THE PHYSICAL PROPERTIES OF POLYSTYRENE AGGREGATED GYPSUM BLOCKS

Polystyrene aggregated gypsum blocks

B. SAYIL and E. GÜRDAL
Istanbul Technical University, Faculty of Architecture
Institute for Building Materials and Physics, Istanbul, Turkey

Durability of Building Materials and Components 8. (1999) *Edited by M.A. Lacasse and D.J. Vanier*. Institute for Research in Construction, Ottawa ON, K1A 0R6, Canada, pp. 496-504.

Abstract

Lightweight concrete is widely used in our day as a filling material for sandwich panels in the construction industry. On the other hand, the use of gypsum in this aspect is very limited. Block or panels as partition walls produced by foamed or porous gypsum has not been widely publicised. According to literature, similar types of gypsum panels are produced and used in Israel and the former East Germany. During our literature survey, using polystyrene beads as an aggregate for the production of the gypsum blocks or panels has not been discovered. In this study, we have observed the use and production gypsum composites, using polystyrene beads. Even though it is possible to mix polystyrene beads and gypsum without additives, better results are obtained by wetting the beads using a glue with a polymer base for binding as the mixture become more homogeneous. Production is planned for samples between 200kg/m³ and 800kg/m³ density, among those 500-600 kg/m³ mixtures have been found to be the most economical ones and the cavities filled with gypsum up to the maximum extent. Even though the mechanical strength is not a critical issue for these samples, it is found to be sufficient, in addition good heat insulation and fire retardant properties has been observed.
Due to the above mentioned properties, polystyrene aggregated gypsum can be used in precast or cast in situ panels as a filling material.

Keywords: Gypsum, polystyrene foam, epoxy resins

1 Introduction

Lightweight concrete is widely used in thermal insulation, to decrease the cross sections of reinforced concrete structural elements or in block or panel systems. But use of light-weight gypsum as a filling agent or as prefabricated panels is very rare. For example of these applications is the production of hollowed gypsum blocks for use as domestic partition walls. The application of making gypsum light by foaming is also scarce, and such productions do not permit the material to have a density less than 600kg/m^3. Productions made with light aggregates like perlite and vermiculite are not so effective, due to their small ratios in the mixture.

Using polystyrene foams as light aggregate is quite new. Polystyrene foams produced by the German firm BASF, and sold under the trade name of Styropor are given to the manufacturers as Styropor beads. The manufacturers put these beads in suitable moulds and heat it with steam in order to give them the shape of the mould. Experiences in using half-expanded 1.5-2 mm spherical beads as aggregate material in concrete, were tested since 1949. Although the experiments were highly successful, the application of this practice was not developed, since that condition of polystyrene foam was very expensive at that date,. However when the pre-expanded polystyrene foam beads became economical after 1960's, polystyrene foam cement found a wide enough application field.

Presently, the polystyrene foam finds a wide application as insulation material in board form. It is also widely used in packing. In companies that use polystyrene foam beads by expanding the beads, there is a lot of waste material left because of large dimensions and faulty productions. These left overs are simply crumbled and turned back to polystyrene foam beads. A firm dealing with polystyrene bead production, consulted Istanbul Technical University Faculty of Architecture's Construction Materials Laboratory and wanted to evaluate these leftovers. In the performed research, among other findings, it was understood that these beads could be used together with gypsum, just like in cement to form gypsum with polystyrene foam.

2 Definition

The production of gypsum productions with polystyrene foam aggregate give various advantages with respect to other gypsum mixtures. First of all, crumbled surplus polystyrene foam beads can be purchased after production for a very low price, and very light products are resulted. Polystyrene foam beads can be used as volume 50-70% depending on the density of the gypsum block. By using crumbled polystyrene foam beads the following can be accomplished:

- Very small observed unit volume weight (Δ=11-12kg/m^3)
- Very small heat transfer value (λ=0.04 W/m ^{o}C)
- Durability against moisture penetration due to the closed cellular structure of the beads.
- Due to formation of the beads close to each other, the remaining cavities between them are filled tightly with matrix material which gives a high mechanical strength to the gypsum composite.
- Since the form of the polystyrene foam beads are perfectly spherical, they distribute themselves evenly in concrete or gypsum paste so that construction elements in homogeneous structure can be produced.

