MECHANICAL PERFORMANCE OF GLASS FIBER REINFORCED COMPOSITES MADE WITH GYPSUM, EXPANDED PERLITE, AND SILICA SAND

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Fiber reinforced composites have been widely used for various building purposes. Glass fiber reinforced composite containing white cement, gypsum, silica sand and perlite were analyzed in this research. The flexural strength, shrinkage behavior and the freeze-thaw (F&T) resistance of the composites were examined. It was obtained that the use of expanded perlite and silica sand enhances the shrinkage properties of the composite. Especially, expanded perlite used as the replacement of silica sand at the rate of 15 % has significantly enhanced the mechanical properties of the gypsum added composites against the freeze and thaw (F&T) and the shrinkage effects. Researched composite type and the outcomes of the study can be used in the composite production industry for improving the durability and sustainability.

Keywords: *Glass fiber, gypsum, white cement, composite, silica sand, perlite*

1. Introduction

Gypsum and gypsum added composites have been widely used for many purposes in construction industry due their characteristic fire resistance, thermal and sound insulation properties [1-4]. Different materials can be added to gypsum based composites to improve their mechanical properties [5]. Also, fibers or aggregates in different sieve size can be added to enhance their mechanical behaviors [6-8]. Fibers such as carbon fiber, glass fiber, polypropylene fibers have been widely preferred for the latest relevant studies to improve mechanical properties like flexural strength [9, 10].

Gypsum can be evaluated as the softest binder, since its structure may be severely damaged by hydration reactions. To prevent the solubilization of gypsum in water, gypsum can be used with a water impermeable material during the production of the mixes [11]. The various studies focused on the addition of rice husk, silica fume, iron oxide, blast furnace slag and blast furnace dust to improve water resistant properties of gypsum added composites [12, 13].

As mentioned above, gypsum is reinforced with various types of fiber to increase its mechanical properties like fracture energy and toughness, since it is a very brittle material [14, 15]. These fibers can be classified into two group as natural and manufactured origins. One of the manufactured fibers used widely for producing gypsum composites are the glass fibers. Glass fiber reinforced gypsum composites are not very old and traditional, especially to produce precast gypsum panels. For this reason, conventional design criteria are not totally applicable. Lately, many comprehensive researches have been conducted to gain better understanding of its structural behavior [16-18]. In-situ and none-destructive test were performed with the aim of developing design rules for the precast gypsum added composites. Moreover, many academics have focused on the shrinkage limitation problem of the gypsum added composite panels. [19,20].

Shrinkage mechanism can be resulted in higher repair costs and shorter service life of the construction materials [21]. Shrinkage behavior of gypsum is known and accepted as detrimental, as a result of internal stress created during the straining of the material. Structural and surface cracks can be observed when gypsum based structures get dry. Those cracks reduce the bearing capacity of the structures and lead to fatigue failure like concrete shrinkage behavior. For a long and safe service life of the gypsum based composite, the shrinkage effect should be monitored and limited [22].

Perlite is originated from alumino-siliceous volcanic rock. When heated, it gets expanded and reached a form of a cellular material with low density [23]. Expanded perlite has excellent heat and acoustic insulating properties depending on its porous microstructure [24]. The perlite based composite becomes lately, one of the most popular mineral filler due to its lightweight structure [25,26].

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As of 2012, global perlite registered perlite production is 2.6 million tons per year. China leads the perlite production and is followed by Greece, the USA and Turkey [27]. In concrete production, expanded perlite is used as lightweight aggregate replacement material at required ratios to obtain aimed mechanical properties due to its lightweight properties. The research results show that some mechanical properties like compressive strength and modulus of elasticity decrease with the increase expanded perlite amount in mix designs. However, the thermal conductivity decreased with higher expanded content [28].

Although numerous researches concerned the use of expanded perlite in concrete design technology, the possibility of using it for gypsum containing composites with the addition of white cement and silica sand has not been investigated in terms of shrinkage behavior. The object of this study was to investigate the effect of silica sand and expanded perlite to the mechanical properties of the gypsum added composites like shrinkage behavior and F&T resistance.

