131–145 % when adding fiber P. roxburghii and 225–235 % when adding fiber G. optiva for the cubical and cylindrical specimens respectively.

Zak *el al.* (2016) presented an experiment to enhance the compressive strength of earth bricks using different admixtures of earth, cement, gypsum, hemp and flax fibers. The results indicated that the impacts of adding fibers hemp and flax is very limited on the compressive strength. Cement and gypsum reduced the binding force of the clay and highly decreased strength.

Villamizar *el al.* (2012) investigated the effect of adding coal-ash and cassava skins on the properties of mud blocks. Results showed that stabilizing earth blocks with coal-ash improved the compressive and bending properties when added as less than or equal to 5 %.

Ahmed *el al.* (1988) investigated the properties of date palm frond and concluded that tensile strength of the stalk walls is double that of the cores. The elasticity modulus of stalks is between 10 to 30 KN/mm2.

Arikan and Sobolev (2002) studied the effect of different admixtures on the compressive strength consistency. The additive admixtures are a superplasticizer, a water-soluble polymer, a retarding, and an air-entraining. The results proved that admixtures slightly increased the setting time, whereas, the application of a retarding admixture allowed control of a setting time of 1 to 3 hours.

Li *el al.* (2003) stated that the addition of cotton stalk to gypsum had a substantial impact on its mechanical properties. Cotton stalk fiber is treated with emulsion to increase its combination with gypsum. The results illustrated that, although the composite of gypsum had lower strength, its insulation and fire resistance properties had improved.

On the other hand, Wu (2004) studied the shear performance of gypsum panels when being longitudinally reinforced with glass fiber. The attained results showed that persistence of the longitudinal reinforcement had no significant issue on the shear strength, whereas it caused a small impression on their early stiffness, stiffness degradation, ductility ratio, and energy dissipation capacity.

Abu-Sharkh and Hamid (2004) studied the properties of a composite material produced by mixing palm leaves, polypropylene, and stabilizers. The results proved that uncompatibilized specimens are more stable than compatibilized ones. They justified their results that maleate polypropylene has low stability.

Kriker *el al.* (2005) tested the properties of palm date fiber reinforced concrete. It is found that increasing percentage and length of fiber in curing improved the flexural strength and the toughness coefficient and reduced the compressive strength.

Turgut and Algin (2007) mixed limestone powder and wood sawdust. The properties of the obtained material such as weight, water absorption, compressive strength, flexural strength and ultrasonic velocity satisfied the appropriate international standards. Therefore, the product had potentials for uses for walls, ceiling panels, sound panels, wooden board substitute, and a cheap alternate to concrete blocks.

Liangyuan and Zongli (2007) debated the features inducing the performance of gypsum-based composite material such as water/cement ratio, and retarder quantities. It is concluded that the strength and coefficient of softness increased compared to gypsum. Portland cement quickened the thickening and improved the strength and softness coefficient of composite, but over dosage caused the fall of these coefficients.

Jia-yan *el al.* (2008) studied the connection between wood-gypsum ratio and water gypsum ratio and explored the effects of temperature on hydration process and the gypsum morphology. It is concluded that both Water-gypsum ratio and wood-gypsum ratio are crucial to improve the properties of the boards in 40°C and to shorten the hydration time and strengthen the boards.

Okunade (2008) examined the impacts of adding sawdust and wood ash admixtures to clay mix to produce bricks. The results showed that the key influence of the sawdust admixture is reducing the dry density of the brick. Furthermore, the wood ash admixture attained denser products with higher compressive strength.

Brencis *el al.* (2001) produced an energy saving material made of foam gypsum and fibrous hemp in which sound absorption coefficient increased. It is also found that short fibers' reinforcement increased the density of foam gypsum, while long fibers decreased it.

Hai Alami (2013) studied the properties of clay mixture with desert solid wastes such as fronds and pits. It is proved that crushed pits expressively improved the strength of clay bricks adding more 85 % toughness, and 15 % strength.

Zhou *el al.* (2013) studied the properties of gypsum-based composites produced by mixing the powder of gypsum with latex and Polyvinyl Acetate (PVA). Release time, density and impact strength are investigated. It is proved that PVA contributed to delaying of time release and increased impact strength. On the other side, sawdust reduced the density.

Sari (2014) compared between two mixtures of polyethylene glycol with gypsum and clay in regard to low temperature-thermal energy storage. It is proved that compatibility between components in regard to capillary and surface tension enabled the composite for passive thermal energy storage applications in buildings.

