Scientific Research and Essays Vol. 6(7), pp. 1673-1680, 4 April, 2011
Available online at http://www.academicjournals.org/SRE
DOI: 10.5897/SRE11.275
ISSN 1992-2248 ©2011 Academic Journals

Full Length Research Paper

Investigation the using possibilities of some mineral-bound organic composites as thermal insulation material in rural buildings

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Accepted 1 April, 2011

Using possibilities of some mineral-bound organic composites as thermal insulation material in rural buildings was investigated in this research. For this purpose, using rice husk (RH) and ground sunflower stem (SS) as the main material and cement and gypsum as mineral-binding materials, series I and series II samples with the volumetric mixing ratio of 1/3, 1/6 and 1/9 were produced. Thermal conductivity of cement-bound samples of serials-Ib3 and Ic3 were found to be 0.062 and 0.065 W/mK, respectively, whereas thermal conductivity of gypsum-bound sample as of serials-IIb2, IIc2, IIb3 and IIc3 were obtained as 0.063, 0.065, 0.054 and 0.057 W/mK, respectively. Measurement and test results carried out on the samples showed that, serials-Ib3 and Ic3 among the cement-bound samples; serials-IIb2, IIc2, IIb3 and IIc3 among the gypsum-bound samples may be used as thermal insulation materials in rural buildings. Use of these organic wastes in this way could be an economic alternative to common destruction method of burning, harmful to the environment.

Key words: Thermal insulation, insulation materials, organic composites, rural buildings.

INTRODUCTION

Today, one of the most challenging problems of the world is to supply cheap and clean energy. Increasing energy consumption day by day leads to increase in environmental problems seriously such as environmental pollution and diminishing natural resources. Particularly, non-renewable energy sources, being limited and polluting more than other energy sources, make this problem an important issue. Although, fossil-based energy sources are the most significant environmental pollutant, approximately 86% of the world's total energy consumption is provided by them (Altin, 2007). Turkey displays a negative picture in terms of used energy amount and type of energy source. According to the World's Energy Report published by British Petroleum (BP) every year, while there was 2.4% increase in the average energy consumption of the world in 2009 in comparison to 2008, this rate for Turkey was around 5.0% (Anonymous, 2010a). Moreover, approximately 70% of the total energy used in Turkey is imported, which has an increasing trend continuously year by year and expected to reach 78% by the year 2020 (Anonymous, 2009a). This clearly shows that, the adoption of the efficient use of energy in Turkey will provide many benefits in terms of economic, social and environmental aspects. Construction activities consume 40% of the total energy used globally each year. In a study conducted by International Energy Agency (IEA) countries, which also includes Turkey, it is reported that structures are seen as a major energy consumer, with half of the total electricity and one-third of the total natural gas consumption (Anonymous, 2007). This reveals that, as other sectors, construction sector should use energy efficiently.

One of the reasons responsible for this high energy consumption is that, insulation of the buildings is not done properly. Buildings in Turkey, particularly agricultural buildings in rural areas, are not designed in accordance with the terms of heat economy and cause large amount of fuel consumption. Approximately half of the total energy consumed in Turkey is to heat buildings.

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Table 1. Physical and chemical properties of cement (Anonymous, 2005).

Component	Ratio of component (%)
Chemical properties	
SiO_2	20.4
Al_2O_3	5.61
Fe_2O_3	3.27
CaO	63.01
MgO	2.49
SO_3	2.26
Cl	0.006
Heating lost	1.64
Non-detected	1.68
Physical properties	
Specific weight (g/cm^3)	3.05
Specific surface (cm^2/g.Blaine)	3470
Volumetric swelling (mm)	7
Priz starting time (h/dk)	03:10
Priz ending time (h/dk)	04:15

Table 2. Technical properties of building gypsum (Anonymous, 2009b).

Water-gypsum rate	% 70
Start of freezing	8-12 dk
Compressive strength	Min. 100 kg/cm^2
Gravimetric water suction ratio	% 42
Fineness	0.2 mm
Hardness of dry surface	50 Shore D.