2. Materials and method

2.1. Materials

Gypsum added mixes according to the TS EN 13279-1 [29] was used within the scope of this research. The properties of the gypsum binder were presented in Table 1.

Table 1

Properties of the Gypsum

Chemical, mechanical and physical properties	
Chemical composition	CaSO4.xH2O (x=2)
Harmful substances (Gefahrstoffverordnung)	Concentration, Max value: 6 mg/m³
Compressive strength (MPa)	2.7
Flexural strength (MPa)	1.2
Dry density (kg/m^3)	600-1000
Workability time (min)	70-100
Final setting time (min)	140

Silica sand having the AFS values of 30 to 35 was used, the properties of the sand listed in Table 2 and Fig. 1. AFS number was calculated as follows. The sand retained on each sieve was weighed and recorded. The retained amounts were divided by total sample weights to obtain retained percentage values. The retained percentages were then multiplied by a factor. Finally, calculated grain fineness numbers were divided by 100 and AFS grain fineness number was obtained [30].

A commercial expanded perlite was used for this study. The particle size distribution and the properties of this material were given in Fig. 2 and Table 3, respectively.

Alkali resistant glass fiber with 20 µm diameter and 12 mm length were used the properties of the glass fiber were given in Table 4.

Table 2

Properties of silica sand

Physical properties	
Clay Content (%)	0.6 - 0.8
Specific Weight (t/m^3)	2.68
AFS value	34.6
Chemical composition (%)	
SiO_2	98.60
Fe_2O_3	0.13
MgO	0.03
CaO	0.01
K_2O	0.09
Na_2O	0.02
Al_2O_3	1.12

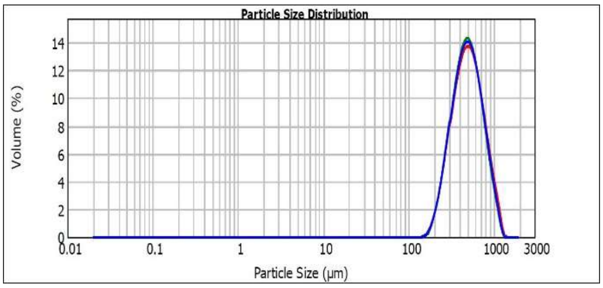


Fig. 1 - Particle size distribution of Silica Sand.

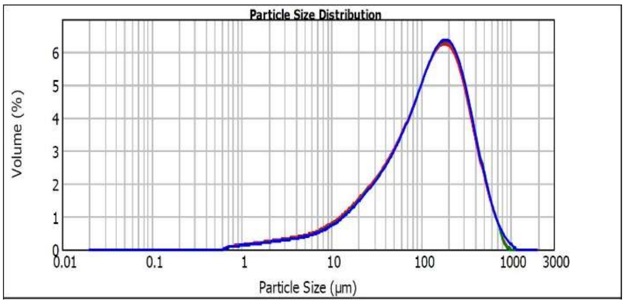


Fig. 2 - Particle size distribution of Expanded Perlite.

Table 3

Properties of the Expanded Perlite

Chemical composition (%)						
SiO_2	Al_2O_3	K_2O	Na_2O	MgO	Fe_2O_3	CaO
72	12	4.1	3.4	0.2	2.5	3

Table 4

Properties of the alkali resistant glass fiber

Mechanical and physical properties	
Ultimate strength, bending (MOR, MPa)	20-28
Elastic limit, bending (LOP, MPa)	7-11
Ultimate strength, tensile (MOR, MPa)	8-11
Elastic limit, tensile (LOP, MPa)	5-7
Compressive Strength (MPa)	50-80
Elastic Modulus (GPa)	10-20
Dry density t/m^3	1.9-2.1

CEM I 52.5 R (White Portland Cement) manufactured by Cimsa cement manufacturing plant which complies with TS EN 197-1 was used for the mix design. CEM I 52.5 R type cement is widely used for academics for the similar researches due to its superior properties [31]. The chemical and physical properties of the white cement were presented in Table 5. The particle size distribution properties of the cement were also given in Figure 3.

