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İ Ç İ N D E K İ L E R / C O N T E N T S

The Properties of Expanded Polystyrene - Pumice - Gypsum Blocks as a Building Material

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Most of buildings in rural areas are made out of stone, hollow concrete blocks, adobe(mud bricks), brick and wood. But these materials do not have both sufficiently compressive strengths and thermal conductivity. The aim of this study was to investigate the effect of waste expanded polystyrene (WEPS) and pumice aggregate on strength and thermal conductivity of gypsum blocks. A lot of new wall materials can be made by mixing those materials in different volume fractions. The compressive strength, density, water absorption and thermal conductivity of samples produced were determined. It is observed that these WEPS and pumice gypsum blocks have sufficient strength for their use in general building construction. The thermal insulation properties were quite good as a result of the thermal conductivity tests. This composite material can be suggested for use in building applications as partitions.

Keywords: Expanded polystyrene, Gypsum, Blocks, Pumice, Conductivity, Strength

Yapı Malzemesi Olarak Üretilen Genleştirilmiş Polistiren- Pomza -Alçı Karışımlı Blokların Özelliklerinin Araştırılması

Kırsal yörelerdeki yapıların çoğu taş, beton blok, kerpiç, tuğla ve ahşaptan yapılmıştır. Ancak bu malzemeler yeterli basınç dayanımlarına ve ısı yalıtım özelliklerine sahip değildir. Bu çalışmanın amacı, atık genleştirilmiş polistiren (WEPS) ve pomza agregaların üretilen alçı blokların dayanım ve ısı iletkenlikleri üzerine etkisini araştırmaktır. Bu malzemelerin farklı hacimlerde karıştırılmasıyla birçok yeni duvar malzemeleri yapılabilir. Üretilen örneklerin basınç dayanımı, yoğunluk, su emme ve ısı iletkenlikleri belirlenmiştir. WEPS ve pomza alçı blokların yapılarda kullanımı durumunda yeterli basınç dayanımına sahip olduğu belirlenmiş olup, yapılan ısıl iletkenlik testleri sonucunda ısı yalıtım özellikleri oldukça iyi sonuçlar vermiştir. Elde edilen kompozit malzemelerin bina uygulamalarında iç kısımlarda bölme duvarı olarak kullanılması önerilebilir.

Anahtar Kelimeler: Genleştirilmiş polistiren, Alçı, Bloklar, Pomza, İletkenlik, basınç dayanımı

1. Introduction

The uses of lightweight concrete has been increasing in the construction of modern buildings , owing to the advantage that lower density results in a significant benefit in terms of load bearing elements of smaller cross sections and a corresponding reduction in the size of the foundation (Anonymous, 2003). Lightweight aggregates are generally classified in to two types- natural (pumice, diatomite, volcanic cinders, etc.) and artificial (perlite, expanded shale, clay, slate, sintered PFA, etc.). Expanded polystyrene (EPS) beads are a type of artificial ultra-lightweight (density of less than 300 kg/m^3), nonabsorbent aggregate (Short and Kinniburgh, 1978; Kayyali and Haque, 1997). It can be used to produce low density concretes required for building applications like cladding panels, curtain walls, composite flooring systems, and load-bearing concrete blocks (Cook, 1983). EPS aggregate has a closed cell structure consisting essentially of 98% air (Anonymous, 2003). By incorporating the EPS beads at different volume percentages in the concrete, mortar, or cement paste, a wide range of concrete densities can be achieved. Moreover the use of high volume fly ash as a supplementary cementations material in concrete applications is very much preferred for economy and durability apart from the advantages that are related to the environmental aspects(Ganesh Babu and Saradhi Babu,2003).

At present, all kinds of gypsum products are widely used in the building trade because of their various fine performances(Li et al., 2003). Gypsum-based renders and plasters have become the material of choice for indoor finishing in many countries. Excellent performance, attractive appearance, easy application, and its healthful contribution to living conditions have made gypsum a most popular finishing material for centuries (Arikan and Sobolev, 2002; Duggal, 1998; Ragsdale and Raynham, 1972). This building material is abundant in Turkey and has high purity. The natural gypsum rock reserves of Turkey are estimated to be about 1.2 billion tons. Availability, the relatively low level of start-up investment, and a favorable market situation, all provide conditions for growth and the profitable industrial production of gypsum-based materials in Turkey (Arikan and Sobolev, 2002).