3 Material

3.1 Polystyrene foam beads used as aggregate

The basic material is expanded Polystyrene foam, produced by the German firm B.A.S.F. and being exported to the world under the name of Styropor since 1952. Manufactured as board and sandwich panels, it is widely used in construction, insulating and packaging industries.

The manufacturing of the material is realised in two stages. Stage one; the unexpanded material called polystyrene foam bead is pre-expanded. Stage two; these beads are closed in forms and fused together . At this moment the beads touch and are welded to each other in the contacting boundaries and reach their final form as blocks, boards or shaped mouldings.

The raw material consists of fine cellular beaded polystyrene which is subjected to a pre-expansion process. In this process, the fine polystyrene beads containing an expanding agent are heated in steam, the expanding agent in the fine beads vaporises and the vapour of the agent mixed with steam expands the beads up to 50 times their original volume, to a diameter of 1.5-6mm.

Unit dimensions of polystyrene foam beads depend on the dimensions of the vessel where the pre-expanded beads are placed, expansion period and the heat of the steam. With this method , the polystyrene foam beads can be produced in different sizes and densities .

The dimensions of polystyrene foam beads used in this study are between 2 and 4 mm and average 3 mm. Since in previous research, it was found that the dimension of the beads have no effect on the resistance of the concrete produced, the effect of the dimensions were not examined (Lightweight Concrete 1975). It was accepted that the apparent density of the polystyrene foam beads has no effect also on the resistance, because the density of the beads are so lower than the density of the gypsum, that the density of the beads are negligible when the whole composite material is considered. In order that the material should be produced economically, the apparent density of the beads should be about 12-15 kg/m^3 (1). The polystyrene foam beads used in this research are maintained made by a water and thermal insulation firm and their volume weight is Δ = 11.17 kg/m^3. The density of the same material is 18 kg/m^3.

3.2 Gypsum

The gypsum used in this research is a commercial gypsum hemi-hydrate ($CaSO_4 \cdot ½ H_2O$) product, which is commonly used for internal decorations. From the preliminary tests on this material, it has been found out that, the material starts to set after 10 minutes and ends setting after 16 minutes, using a normal consistency and 60% water/gypsum ratio. Only distilled water was used in the preparation of the specimens and no further retarders or other additives were added. The compressive strength of this gypsum was 16 MPa (160 kgf/cm^2) after its setting time.

3.3 Bonding additive

Adhesion between the polystyrene foam beads which are organic and inorganic based mineral binders, is very low. To overcome this problem, a bonding agent had to be used. As bonding agents only plastic dispersions or adhesive resins can be considered, since these have no adverse effects on the gypsum properties and do not attack the polystyrene beads. In this study an epoxy based bonding agent (produced by Köster company ECC Resin), is used. Using this material, delayed the setting time of the gypsum and in addition, increased the mechanical strength and moisture resistance of the gypsum matrix .

4 Preparation of the test samples

The mixing of low-density aggregates and mineral binders, may sometimes cause difficulties. Therefore, it is preferred not to keep the matrix elements very fluid and viscous. In the production of the gypsum composite, sand and similar fillers are also not used. As a result, it is hard to exceed the maximum application of polystyrene foam over 600 kg/m^2.

In the production of the gypsum composite it is not easy to mix gypsum, water and expanded beads because of the great density differences between these two materials. In order to maintain a homogeneous mixture, the surface of polystyrene foam beads must be covered with the gypsum binder. The bonding additive should ensure that the gypsum binder actually coats the surfaces of the beads and not accumulate in the cavities. For this reason various kinds of polymer dispersions or organic based glues can be used that won't affect the setting of the gypsum. For example, PVAc, acrylic and epoxy dispersions can be used in gypsum without a problem.