Table 5

The chemical and physical properties of CEM I 52.5 R cement

Chemical Properties (%)		**Physical and Mechanical Properties**	
SiO_2	21.6	Specific weight (t/m^3)	3.06
Al_2O_3	4.05	Specific surface (cm^2/g)	4600
Fe_2O_3	0.26	Whiteness (%)	85.5
CaO	65.7	Initial setting time (min.)	100
MgO	1.30	Final setting time (min.)	130
Na_2O	0.30	Water for standard consistency (%)	30
K_2O	0.35	Volume Constancy (mm)	1
SO_3	3.30	0.045 Sieve residue (%)	1
Free CaO	1.6	0.090 Sieve residue (%)	0.1
Chloride (Cl)	0.01	Compressive Strength at 2 days (MPa)	37
Insoluble	0.18	Compressive Strength at 7 days (MPa)	50
Loss on Ignition	3.20	Compressive Strength at 28 days (MPa)	60

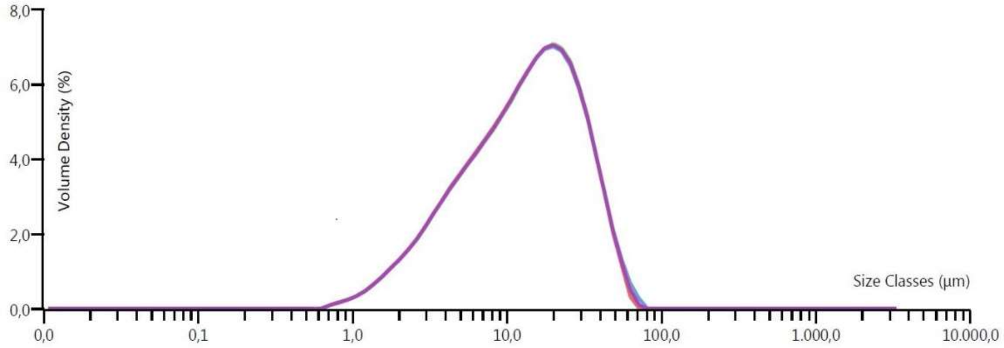


Fig. 3 - Particle size distribution of White Cement.

Table 6

Mixture designs

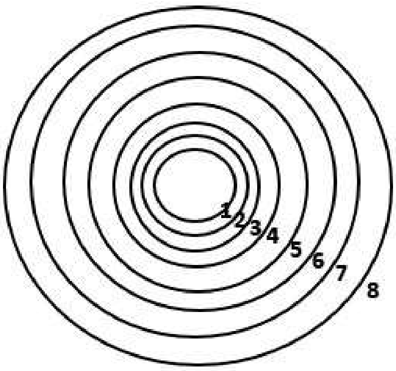
Mixture Code	**Silica Sand(kg)**	**Expanded Perlite (kg)**	**Fiber kg)**	**Gypsum(kg)**	**White (kg) Cement**	**Water/Cement**
R_1	0	0	1 kg	50	50	0.4
R_2	0	0	1.5 kg	50	50	
A_1	25	0	1 kg	25	50	
A_2	25	0	1.5 kg	25	50	
B_1	23.75	1.25	1 kg	25	50	
B_2	23.75	1.25	1.5 kg	25	50	
C_1	22.5	2.5	1 kg	25	50	
C_2	22.5	2.5	1.5 kg	25	50	
D_1	21.25	3.75	1 kg	25	50	
D_2	21.25	3.75	1.5 kg	25	50	
Static viscosity (TS EN 1170-1), circle number						4

2.2. Method

Mix proportions and experimental set of the composite are given in Table 6. The reference mix was composed of glass fiber, white cement, and gypsum. The silica sand was replaced by expanded perlite by 5 %, 10 % and 15 % by weight of the silica sand. The gypsum mixtures containing white cement, silica sand and expanded perlite were mixed in a mixer for 5 minutes to obtain a homogenous dry mixture. Water and glass fibers in 12 mm length were added just before the spraying process and mixed for 5 minutes again. The glass fibers were added by weight as detailed in Table 6.