Gypsum blocks are used in multistoried apartment houses for non-load bearing purposes in making curtain and partition walls of these houses(Kumar, 2002; Kumar, 2003). Use of EPS-gypsum blocks in this type of construction is aim mainly to achieve economy and make profits. The buildings in rural settlements in the category of low or middle-income groups mostly have single or two-storied dwelling units. Therefore, not only the cost effectiveness but also the strength and durability of EPS-gypsum blocks are very important for them.

In many regions, pumice and gypsum are available. At the same time, EPS used by packaging material is almost available everywhere. If these materials can be used to make EPS-gypsum blocks, will be improvement some properties of buildings such as lightweight, proper acoustics and thermal insulation characteristics and durability. Pumice and gypsum are obtained from mineral sources, and EPS is procured from packaging materials such as television, refrigerator, washing machine and etc.

Gypsum blocks containing 50–70% crumbled polystyrene foam beads were discussed by Sayil and Gurdal (Sayil and Gurdal, 1999). The density of such composite changed from 690 to 208 kg/m^3, and the thermal conductivity coefficient decreased from 2.74 to 0.183 W/m°C (Laukaitis et al., 2005).

For application of EPS-gypsum blocks in housing sector, comprehensive research are needed. With this point of view, the properties of blocks manufactured with pumice, EPS and gypsum were investigated. The aim of this work is to produce EPS-gypsum blocks and EPS-pumic-gypsum blocks for low cost housing development by utilizing the EPS and pumice aggregate in the gypsum. Also, it is to study the compressive strength, water absorption, density and thermal conductivity of blocks produced.

2. Meterial and Methods

The materials used for gypsum solid blocks were pumice, waste expanded polystyrene (WEPS), gypsum and water. The chemical compositions of gypsum used in the cementitious binder and of pumice used as aggregate are given in Table 1. Gypsum was manufactured by BMT Company in Sivas, Turkey and it was procured in paper sacks from local suppliers. WEPS was obtained from packing such as television and refrigerator. This waste was crushed and had a size range between 2 and 4 mm beads. Pumice aggregate passing through 4 mm sieve were retained on 0.25 mm sieve and had mostly 2 mm size. The bulk density of expanded polystyrene (EPS) beads and pumice aggregate were 20 kg/m^3 and 575 kg/m^3, respectively.

The mix proportions of pumice, WEPS and gypsum for solid blocks are given in Table 2. The mix proportions are given in terms of % volume of the ingredients. Series I contains gypsum and EPS, while Series II and III contain gypsum, EPS and pumice. Kumar (2003) mentioned that shrinkage cracking is a major weakness in gypsum-based blocks. Shrinkage cracking can be minimized by keeping the water content of binder as low as possible. Hence, in this study, a low slump mix was used to limit the shrinkage. All the gypsum solid blocks containing EPS and pumice were manufactured as recommended by Turkish Standards (TS EN 12859, 2009; TS 3682,1982) and were modified by considering the efficiency of EPS, similar to the mixes designed for previous studies(Kumar, 2003). The detailed mix proportions are given in Table 2.

Table 1. Selected properties of gypsum and pumice used in the study

Gypsum		Pumice (%)	
Water/gypsum	% 70	MgO	0.01
Freezing Start	10-12 min.	Al_2O_3	13.20
Freezing Ending	25-30 min	SiO_2	71.35
Water absorption (by weight)	% 38	CaO	1.84
Hardness of dry surface	55 shore D.	Fe_2O_3	1.54
Compressive strength (MPa)	10	SO_3	0.04
Density (g/cm^3)	2.597	K_2O	5.00
Water content	2.5	Na_2O	3.40
		TiO_2	0.25
		SO_3	3.37