Dai and Fan (2015a) developed a complex from gypsum and sawdust with a water-based epoxy spray. It is proved that sawdust water increased the flexural and compressive strength of gypsum by 10 % and 7 % respectively. Furthermore, analysis with optical microscopy confirmed that decrease of water uptake enlarged the gypsum covering ratio from 42 % to 68 %.

Dai and Fan (2015b) studied the mechanical properties of a Bio-composite of wood sawdust and Gypsum. It is concluded that the saw dust ratio of 20% gained better flexural and compressive strengths compared with the 30% ratio.

Algarny *el al.* (2016) surveyed the feasibility of adding palm tree sawdust to gypsum powder to produce blocks for indoor usage. It is resolved that the shrinkage value, weight, and porosity value are significantly reduced by increasing the ratio of sawdust to gypsum powder, whereas compressive strength is increased at the same time.

3. MATERIALS AND METHODS

The materials used are pure gypsum powder, palm tree saw dust, and the ashes resulting from the burnt saw dust of the local palm tree fronds in the Eastern Province of the Kingdom of Saudi Arabia. Different mixing ratios of ash or saw dust to gypsum are added to produce gypsum cubes of 5×5×5 cm, Table 1. Three different laboratory tests are conducted at the same time for every two groups of the samples: weight, porosity, and compression strength. Humboldt Mortar Laboratory Mixer of 5L, which supports the ASTM C305 standard, is used. It is a bench top type that provides two mixing speeds of 140±5 rpm and 285±10 rpm. It has the dimensions of 235×396×568 mm. Materials described are mixed together in the dry state. Then, water is added and mixed until the mixture became homogeneous before conducting the tests. Mixing time is not to exceed one minute, so as not to get water evaporates. Each test is equipped with a number of 25 specimens, at a rate of 5 specimens for each mixing ratio. The result recorded in the test is the average value of the 5 specimens of each mixing ratio. The total number of the tested specimens are 150 specimens. Unlike a number of other specimens that are excluded for defects during the casting or the processing of the test raising, the number of specimens that are actually consumed to more than 200 specimens. In the weight test, the specimens are casted in their molds and left for 24 hours. Then, they are taken out and weighed by a digital scale. The arithmetic average is calculated for each mixing ratio using the recorded weights of 5 different specimens. The results are shown in Fig. 1. In order to conduct the porosity test, the specimens are undergone the following steps:

1. The dry weights of the specimens are measured by a digital scale.
2. The specimens are immersed in water for 24 hours.
3. The wet weights of the specimens are measured by a digital scale.
4. The following formula is applied to calculate the value of porosity in the specimen (ASTM 2000):

$$P,\% = [(W - D)/V] \times 100 \quad (1)$$

P: Porosity W: Saturated weight
D: Dry weight V: Specimen Dry Volume

The results are shown in Fig. 3.

In the compressive strength test, for each admixture, five cubic specimens from each mixing ratio are prepared in a total of 50 specimens required for the test. The specimens are compressed in the compression strength instrument and the results are shown in Fig.4.

Table 1. Mixing ratios.

Gypsum (gm)	Ash / Sawdust %	Ash / Sawdust (gm)	Water (gm)
3000	0	0	1950 (65 % of Gypsum weight)
	1	30	
	2	60	
	3	90	
	6	180	

4. RESULTS AND DISCUSSION

4.1 Weight Test

As shown in Fig. 1, adding ash or sawdust reduced the specimens' weights. Similar results have been reported by the researchers Algarny *el al.* (2016), Li *el al.* (2003), and Arikan and Sobolev (2002). The addition of saw dust reduced the weight of the specimen more effectively than adding ash, as shown in the values of R2 for the trend lines of both results. It can be justified as the saw dust has less density and less weight for a specific volume compared to the ash. Taking into account the constant volume of the cubic specimen tested, adding more saw dust reduces more weight of the specimen than adding more ash.

Results indicate that the maximum weight reductions are 3.62% and 4.9% of the control specimen for ash and saw dust respectively at 6% mixing ratio. So, saw dust-gypsum admixtures would have more benefits for the construction industry and reduce the internal loads and stresses on the structural and construction elements of the buildings (Fig. 2).