The water used during the experimental works was potable water and at 21 C°. Static consistency of the glass fiber added mixes were measured as per the requirements of the EN 1170-1 (Fig. 4). This slump test was performed with a cylindrical funnel (height:60mm, inner radius:57mm, outer radius:65mm). Two different molds as 40 x 40 x 40 mm and 160 x 40 x 40 mm were prepared for the mechanical tests. All test specimens were kept at the molds for 24 hours at room temperature. Compressive and flexural strength of the specimens were measured complying the TS EN 13279 for 1 day, 7 days and 28 days [29].

Water absorption values were measured by keeping specimens in water for 24 hours. Freezing and thawing resistance of the specimens were determined by the requirements of ASTM C 666 [32]. During the F&T tests, the position of the specimens was frequently changed in order to obtain extreme temperature conditions at different locations of the test cabinet. This type of experiment puts the specimens through a series of rapid temperature



Circle Number	0	1	2	3	4	5	6	7	8
Circle Diameter(mm)	65	85	105	125	145	165	185	205	225

Fig. 4 - Static consistency measurement.

Table 7

Mechanical properties of the gypsum added composite

Mixture Code	**Density (g/cm³)**	**Water absorption (%)**	**Bending Strength (MPa)**			**Compressive Strength (MPa)**		
			1-day	**7-day**	**28-day**	**1-day**	**7-day**	**28-day**
R_1	1.61	20.73	12.44	18.45	21.52	19.25	26.41	36.74
R_2	1.63	20.45	13.01	19.23	21.98	20.14	28.11	38.14
A_1	1.72	21.23	13.07	19.27	22.43	19.89	27.74	38.84
A_2	1.78	21.01	14.28	20.75	23.78	21.13	29.13	39.01
B_1	1.69	21.41	12.17	18.51	21.11	18.95	26.03	35.94
B_2	1.67	21.38	12.32	20.24	22.03	19.03	26.32	37.64
C_1	1.53	21.47	11.84	18.14	20.24	18.35	25.87	35.42
C_2	1.51	21.43	12.23	18.54	20.37	18.81	26.14	35.92
D_1	1.47	21.54	11.67	17.21	19.51	18.07	25.57	34.21
D_2	1.44	21.49	12.08	17.37	19.78	18.24	25.94	34.94

changes it may face during the transportation and utilization processes. Strength losses were calculated as percentages according to the strength differences between the no F&T cycle applied samples, and the specimens exposed to the F&T cycles. Shrinkage behavior of the mixes were measured with the help of laser based shrinkage test equipment. Specimens with the dimensions of 40 x 40 x 160 mm were used for the relevant shrinkage tests. The movements in first 24 hours were recorded. The mixes were sprayed into the molds with a slurry nozzle.

3. Results and discussion

Mechanical properties of the composite can be found in Table 7. Compressive strength values of the specimens are related to fiber and perlite content. The test results showed that the compressive strength of the composite decreases with the increase of expanded perlite ratio. It was also observed that the increase in fiber content of the specimens resulted in increase in compressive strength values. Many studies have indicated that high expanded perlite content reduces the compressive strength and unit weight. The test results were complied with the relevant researches in the literature [28,33].

Compressive strength of the specimens is reduced due to lower strength of expanded perlite aggregate, when silica sand is replaced by the expanded perlite aggregates. Porous structure of the expanded perlite aggregates effects the decrease in the compressive strength, as well. Bending strength values were affected by the same reasons as just explained above. The specimens after the 28-day varied between the 19.51 MPa and 23.78 MPa.

Unit weight and strength properties of the gypsum composite are related to each other. The test results showed that the compressive strength values increased when the unit weight increased. According to the test data, the unit weight of the specimens can be reduced by replacing the silica sand by expanded perlite aggregates. When the silica sand replaced for 15 % by weight, the unit weight reduced about 19 %. As widely known, the specific gravity of the expanded perlite is lower compared to the silica sand; therefore, the mixes produced with more amount of expanded perlite had lower unit weight and density.