However, up to 50% energy saving is likely, if careful measures are taken with the idea of energy economy in the buildings. This can only be achieved by insulation of buildings appropriately and sufficiently (Anonymous, 2008a). In rural areas, houses, animal production and product storage buildings under the influence of continental climatic conditions must be insulated. With the insulation of rural buildings, not only significant amount of energy is saved but also human heath, quantity of animal production and quality of stored agricultural products are improved.

Therefore, either building elements must be insulated or constructed by the materials with the low thermal conductivity. To ensure widespread use of insulation materials in rural settlement areas, readily available insulation material should be preferred. Having been subjected to a simple process and bound by a binding material, some organic plant residues left after the harvest may be used to obtain composite material for insulation purpose.

This study was carried out to investigate some physical, mechanical and thermal properties of some mineral-bound organic composites which may be used for thermal insulation purposes in rural buildings and to illustrate types of applications in practice.

MATERIALS AND METHODS

In the study, rice husks (RH) and sunflower stalks (SS) as main organic materials and two types of minerals, hydraulic and non-hydraulic, as binding materials were used. The hydraulic binder was the Portland cement (PC 42.5) suitable with the Turkish Standards (TS EN 197-1) (Anonymous, 2005) and non-hydraulic binder was gypsum in accordance with TS EN 13279-2 (Anonymous, 2009b) with a minimum compressive strength of 100 kg/cm^2. Physical and chemical properties of cement are presented in Table1 while those of building gypsum are given in Table 2. The mixing water quality (tap water) was consistent with the criteria defined in TS 1247 (Anonymous, 1984). The water/cement ratio was 0.45 for hydraulic binder as explained in TS 802/T2 (Anonymous, 2002a) while the water/gypsum ratio was 0.70 for non- for hydraulic binder as defined in TS EN 13279-2 (Anonymous, 2009b).

Rice husks were obtained from the rice factories in the region whereas SS were collected from the farmers' field after the harvest. Sunflower stalks were grounded to 2 to 5 mm size particles by a laboratory type roller grinder. Oven-dry loose and pressed unit weight of RH and SS were determined following the procedure described in TS EN 1097-6 (Anonymous, 2002b). Organic composites prepared using cement as binder material was defined as serial-I, while organic composites prepared using gypsum as binder material was defined as serial-II. In the production of organic composites, volumetric mixing ratio was preferred for the simplicity reason. The produced composite sample serials and the mixing ratios of materials are presented in Table 3. The rate of binder materials in both serial samples were kept constant as seen in Table 3 and some physical and mechanical properties and thermal conductivities of organic composites with different mixing ratios were investigated. The unit weights of produced organic composites were computed from the measured weights and volumes of the samples (that is weight/volume). To determine the water absorption rate, known volume of samples were soaked in pure water and waited until the weight of the samples reached to a constant value. Then, the samples were removed and their surfaces were cleaned. The water absorption rate was calculated using the equation (wet weight–dry weight) / dry weight (Ones, 1988).

In cement-bound serial-I model, standard samples in 40x40x40 mm dimensions were prepared to determine compressive strength according to the principles explained in EN12390-3. Similarly, samples with 40x40x60 mm in dimensions were arranged as described in TS EN 12390-5 to find out the bending strengths. Standard samples removed from the molds after 24 h were subjected to a curing until the end of 28 days and then tests were performed (Anonymous, 2010b, c).

In gypsum-bound serial-II models, compressive and bending strengths were investigated on the standards samples having the same dimensions with serial-I model following the procedure explained in TS EN 13279-2. The prepared samples were kept in the molds for 24 h at 90% relative humidity and 20°C temperature. Then, they were heated in an oven at 40°C until bringing to a constant weight. Finally, they were examined (Anonymous, 2009b). Fully automatic hydraulic-pressed test instrument was used in the experiments. Three samples were used for each serial in each test. In the analysis of compressive and bending strengths of the samples, averages values of the three measurements were taken into consideration.

Thermal conductivity values of serials-I and II samples were obtained using "hot-wire" method by Shoterm-qtm device in accordance with ISO 8894-1. Three readings were performed at

Table 3. The produced composite sample serials and the mixing ratios of materials.