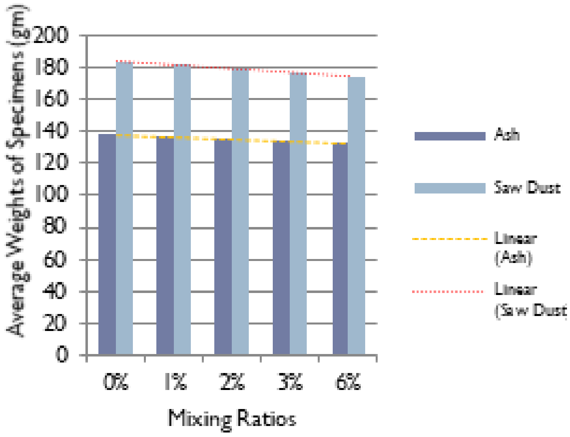

Figure 1. Relationship between the weights of the specimens and the applied mixing ratios of the additives.

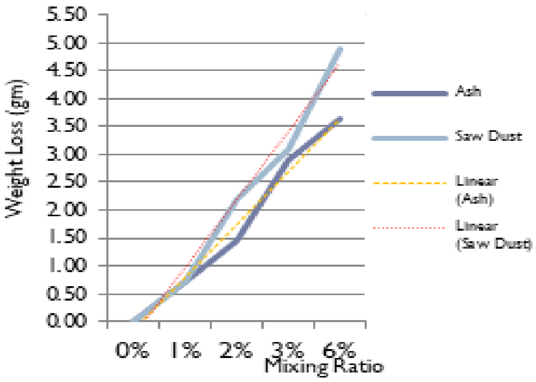

Figure. 2. Relationship between the weight loss of the specimens and the applied mixing ratios of the additives. Weight loss is directly proportional to mixing ratios.

4.2 Porosity Test

As shown in Fig. 3, the addition of ash and sawdust significantly reduced the porosity value of the specimens. Lower porosity is recorded in higher mixing ratios. The result is consistent with the work reported by Algarny *el al.* (2016), and Okunade (2008). The porosity values are reduced by 4.80 % and 3.77 % in the 6 % admixtures of gypsum-ash and gypsum-sawdust respectively compared to the control specimens. Sawdust has a limited impact on decreasing the porosity of gypsum cubes compared to the ash, which might be because sawdust has a lower density and bigger particle size compared to ash. Therefore, for a specific weight of ash or saw dust added to the gypsum powder, sawdust has a relatively higher volume than ash leading to keeping more gaps between the particles of the gypsum powder compared to the case of adding ash which has a compacted higher density compacted form that introduces smaller quantities of gaps among the gypsum particles. So, gypsum-ash cubes are more convenient to applications that need less porosity compared to sawdust-gypsum cubes that suits the need for more porous materials.

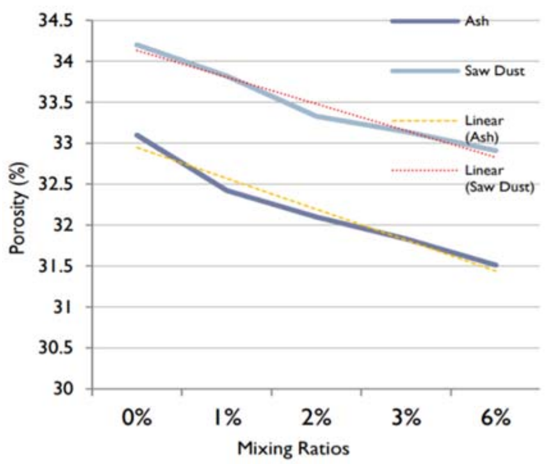

Figure 3. Relationship between the porosity of the specimens and the applied mixing ratios of the additives.

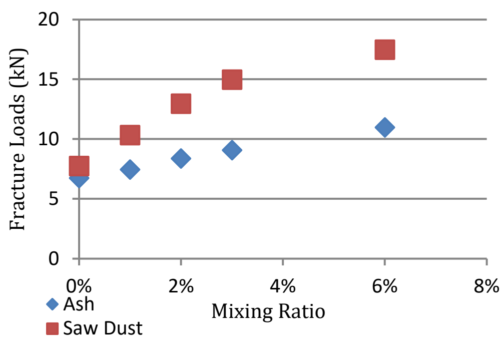

Figure. 4. Relationship between the fracture loads of the specimens and the applied mixing ratios of the additives. Fracture load is directly proportional to mixing ratios.