Water absorption values of the gypsum added composites varied between the 21.54 % and 20.45 % as seen in Table 7. The maximum value was obtained as 21.54 % for the mixture

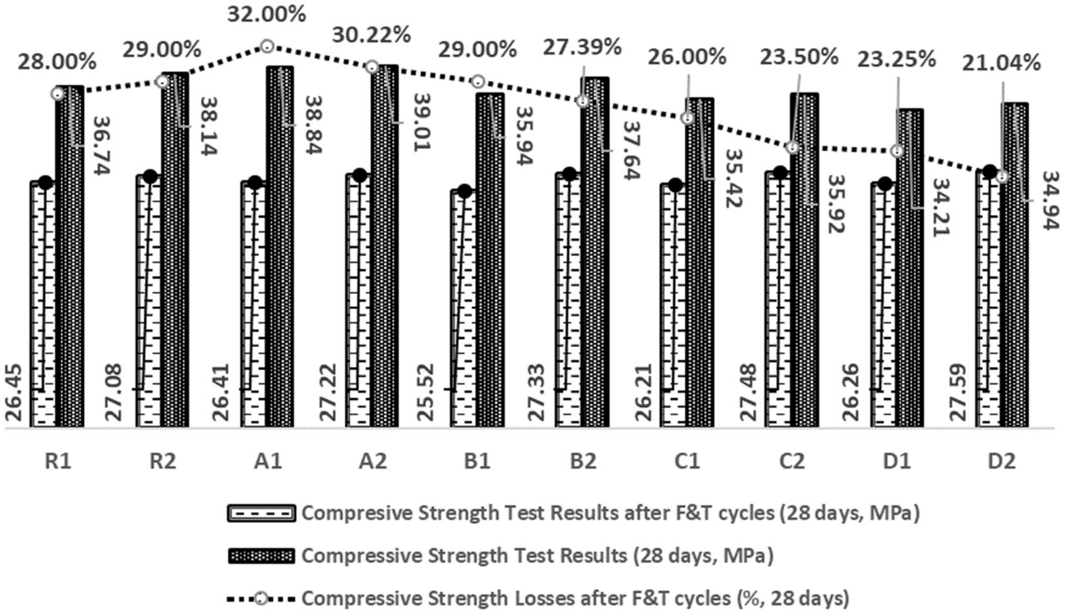


Fig. 5 - Compressive Strength Losses after F-T cycles.