Sample serials			Volumetric mixing ratios	Amount of composite material			
				Cement	Gypsum	Rice husks	Sunflower stalks
Serial-I	a	1	1/3	1	-	3.0	-
		2	1/6	1	-	6.0	-
		3	1/9	1	-	9.0	-
	b	1	1/3	1	-	-	3.0
		2	1/6	1	-	-	6.0
		3	1/9	1	-	-	9.0
	c	1	1/3	1	-	1.5	1.5
		2	1/6	1	-	3.0	3.0
		3	1/9	1	-	4.5	4.5
Serial-II	a	1	1/3	-	1	3.0	-
		2	1/6	-	1	6.0	-
		3	1/9	-	1	9.0	-
	b	1	1/3	-	1	-	3.0
		2	1/6	-	1	-	6.0
		3	1/9	-	1	-	9.0
	c	1	1/3	-	1	1.5	1.5
		2	1/6	-	1	3.0	3.0
		3	1/9	-	1	4.5	4.5

each point and three points were chosen for each sample. The averages of the readings were used to compute thermal conductivity (Anonymous, 1987). Having considered the aforementioned physical, mechanical and thermal characteristics of these organic composites and also taking the heat insulation principles defined in TS 825 into consideration, the using possibilities of them as thermal insulation material in rural buildings was examined (Anonymous, 2008b).

RESULTS

Unit weight of main materials

Rice husks were obtained from the rice factories in the region, whereas SS were collected from the farmers' field after the harvest. Sunflower stalks were grounded to 2 to 5 mm size particles by a laboratory type roller grinder. Oven-dry loose and pressed unit weight of RH and SS were determined following TS EN 1097-6 (Anonymous, 2002b). The unit weights of oven-dry loose and pressed SS were found to be 87.0 and 310 kg/m^3, respectively. The unit weights of oven-dry loose and pressed RH were 105.0 and 412 kg/m^3, respectively.

Using possibilities of produced composites as thermal insulation material

The energy consumption in the buildings, particularly for heating, is the significant part of the total use, which clearly proves the importance of thermal insulation. Wise use of energy obtained from very limited natural resources, by paying high cost is a prominent responsibility in terms of economic and environmental aspects. In this research, the usage possibilities of produced composite materials as insulation material in the buildings, particularly in rural areas, were examined. Following the procedure given under methods, the thermal conductivity values of the samples in both serials produced for thermal insulation purposes are presented in Table 5. Based on the thermal conductivity value of the glass wool, given as 0.040 W/mK by TS 825, equivalent thicknesses of the samples to 1.0 cm glass wool were also calculated (Table 5) (Anonymous, 2008b). Table 5 shows that thermal conductivity values varied from 0.062 to 0.145 W/mK for serial-I samples and from 0.054 to 0.089 W/mK for serial-II samples.

DISCUSSION

Unit weight of main materials

Both materials, SS and RH, may be classified as lightweight organic aggregates in terms of their oven-dry unit weights. These small unit weights are considered as an advantage, in terms of using these waste materials profitably for different purposes such as thermal insulation.

Evaluation of the experimental results

The obtained results of volumetric mixing ratios, oven-dry

Table 4. Some physical and mechanical properties of produced composite materials.

Sample serials			Volumetric mixing ratios	Oven-dry unit weight (kg/m^3)	Compressive strength (kg/cm^2)	Bending strength (kg/cm^2)	Water absorption rate (%)
Serial-I	a	1	1/3	951	32.62	6.35	39
		2	1/6	634	13.55	3.11	54
		3	1/9	533	8.43	2.24	65
	b	1	1/3	704	19.41	4.10	55
		2	1/6	505	10.44	2.58	69
		3	1/9	372	6.56	1.92	72
	c	1	1/3	718	22.39	4.61	50
		2	1/6	519	12.01	2.85	61
		3	1/9	385	7.12	2.01	68
Serial-II	a	1	1/3	593	5.67	1.77	46
		2	1/6	491	3.37	1.38	58
		3	1/9	443	2.44	1.22	72
	b	1	1/3	562	7.80	2.13	59
		2	1/6	448	4.41	1.56	67
		3	1/9	321	3.38	1.39	78
	c	1	1/3	570	6.40	1.89	54
		2	1/6	458	3.85	1.46	63
		3	1/9	374	2.95	1.30	76

Table 5. The thermal conductivities of the produced samples of the serials and their equivalent thicknesses to 1.0 cm glass wool.