In the production of test samples Köster ECC epoxy emulsions are used as the bonding additive. The specimens for the trials are prepared in cylindrical moulds of 10 cm in diameter and 20 cm height. Bonding additive proportion is designed as 1/40 of the mixing water. The densities of the gypsum samples have been designed as 200 kg/m^3, 300 kg/m^3, 400 kg/m^3, 500 kg/m^3, 600 kg/m^3, 700 kg/m^3, and 800 kg/m^3. The calculated proportions of the matrixes of the materials are shown in Table 1.

Table 1: The matrix of the 1m^3 gypsum compound and its proportions

Density (kg/m^3)	Gypsum (kg)	Polystyrene foam (kg)	Water (lt)
200	152	15	91.2
300	235	15	141
400	317	15	190
500	400	15	240
600	482	15	290
700	565	15	339
800	647	15	388

In the production phase it was found that these proportions needed changing, as a result of the beads receding from each other. The proportion amounts were decreased. The real matrixes that are taken for 1 m^3 composite samples are shown in Table 2.

Table 2: The real mixing values of 1m³ gypsum composite

Density (kg/m³)	Gypsum (kg)	Polystyrene beads (kg)	Water (lt)
200	162.000	11.141	97.080
300	249.550	11.141	117.770
400	336.450	10.822	159.150
500	424.300	10.742	200.530
600	511.520	10.663	241.910
700	599.380	10.584	257.830
800	606.590	10.584	318.310

The mixtures prepared in the ratios mentioned above were poured into 10cmx20cm cylindrical moulds. It is found out that the epoxy emulsion which is added into the gypsum mixing water, with the proportion of 2-2.5% decreases the amount of mixing water and increases the flow property and the setting time of the specimens. However the high prices of epoxy resins (approximately 37 DM/kg) forces further new researches on other emulsions although a quite small quantity is required for the gypsum and polystyrene composites. The moulded samples were cured in an oven at 40ºC for 24 hours to be dried and then their volume units are measured. The results are summarised in Table 3

Table 3:The average volume weights of the cast test samples

Prepared (kg/m³)	200	300	400	500	600	700	800
Result (kg/m³)	208	265	397	493	577	655	690

The heat transfer, water vapour permeance, diffusion resistance factor and mechanical strengths of the test samples are evaluated according to the unit volume mass. The real material proportions in 1 m^3 gypsum composite according to the volume weight values are given in Table 4

The specifications of the gypsum composite are evaluated according to the volume ratios of the materials that are present in the composite.

Table 4: The gypsum and polystyrene foam matrixes in 1 m³ gypsum composite

Density of the composite material (kg/m³)	Polystyrene foam beads (in kg)	Gypsum matrix (in litre)	Polystyrene foam beads (in kg)	Gypsum matrix (in litre)	Cavity limits (in litre)
208	11.100	198.900	616.67	164.00	220.00
285	9.550	315.310	530.55	196.35	273.00
397	10.460	387.041	581.11	297.72	121.17
493	10.272	482.791	570.67	371.38	57.95
577	9.957	566.743	553.17	435.96	10.87
655	9.575	645.360	531.94	467.39	0.67
690	8.120	680.847	451.11	519.73	29.00

5 Properties of polystyrene foam gypsum composite

5.1 Segregation

Polystyrene foam gypsum can be used anywhere light-filling material is needed in construction. Mixtures with a density of 200 kg/m^3, density is the lowest are not satisfactory in construction and have the tendency to segregate.

Examples over this density do not segregate easily because of the rich amount of gypsum surrounding in their composition. That's why more gypsum should be used in order to increase the density. In the samples with the density of 550-600 kg/m^3 , the amount of the cavities are very little and polystyrene foam beads usage is dense enough so that the material reveals high compressive strength. (Figure 1).