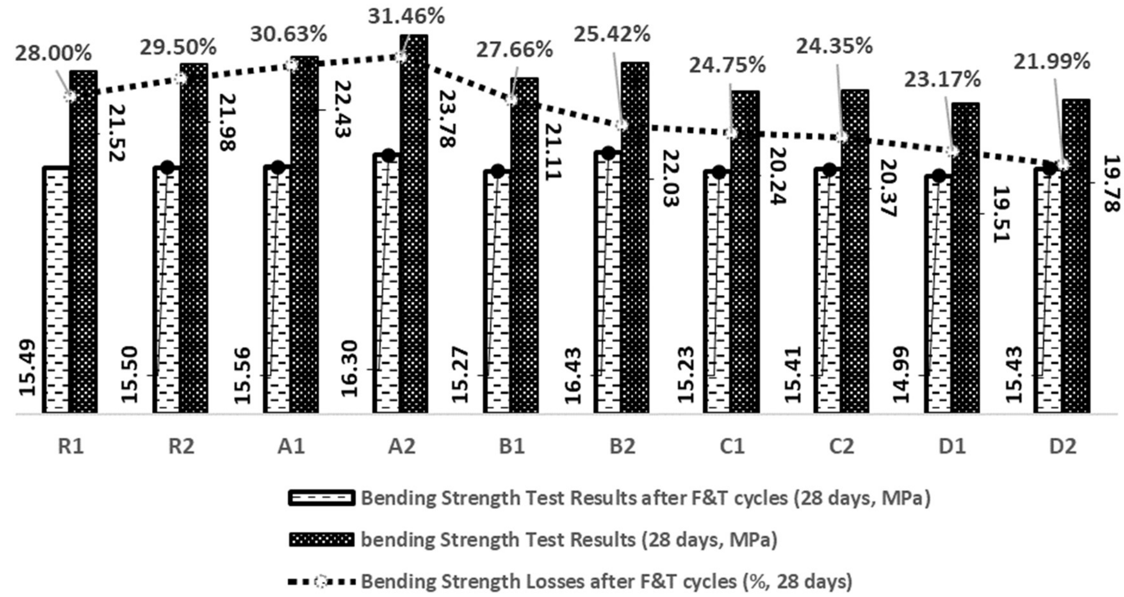


Fig. 6 - Bending Strength Losses after F-T cycles.

D_1. The lowest value was recorded as 20.45 % and it was belonged to the second reference mix. Replacement of expanded perlite with the silica sand 15 % by weight of increases water absorption up to 5 % compared to the reference mixes. This result can be attributed to the porous structure of the expanded perlite aggregates and the composition of the D_1 and D_2 composites. These types had less binder material amount compared to the other mixes. Higher water/binder ratio of the composites is also a factor affecting the water absorption amount and the strength test results.

As shown in Figure 5 and Figure 6, strength loses of the gypsum added composites with expanded perlite after F&T cycles have lower percentages compared to the mixes without any expanded perlite content. It was also obtained that F-T cycles weakened the adherence between the glass fibers and the matrices, shown by the difference between the 28-day strength values of the F-T cycled and the other specimens. The strength loss of composites with silica sand and expanded perlite type aggregates is less than that with no aggregates as seen in Fig.5 and Fig. 6. And it was also noted that the fiber change of 5 % of the mixes has no distinct effect on the strength losses.

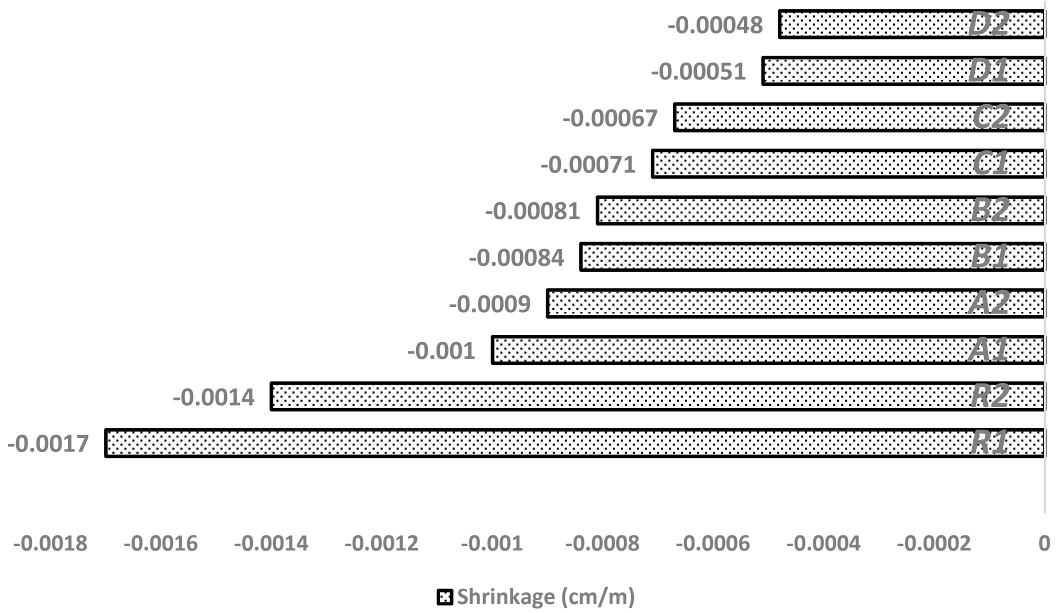


Fig. 7 - Shrinkage Behavior of the Composites (1-day, cm/m).