Sample serials			Volumetric mixing ratios	Oven-dry unit weight (kg/m^3)	Thermal conductivity (W/mK)	Equivalent thickness to 1 cm glass wool (cm)
Serial-I	a	1	1/3	951	0.145	3.63
		2	1/6	634	0.096	2.40
		3	1/9	533	0.081	2.03
	b	1	1/3	704	0.107	2.67
		2	1/6	505	0.074	1.85
		3	1/9	372	0.062	1.55
	c	1	1/3	718	0.114	2.85
		2	1/6	519	0.078	1.95
		3	1/9	385	0.065	1.63
Serial-II	a	1	1/3	593	0.089	2.22
		2	1/6	491	0.070	1.75
		3	1/9	443	0.067	1.67
	b	1	1/3	562	0.085	2.12
		2	1/6	448	0.063	1.57
		3	1/9	321	0.054	1.35
	c	1	1/3	570	0.086	2.15
		2	1/6	458	0.065	1.62
		3	1/9	374	0.057	1.42

unit weights, compressive strengths, bending strengths and water absorption rates in the experiments for the samples of serials-I and II are presented in Table 4. The unit weight is one of the most important characteristics of a material. Table 4 reveals that, the unit weight of cement-bound serial-I samples are greater than that of

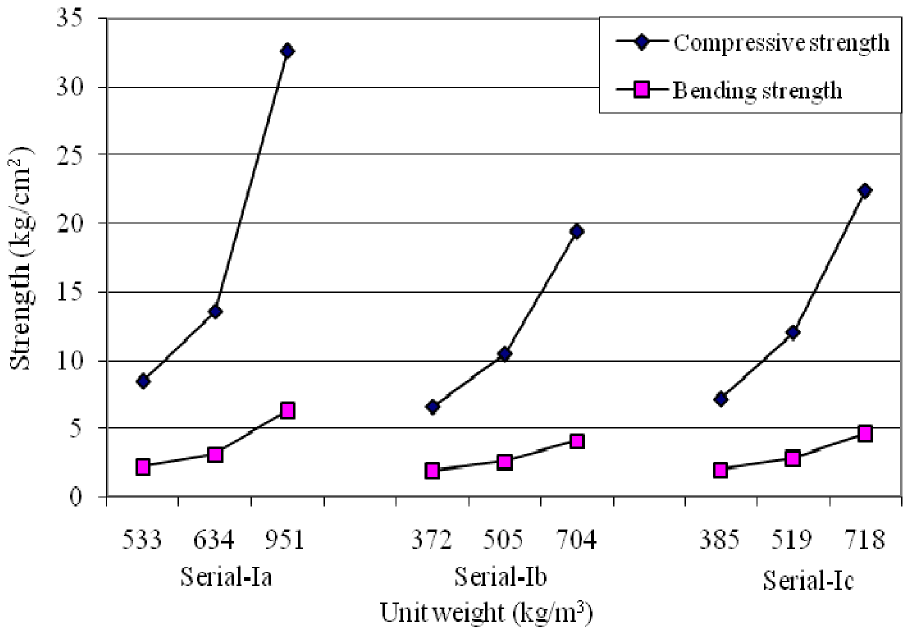

Figure 1. The changes in compressive and bending strengths of serial-I materials with the unit weights.

serial-II samples, when the same mixing ratios are compared. This is because the unit weight of the cement is greater in comparison to gypsum. As expected, unit weight of the samples produced using SS are smaller than that of the samples using RH in both serials, reflecting the unit weights of organic residues, RH (105 kg/m^3) and SS (87 kg/m^3). The unit weight values of the samples in both serials decrease regularly while the mixing ratios change from 1/3 to 1/9. Unit weight of composite materials should be smaller due to their textures. A material with a smaller unit weight is preferable because they are transported, applied and worked easily (Toydemir, 1988).