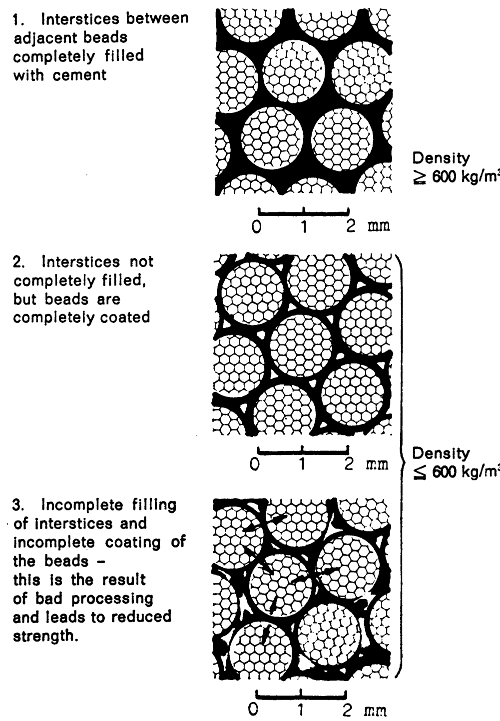

Fig. 1:The structure of gypsum composite (Köhling 1960)

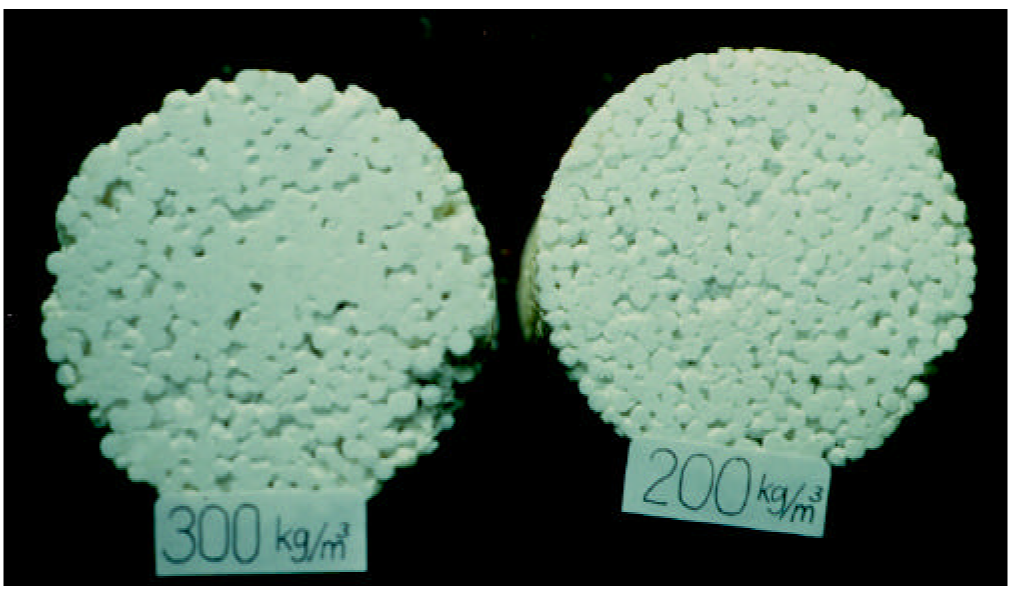

Fig. 2: Gypsum composite samples with different densities

The physical and mechanical properties of the material differ with its density. Naturally, as the density of the material increases, the mechanical strength and vapour diffusion resistance factor increases and the heat transmission ratio decreases.

5.2 Mechanical properties

Since these materials will not be used in flexure or tensile conditions, their values in these aspects are not investigated.

The compressive strengths of the cylindrical test samples with 10 cm diameter and 20 cm height were tested on an MFL Brand 100 kN Universal tester, and the following results were found.