The shrinkage behaviors of the gypsum composites are presented in Fig. 7. In general, composite with expanded perlite and silica sand content were efficient in controlling shrinkage behavior compared with no aggregate added mixes. Additionally, comparing the expanded perlite content of the mixes, it was obtained that increase in perlite aggregates amount limited the shrinkage values as shown in Figure 7. The minimum shrinkage was obtained as -0,00048 cm/m for the D2 mix. A possible explanation of for this drop can be that 15 % of expanded perlite replacement have a great effect on the shrinkage properties of the gypsum composite due to its porous structure. This feature might be related to the distribution and the adherence between the other ingredients of the mixes, and further study is needed.

4. Conclusions

The conclusions of the using expanded perlite and silica sand with the addition of glass fibers and white cement to produce gypsum added composites can be drawn as follows:

(1) For specimens not subjected to F-T cycling, their mechanical properties like compressive and bending strength increased with the fiber content up to 1.5 %.

(2) Following F-T cycles, the specimens without any aggregates had a significant loss in both compressive and bending strength compared with the other results.

(3) Porous structure of expanded perlite and its usage up to 15 % of the silica sand decreased the density of the composite, and enhanced the shrinkage behavior of the composite; however, there existed the loss in strength values.

(4) The water absorption test results indicate that replacement of the silica sand with the expanded perlite aggregate increases porosity property in parallel with the recorded density values, and this may lead to improvement in thermal conductivity properties of the gypsum added glass fiber reinforced composites.

(5) Crack occurring during the shrinkage behavior in first 24 hours can be controlled with the addition of expanded perlite aggregates in case it falls in the limitation of the aimed mechanical properties.

REFERENCES

1. S. G. Gonzalez, J. Gadea, A. Rodríguez, M.T.B. Varela, V. Calderon, Compatibility between gypsum and polyamide powder waste to produce lightweight plaster with enhanced thermal properties, Construction and Building Materials, 2012, **3**, 179.
2. M.H.P. Gazineu, V.A. D. Santos, C.A. Hazin, W.E. de Vasconcelos, C.C. Dantas, Production of polymer-plaster composite by gamma irradiation, Prog. Nucl. Energy, 2011, **53**, 1140.
3. D. Heim, J.A. Clarke, Numerical modelling and thermal simulation of PCM–gypsum composites with ESP-r, Energy Build.,2004, **36**, 795.
4. M. Li, Z. Wu, M. Chen, Preparation and properties of gypsum-based heat storage and preservation material, Energy Build.,2011, **43**, 2314.
5. M. Murat, A. Attari, Modification of some physical properties of gypsum plasterby addition of clay minerals, Cement and Concrete Research,1991, **2**, 378.
6. G. Murali, A.S. Santhi, G. M. Ganesh, Loss of mechanical properties of fiber-reinforced concrete exposed to impact load, Romanian Journal of Materials, 2016, **46**(4), 491.
7. H.A. West, A.F. Sprecher, Fiber reinforced composite materials, Journal of Materials Education,1191, **13**, 161.