Porous materials may absorb water when touching. Water absorption in high levels is not preferred since many properties of the materials are affected adversely. Therefore water absorption ratio of the materials needs to be quantified (Uzer, 1996). Tests done for this purpose showed that, water absorption ratio increased with an increase in the amount of organic matter in the mixture. As seen in Table 2, water absorption ratio of serials-I and II samples varied between 39 and 72% and between 46 and 78%, respectively. When the samples in gypsum-bound serial-I and cement-bound serial-II with the same organic matter content are compared, water absorption ratio of the samples in serial-I were smaller. This is because water absorption rate of gypsum is higher than that of the cement. In general, both serials have high water absorption rate since RH and SS in the composite materials have high water absorption rate. Therefore, water and moisture insulation should be provided where these composites are used.

Investigation of compression and bending strength of composites are of great importance, in using for different purposes. Table 4 shows that, at 10% deformation as reported by Anonymous (2008b), compressive and bending strengths of serial-I samples change between 32.62 and 6.56 kg/cm^2 and between 6.35 and 1.92 kg/cm^2, respectively, depending on the mixing ratios. Similarly, values between 7.80 and 2.44 kg/cm^2 and between 2.13 and 1.30 kg/cm^2 were obtained respect-tively for compressive and bending strengths of serial-II samples. Table 4 reveals that, mechanical properties of RH containing samples are better than that of SS containing samples in serial-I, whereas SS containing samples are better in serial-II in terms of mechanical properties. This is because of a better adherence between binding and organic materials used. The changes in compressive and bending strengths with the unit weights are illustrated in Figure 1 for serial-I and in Figure 2 for serial-II samples.

Generally, a decrease in the unit weight decreases the mechanical strength of a composite material. As seen in Figures 1 and 2, mechanical strengths of all samples in both serials decreased with the decreases in the unit weights, depending on the adherence between the organic and binding material. This is because, as a skeleton material, unit weights and carrying strength of organic materials are generally small, and reflected these characters to the produced materials' properties. The same findings were also reported by Mannan et al. (2006), in the study carried out on the production of light-weight concrete, using palm crust as coarse aggregates at different ratios.

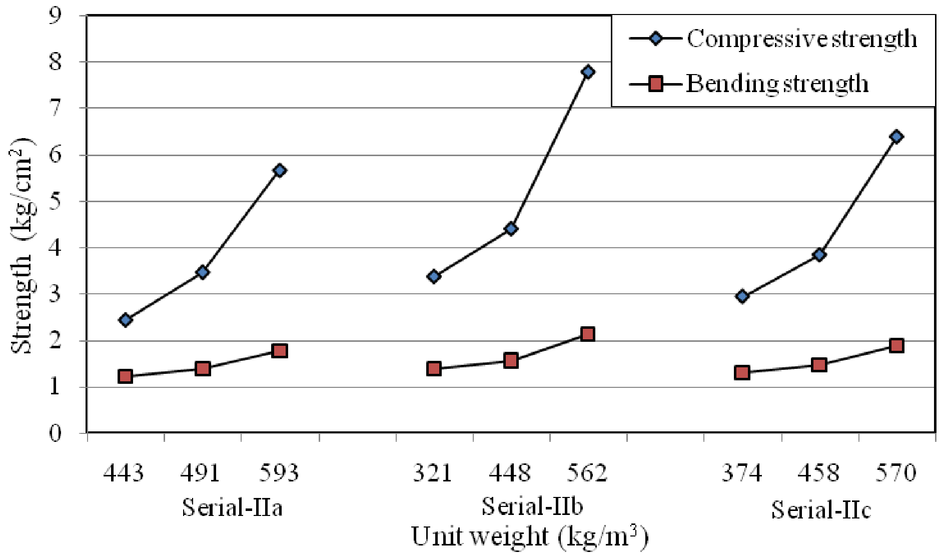

Figure 2. The changes in compressive and bending strengths of serial-II materials with the unit weights.