Table 2. The mix proportions

SI number	Mix number	Constituent materials (Volume)		
		gypsum	pumice	EPS
Series I	1	1	-	3
	2	1	-	2
	3	1	-	1
	4	2	-	1
	5	3	-	1
Series II	6	1	3	-
	7	1	2	-
	8	1	1	-
	9	2	1	-
	10	3	1	-
Series III	11	1	2	2
	12	1	2	1
	13	1	1	2
	14	1	1	1
	15	2	2	1
	16	2	1	1
	17	3	2	1
	18	3	1	1

Cubes 50 x 50 x 50 mm were cast for compressive strength test, and prisms 120 x 100 x 50 mm were done for heat conductivity test. Before casting, EPS beads and pumice were wetted initially with a part of the mixing water before adding gypsum. Then, the mixture of water and gypsum together with EPS beads and pumice were put in the laboratory mixer, and completely mixed. Mixing was continued until a uniform consistency. Prepared compounds were cast in molds, and compacted by on a vibration table. Specimens were covered with cling film to prevent water loss for 24 h after casting and cured in air with Relative Humidity of 65% at the 23±2 ^{o}C for 28 days after demoulding.

The samples were held in water for 24 hours to determine water absorption and unit weight experiments and heat conduction coefficient measurements were conducted. The mechanical resistance was determined considering compressive strength values of the samples. According to procedures given by TS 451(1983), compressive strength test was conducted with a universal experimenting tool with 14 N/mm^2/min loading speed. Heat conduction coefficient was found using a KYOTO 500 model device with hot wire method.

3. Results and Discussion

A number of gypsum blocks were made with different proportions of pumice, EPS and gypsum. The experimental results are presented in Table 3.

Dry density: Density is one of the important parameters which can control many physical properties in lightweight concrete. The previous studies indicate that the density of EPS concrete decreases with increase in volume of EPS aggregate (Saradhi Babu et al., 2005). Since weight of a construction material is an important factor in transportation, application and processing, composite materials with low density are desired (Guozhonget al.,2003). The dry density values of specimens in Series I(EPS-gypsum) and Series II (pumice-gypsum) were between 528 kg/ m^3 to 1206 kg/$m^3$and 756 kg/m^3 to 1340 kg/m^3, respectively (Table 3). The dry density values of Series III (EPS-pumice-gypsum) varied ranging from 760 to 1256 kg/m^3. The lowest density value was determined for Mix 1 and specimens including Mixes 6 and 11 followed this value, respectively. This may be due to the fact that the lower density gypsum blocks generally have high amount of EPS. Present findings are similar to recommended by Turkish Standards(TS EN 12859, 2009; TS 1471, 1974) for gypsum blocks apart from Mixes 8,9,10 and 18.

Compressive strength: The compressive strength values of specimens in Series I (EPS-gypsum) and Series II (pumice-gypsum) produced were found between 1.0 MPa–9.6 MPa and 4.0 MPa–16.5 MPa, respectively. The compressive strength values of specimens in Series III (EPS–pumice-gypsum) were determined to be between 2.2 MPa and 10.4 MPa. The compressive strength value for gypsum blocks should be at least 4.0 MPa according to Turkish Standards(TS 3682, 1982). The strength of EPS and pumice gypsum blocks appears to increase linearly with an increase in block density, or with a decrease in the EPS and pumice volume. Series I (EPS-gypsum) and Series II (pumice-gypsum) were designed with the same volume binding material. The compressive strength values of specimens in Series II were higher according to those of Series I. This variation of strength is mainly due to the difference in strength of the aggregates, as EPS aggregates have almost zero strength.

Water absorption: The water absorption valuesofspecimens containing EPS and pumice aggregate are given in Table 3. The water absorption values in Series I and II were observed between 36% to 18% and 40% to 16%, respectively.