8. Q.L. Yu, H.J.H. Brouwers, Development of a self-compacting gypsum-based lightweight composite, Cement and Concrete Com posites, 2012, **34**, 1033.
9. S. Korkmazi, F. Birinci, Increasing the Tensile Strength of Fiber Reinforced Self-Compacting-Concrete, and Effects of Fiber Type and Orientation, Romanian Journal of Materials, 2017, **47**(3), 361.
10. M. Dima, C. Francu, Method for testing glass fibre reinforced polymer composites (GFRP's) with polyester matrix, Romanian journal of materials, 2014, **44**(3), 304.
11. G. Camarini, J. A. D. Milito, Gypsum hemihydrate–cement blends to improve renderings durability, Constr. Build. Mater.,2011, **25**, 4121.
12. A.A. Khalil, Effect of some waste additives on the physical and mechanical properties of gypsum plaster composites, Constr. Build. Mater., 2014, **68**, 580.
13. G. Yakovle, Anhydrite and gypsum compositions modified with ultrafine manmade admixtures, Procedia Eng., 2015, **108**, 13.
14. D. R. Merino, F. H. Olivares, Reinforced plaster by means of the synergic action between concrete additives (superfluidifiers, fluidiflers and airing-plasticizers) and E glass flbres, Materiales de Construcción,2000, **260**, 27.
15. A. G. Santos, Escayola reforzada con fibras de polipropileno y aligerada con perlas de poliestireno expandido, Materiales De Construcción, 2009, **59**, 105.
16. Y.F. Wu, M. P. Dare, Flexural and shear strength of composite lintels in glass fiber reinforced gypsum wall constructions. J Mater Civil Eng, 2006, **18**(3), 415.
17. K. Liu, Y.F. Wu, X. Jiang, Shear strength of concrete filled glass fiber reinforced gypsum walls, Mater Struct., 2008, **41**(4), 649.
18. M. Janardhana, A. M. Prasad, D. Menon, Studies on the behavior of glass fiber reinforced gypsum wall panels, In Proceedings of the 8th US national conference on earthquake engineering, San Francisco, California, USA, 2006, Paper no. 1326.
19. K. Zhao, X. Zhang, T.J. Wei, Full-scale model test on the performance of a fivestorey fiber plaster board building, In Proceedings of the seventh international RILEM symposium fiber reinforced concrete, design and applications (BEFIB-2008 symposium), 2008.
20. X. Jiang, Y. Gu, J. Dong, T. Zhou, Research on seismic properties of the structure for reinforced plasterboard filled with concrete, Earthquake Eng Eng Vib, 2006, **26**(3), 165.
21. C. Jun, L. Gengying, Mechanical Properties and Drying Shrinkage of Self-Compacting Concrete Containing Fly Ash, Romanian Journal of Materials, 2016, **46**(4), 480.
22. P. K. Metha, J.M.P. Monteiro, Concrete-Microstructure, Properties, and Materials. 3rd ed. McGraw-Hill, 2006, 49.
23. A. Różycka, W. Pichór, Effect of perlite waste addition on the properties of autoclaved aerated concrete, Construction and Building Materials,2006, **120**, 65.
24. K. Sodeyama, Y. Sakka, Y. Kamino, Preparation of fine expanded perlite, J. Mater. Sci.,1999, **34**, 2461.
25. D. Sun, L. Wang, Utilization of paraffin/expanded perlite materials to improve mechanical and thermal properties of cement mortar, Constr. Build. Mater., 2015, **101**, 791.
26. M. Jedidi, O. Benjeddou, Ch. Soussi, Effect of Expanded Perlite Aggregate Dosage on Properties of Lightweight Concrete, Jordan J. Civ. Eng.,2015, **9**, 278.
27. Perlite and Vermiculite: 2014 Market Review and Forecast, Merchant Research& Consulting Report, 2014.
28. O. Sengul, S. Zaizi, F. Karaosmanogu, M.A. Tasdemir, Effect of expanded perlite on the mechanical properties and thermal conductivity of lightweight concrete, Energy Build.,2011, **43**, 671.
29. TS EN 13279-1, Gypsum binders and gypsum plasters – Part 1: Definitions and requirements, Ankara, 2009.
30. Silica Sand Tests, Metallurgy Technology, Turkish Republic Ministry of Education, 521MMI279, Ankara, Turkey, 2011.
31. C. Moraru, CEM I 52, 5R CIMENT DE ÎNALTA PERFORMANTA*/CEM I 52.5 R HIGH-PERFORMANCE CEMENT, Romanian Journal of Materials,2012, **42**(4), 336.
32. ASTM, C. 666. Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing, Annual Book of ASTM Standards, 2008, **1**, 991.
33. I.B. Topçu, B. Isıkdag, Effect of expanded perlite aggregate on the properties of lightweight concrete, J. Mater. Process. Technol.,2008, **204**, 34.

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