Using possibilities of produced composites as thermal insulation material

Smaller thermal conductivity values for serial-II in comparison to the serial-I are due to binding materials. For a material to be classified as heat insulator, its thermal conductivity (λ) should be less than 0.065 W/mK as indicated in TS 825 (Anonymous, 2008b). According to this classification, among cement-bound samples, serials-Ib3 and Ic3 with 1/9 mixing ratio; among gypsum-bound samples, serials-IIb2 and IIc2 with 1/6 mixing ratio and seri-IIb3 and IIc3 with 1/9 mixing ratio may be defined as thermal insulation material. In a similar study carried out by Karaman et al. (2006), decreases in the thermal conductivity of the samples produced with the increase in the amount of tree leaves and pumice as aggregates added in the gypsum.

On the other hand, TS EN 13162 suggests a compressive strength value greater than 1.02 kg/cm^2 and a bending strength value larger than 0.25 kg/cm^2 for mineral wools as thermal insulator at 10% deformation (Anonymous, 2010). When these values are compared with the values presented in Table 4, both serial samples are considered suitable in terms of compressive and bending strength. However, because of high organic matter content and thus high porosity, their water absorption ratios are quite high. Therefore, moisture insulation should be properly done, if these materials are to be used for thermal insulation purposes. An alternative thermal insulation plates to other insulator can be manufactured in the thickness equivalent to 1.0 cm thick glass wool (Table 5) and may be applied easily and economically in the buildings of rural areas where heat insulation is required. Since the effectiveness of thermal insulation is related to moisture insulation to a large extent, moisture insulation should also be done properly with thermal insulation. Vapour is transported continuously from cool side to the warm side due to the differences in outside and inside temperatures of the buildings, particularly in winters. Since moisture entering into the insulation material deforms its insulation properties, vapour should be broken by brokers before reaching the point of the condensation (Anonymous, 2008b).

Insulation of the walls by the plates produced using organic composites may be done in different ways. However, the types seen in Figure 3 may be proposed due to effective implementation of isolation and ease application. In stone-wall buildings with very high thermal conductivity, internal surface may be covered with insulation plates. As for the brick or briquette wall, for a better thermal insulation a sandwich wall as shown in Figure 3 is suggested. Roofs and ceilings are the other building elements where heat losses occur significantly. Insulation of them may be done as illustrated in Figure 4. In a building, if the insulation is decided as a result of heat balance computation, first of all roof and ceiling insulation is preferred. This is because, the most effective heat bridges occurs at the roof or ceiling due to rising of heated air. Therefore, first, these heat bridges should be broken by heat insulation at these parts of a building. When the roof insulation is not sufficient, then the walls off the building are insulated against heat lost.

Conclusions

In this study, using possibilities of some mineral-bound

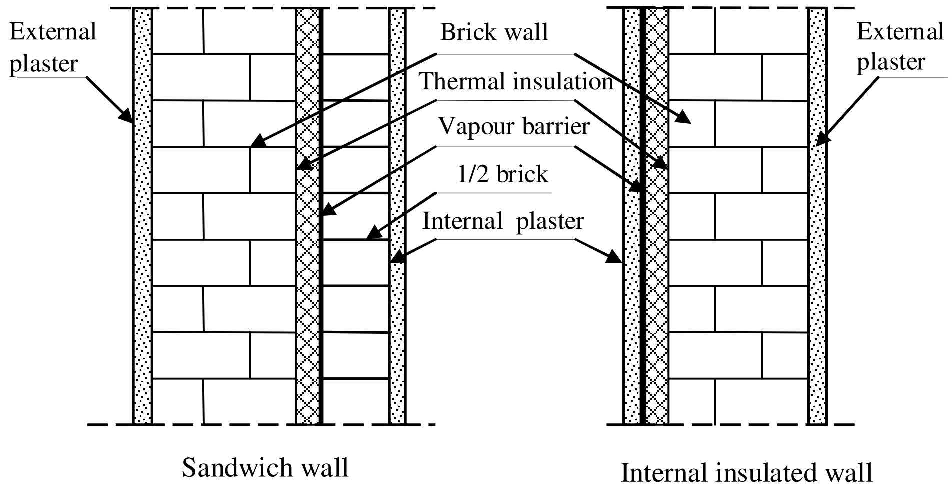

Figure 3. Proposed insulation types for the walls.