4.3 Compressive Strength Test

The results in Fig. 4 show that both the sawdust and ash have significantly increased the compression strength of the specimens and improved their failure resistance, which is consistent with the work reported by Algarny *et al.* (2016), Arikan and Sobolev (2002), and Okunade (2008). The resistance to fracture has increased by125.83 % and 62.9 % for the specimens of 6 % mixing ratio of sawdust and ash content respectively compared to the control specimen which is of pure gypsum. This result is tremendously important and can divert the use of gypsum in new building and construction applications due to its increased resistance to fracture in compression. Adding sawdust to the gypsum cubes will raise its compressive strength to almost double the value it will get if adding ash instead. The fibers content in the sawdust might be responsible for providing stronger bonds among the gypsum particles compared the case of adding ash which has already lost its fiber during the burning process.

The justification of the previous results can be explained as palm contains Wax, Phenol compounds and Pectin (Al-Dosary 2009), which have chemical properties to enhance the physical properties of gypsum powder. Wax solidifies at normal temperature and melts in heat (EB 2019a). When adding water, the wax melts from the emitted heat and spreads within the gypsum particles, then the wax hardens increasing the cohesion of the admixture blocking the pores of gypsum, and reducing the porosity value of the cubes, while increasing its strength. On the other hand, Pectin material gives the rigidity to the plant (Al-Dosary 2009), and when added to gypsum it increases its hardness and compression strength.

In addition, Phenol is soluble in water (EB 2019b), and it interacts with gypsum powder to produce salty water and stimulate the interaction between the granulated particles of gypsum and sawdust and ash of palm granules reducing porosity as well.

5. CONCLUSION

Both sawdust and ash of palm tree have significantly enhanced the physical properties of gypsum cubes tested in this paper. Both induced weight loss but sawdust achieved more reduction. The weight of gypsum specimen is inversely proportional to the amount of sawdust or ash content; as lower weights are recorded with higher content of the additives in the specimen. In line with the previous result, porosity ratio in the specimen of gypsum cubes is inversely proportional to the amount of ash or sawdust. Both additives reduced the porosity of gypsum cubes, but ash has a broader reduction. On contrary, compressive strength of the samples of gypsum cubes is directly proportional to the amount of ash or sawdust, where higher values of compressive strength are recorded in higher ratios of any of them in the specimen. The compressive strength the cubes gain when adding sawdust is almost double of that gained when adding the ash. The overall findings are encouraging for promoting the use of leftover palm tree residues to enhance the physical properties of some building and finishing materials which leads to adding an economic value and securing more environmental protection against soil and air pollution.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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REFERENCES

Abu-Sharkh B F, Hamid H (2004), Degradation study of date palm fibre/polypropylene composites in natural and artificial weathering: Mechanical and thermal analysis. *Journal of Polymer Degradation and Stability* 85: 967–973.

Ahmad F, Abdel-Rahman H, Al-Juruf R, Alam I (1988), Physical, mechanical and durability characteristics of date palm frond stalks as reinforcement in structural concrete. *International Journal of Cement Composite and Lightweight Concrete* 10(3): 175-180.

Al-Dosary N H (2009), Effect of leaf pinaes chemical composition of different date palm cultivar on infection by whit scale insect parlatoria blanchardii targ. *Homoptera: Coccinea: Diaspidae,* Date Palm Research Center- Basrah University, Basrah, Iraq.

Algarny A, Al-Naimi I, Alhefnawi M (2016), Enhancing the properties of gypsum as an indoor finishing material using palm tree residues. *KKU of Basic and Applied Science* 2(2), 111-118.

Arikan M, Sobolev K (2002), The optimization of a gypsum-based composite material. *Journal of Cement Concrete Research* 32 (11): 1725–1728.

ASTM Designation: C 20 – 00 (2000), Standard test methods for apparent porosity, water absorption, apparent specific gravity, and bulk density of burned refractory brick and shapes by boiling water. ASTM. PA. United States.

Brencis R, Skujans J, Iljins U, Ziemelis I, Osits O (2011), Research on foam gypsum with hemp fibrous reinforcement. *Journal of Chemical Engineering Transformation* 25:159-164.

Dai D, Fan M (2015a), Preparation of gypsum/sawdust green composite with spray coating. *RSC Advances Journal. An online article at: http://pubs.rsc.org/en/content/articlelandin/2015/ra/c5ra18707a#!divAbstract*. Last accessed on 22/2/2019.