Table 3. The density, compressive strength, water absorption and thermal conductivity of specimens

SI number	Mix number	Constituent materials (Volume)			Dry density (kg/m^3)	28 days comp. Strength (MPa)	Water absorption after 24 h (%)	Thermal conductivity (W/m°C)
		gypsum	pumice	EPS				
Series I	1	1	-	3	528	1.0	36	0,134
	2	1	-	2	792	3.4	31	0.163
	3	1	-	1	1012	4.7	22	0.181
	4	2	-	1	1108	8.2	21	0,208
	5	3	-	1	1206	9.6	18	0,211
Series II	6	1	3	-	756	4.0	40	0,167
	7	1	2	-	1032	5.2	29	0,195
	8	1	1	-	1240	12.6	19	0,218
	9	2	1	-	1268	13.2	18	0,277
	10	3	1	-	1340	16.5	16	0,294
Series III	11	1	2	2	760	2.2	34	0.153
	12	1	2	1	788	2.5	30	0.175
	13	1	1	2	816	3.1	29	0,189
	14	1	1	1	936	5.0	26	0.219
	15	2	2	1	1108	6.0	20	0.232
	16	2	1	1	1134	7.2	19	0.251
	17	3	2	1	1158	8.0	17	0,259
	18	3	1	1	1256	10.4	16	0,271

Table 4. The properties of some building materials used in wall making(Karadutlu, 2003)

Material	Compressive strength (MPa)	Density (kg/m3)	Water absorption (%)
Hollow concrete block	2–12.5	500–2200	25–35
Clinker bricks	16	800–1800	18
Gas concrete	2–3.5	800-1400	25–35
Lightweight concrete	17	400–2000	24–50

The water absorption values of specimens in Series III were decreased from 34% to 16% depending on the increase in gypsum volume.It shows that the absorption results of specimens increased with increase in the volume of EPS and pumiceaggregate. The specimens with low density showed high absorption apart from Mix 6 in Series II. The higher absorption was seen in specimen containing pumice aggregate. This may be due to the pore structure of pumiceaggregate.The properties of some building materials used in wall makingare shown in Table 4.

Clearly the water absorption of EPS and pumice - gypsum blocks is more compared to that of the traditional blocks. Nevertheless, since the EPS and pumice - gypsum blocks are going to be used only in partitions and curtain walls, the consequences of the high water absorption capacity will be less severe. However, this aspect certainly needs further investigation.

Thermal conductivity: The thermal conductivity of a material varies depending on its density, its moisture content and its mineralogical composition. At a bulk density between 600 and 1200 kg/m^3, gypsum blocks has a thermal conductivity of 0.29–0.58 W/mK according to TS 825Standard (TS 825, 1999). The thermal conductivity resultsof specimens tested in the present study were found between 0,134-0,294 W/mK (Table 3). Series I has the minimum thermal conductivity coefficient, as the density ofspecimens produced by EPS mix in Series I is lower than that of Series II and Series III. At the same time, this increases its thermal insulation capacity. The most important influencing factor on thermal insulation capacity is the density and characteristic of the dry materials. Therefore, it is possible to achieve very good thermal insulation properties of gypsum blocks produced by EPS and pumice aggregate.

As can be seen from Table 3,the values obtained from specimens are close to that of building materials used for thermal insulation. These gypsum blocks can be used as alternative material for thermal insulation purposes.

4. Conclusions

The following conclusions can be drawn from the experimental investigation reported in this paper:

1) The specimens produced have sufficient strength apart from Mixes 1, 2, 11, 12 and 13. These hadpotential as a replacement for conventional hollow burnt clay bricks and hollow concrete blocks.

2) Because of its low density, EPS-gypsum blocks will reduce the dead weight in multi-stored constructions.

3) The thermal conductivities of specimens were experimentally obtained and those values were lower than those of the traditional gypsum blocks. Therefore, the thermal insulation properties were quite good due to EPS and pumice. This was a desirable purpose.

4) Water absorption values of specimens varied significantly with change of EPS and pumice volume. These values decreased depending on increasing of gypsum volume, but the specimens produced had lower water absorption values when compared to water absorption values of the other wall building materials such as hollow concrete blocks and gas concrete.

The utilization of waste EPS and pumice in making gypsum blocks may be help the thermal insulation of buildings and thus may be achieve energy conservation. Therefore, It is further needed to be aware of users for use in partitions and double-leaf walls.

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