Table 5: Compression strengths related to the densities in average

Density (kg/cm³)	208	265	397	493	577	655	690
σ MPa	0.183	0.187	0.556	1.34	1.71	2.47	2.74

5.3 Heat transmission values

In the composite polystyrene foam has the largest volume and it is known as the best heat insulating material. It's heat transfer ratio averages 0.040 W/m^{o}C depending on the moisture content. Gypsum's heat transfer ratio differs with its density and humidity. In preparation of the samples, water/gypsum ratio is taken as 0,47-0,50. The density of the gypsum prepared with this ratio is found as 1,2 g/cm^3 and the heat transfer of this material is λ=0.545 W/m^{o}C (Hohwiller and Köhling 1968). Gypsum-polystyrene foam bead and air mixture's heat transfer ratio found in composites are calculated according to the average values calculation which are given in Table 6.

Table 6: Heat transfer values related to the densities

Density(kg/cm³)	208	265	397	493	577	655	690
λ (W/m°C)	0.183	0.187	0.556	1.34	1.71	2.47	2.74

5.4 Vapour transfer resistance factor

In polystyrene foam gypsum samples up to 400 kg/cm^3 empty spaces that are related with each other are formed. (Figure 1). Therefore their vapour transfer ratios are relatively small. However the vapour transfer resistance of the surplus polystyrene foam beads are very high. In the experiments conducted in the laboratory, the vapour transfer resistance of surplus polystyrene foam are found between 90-150. On the other hand the μ ratio of polystyrene foam panel differs between 25-40 depending on its density. In this study the vapour transfer resistances of the samples having the volume weights of 397kg/m³ and 577kg/m^3 are measured. The average value for the samples with a volume weight of 397kg/m³ is μ=20 and for 577 kg/m³ samples μ=25.

5.5 Behaviour against fire

Polystyrene foam beads used in the samples have the tendency of burning easily. But when they are covered with gypsum they do not burn so easy. In samples up to 400 kg/m^3 , the risk of burning is higher compared with the heavier samples. In an experiment conducted under laboratory conditions, 6 samples, 40x40x10 cm, were exposed to open fire and has been observed. After half an hour, the polystyrene foam beads on the surface of the blocks which had direct contact with fire, evaporated without burning, and the surface temperature of the samples did not exceed 30 ^{o}C. According to these results, gypsum panels of 10 cm thickness and with a density of 500 kg/m^3 have the ability to retard fire for half an hour.

Fig. 3: Behaviour of gypsum-polystyrene foam composite against fire

6 Conclusion

The conclusions of the experimental program which was performed to examine the durability of lightweight gypsum with polystyrene foam beads, can be summarised as follows:

- The lightweight gypsum with polystyrene foam is a perfect heat insulating material with good mechanical strength which can be used in self bearing construction elements, combining thermal insulation with the static function.
- If the lightweight gypsum is designed as a sandwich panel, having an internal layer of lightweight gypsum with polystyrene foam, and gypsum sheets on both faces, it will work as a very good fire delaying element
- Because the material itself is lightweight, there is a considerable reduction of weight in the buildings.
- The Composite of gypsum with polystyrene foam can be used as a filling and heat preserving material in many areas of construction. Among the application areas considered are as a base material in floors that touch the base, in normal floors as elastic and light filling material, load bearing panel

structures. It can be used in ceilings as a heat preserving element and in sandwich elements with an internal layer of lightweight gypsum.

- In restoration of historical wooden buildings, using polystyrene foam gypsum will maintain heat insulation as well as increasing the fire protection which is a very important factor to wooden buildings. In addition polystyrene foam gypsum blocks can be used as a separation or filling wall material.

7 References

Lightweight Concrete , Precast Concrete, (1975), p. 653-656
K. Köhling, Betonstein, (1960), 2/6, p. 208, 212
K. Köhling, (1960), Kunststoffe, p. 60,648-651
R. Hohwiller, K. Köhling, (1968), Betonstein, 34 (2/3) p. 81-87, 132-137
E. Gürdal, (1976), "Kuzey ve Orta Anadolu Alçilari Üzerine bir Arastirma" , Doktora Thesis,