Dai D, Fan M (2015b), Preparation of bio-composite from wood sawdust and gypsum. *Journal of Industrial Crops and Products* 74 (15): 417–424.

Danso H, Martinson D, Ali M, Williams J (2015), Physical, mechanical and durability properties of soil building blocks reinforced with natural fibers. *Journal of Construction and Building Materials* 101 (1): 797-809.

Eg EuroGypsum (2017), Living with gypsum: from raw material to finished product. *An online article at: www.euroGypsum.org*. Last accessed on 11/2/2019.

Encyclopedia Britannica EB (2019a), Wax. *An online article at: http://www.britannica.com/technology/wax*. Last accessed 30/2/2019.

Encyclopedia Britannica EB (2019b), Phenol chemical compounds. *An online article at: http://www.britannica.com/science/phenol*. Last accessed 30/2/2019.

Hai Alami A (2013), Experiments on unfired masonry clay bricks mixed with palm fronds and date pits for thermal insulation applications. *Journal of Renewable and Sustainable Energy* 5 (2): 31-36.

Jia-yan L, Zhen-hua H, Yu-he D, De-xin Z, Wen L, Ling X, Mei Z (2008), The effects of wood-gypsum ratio, water-gypsum ratio and temperature on the properties of the gypsum sawdust board. *Journal of Nanjing University (Natural Science Edition). An online article at: en.cnki.com.cn/Article_en.* last accessed on 20/2/2019.

Karni J, Karni E (1995), Gypsum in construction: origin and properties. *Journal of Materials and Structures* 28 (2): 92-100.

Kriker A, Debicki G, Bali A, Khenfer M M, Chabannet M (2005), Mechanical properties of date palm fibres and concrete reinforced with date palm fibres in hot-dry climate. *Journal of Cement and Concrete Composites* 27 (5):554-564.

Li G, Yu Y, Zhao Z, Li J, Li C (2003), Properties study of cotton stalk fiber / gypsum composite. *Journal of Cement and Concrete Research* 33 (1): 43–46.

Liangyuan L, Zongli S (2007), Research on contributing factors of gypsum-based composite material performance. *New Building Materials. An online article at: http://en.cnki.com.cn/Article_en/CJFDTOTAL-XXJZ200705000.htm.* Last accessed on 06/2/2019.

Okunade E A (2008), The effect of wood ash and sawdust admixtures on the engineering properties of a burnt laterite - clay brick. *Journal of Applied Sciences* 8(6): 1042–1048.

Sari A (2014), Composites of polyethylene glycol with gypsum and natural clay as new kinds of building PCMs for low temperature-thermal energy storage. *Journal of Energy and Buildings* 69: 184–192.

Sharma V, Marwaha B, Vinayak H (2016), Enhancing durability of adobe by natural reinforcement for propagating sustainable mud housing. *International Journal of Sustainable Built Environment* 5 (1): 141-155.

Sharma V, Vinayak H, Marwaha B (2015a), Enhancing compressive strength of soil using natural fibers. *Journal of Construction and Building Materials* 93: 943-949.

Sharma V, Vinayak H, Marwaha B (2015b), Enhancing sustainability of rural adobe houses of hills by addition of vernacular fiber reinforcement. *International Journal of Sustainable Built Environment* 4 (2): 348-358.

Turgut P, Algin H (2007), Limestone dust and wood sawdust as brick material. *Journal of Building and Environment* 42 (9): 3399–3403.

Villamizar M, Araque V, Reyes C, Silva R (2012), Effect of the addition of coal-ash and cassava peels on the engineering properties of compressed earth blocks. *Journal of Construction and Building Materials* 36: 276-286.

Wu YF (2004), The effect of longitudinal reinforcement on the cyclic shear behavior of glass fiber reinforced gypsum wall panels. *Jour-nal of Engineering Structures* 26 (11):1633–1646.

Zak P, Ashour T, Korjenic A, Korjenic S, Wu W (2016), The influence of natural reinforcement fibers, gypsum and cement on compressive stren-gth of earth bricks materials. *Journal of Constr-uction and Building Materials* 106: 179-188.

Zhou S B, Xiao A G, Chen Y Z, Chen G, Hao A P, Chen Y D, Huang X B (2013), The preparation and performance of gypsum-based composites. *Journal of Applied Mechanics and Materials* 310: 46-50.