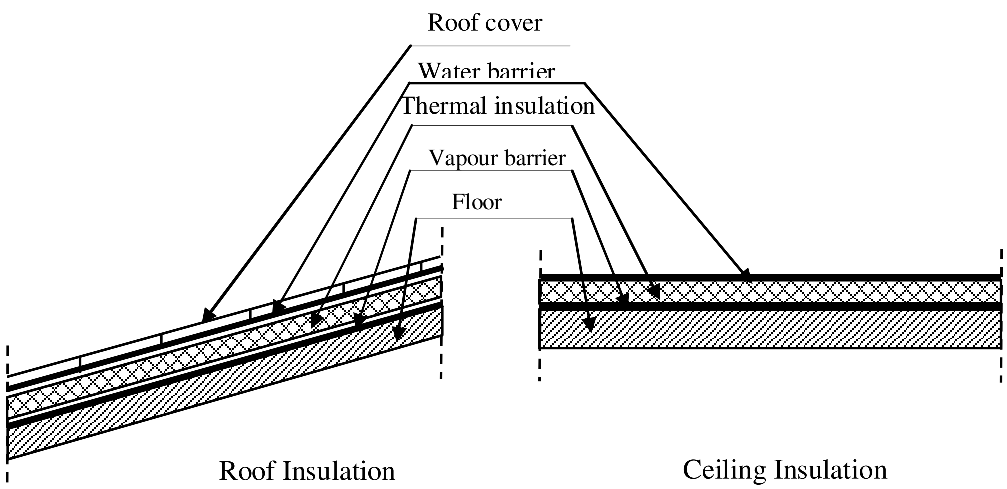

Figure 4. Possible insulation type of roof and ceiling.

organic composites as thermal insulation material in rural buildings were investigated. For this purpose, using RH and ground SS as the main material and cement and gypsum as a mineral-binding material, series I and II samples with the volumetric mixing ratio of 1/3, 1/6 and 1/9 were produced. The following results were obtained from the test done on the produced samples.

1. The unit weights of oven-dry loose and pressed SS were found to be 87.0 kg/m^3 and 310 kg/m^3, respectively. The unit weights of oven-dry loose and pressed RH were 105.0 kg/m^3 and 412 kg/m^3, respectively. Both materials, SS and RH, may be classified as light-weight organic aggregates in terms of their oven-dry unit weights.
2. Gravimetric water absorption ratio of serials-I and II samples varied between 39 and 72% and between 46 and 78%, respectively. When the samples in gypsum-bound serial-I and cement-bound serial-II with the same organic matter content were compared, water absorption ratio of the samples in serial-I was smaller. In general, both serials have high water absorption rate. Therefore, water and moisture insulation should be provided where these composites are used.
3. When the serial samples were compared with each other in terms of unit weight, the unit weight of cement-bound serial-I samples were greater than that of serial-II samples when the same mixing ratios were taken into account. This is because the unit weight of the cement is greater in comparison to gypsum.
4. At 10% deformation, compressive and bending strengths of serial-I samples changed between 32.62 and 6.56 kg/cm^2 and between 6.35 and 1.92 kg/cm^2, respectively, depending on the mixing ratios. Similarly, values between 7.80 and 2.44 kg/cm^2 and between 2.13

and 1.30 kg/cm^2 were obtained respectively for compressive and bending strengths of serial-II samples. These values are greater than the values of an insulation material suggested by TS 825.

5. Thermal conductivity values varied from 0.062 to 0.145 W/mK for serial-I samples and from 0.054 to 0.089 W/mK for serial-II samples. Smaller thermal conductivity values for serial-II in comparison to the serial-I are due to binding materials.

6. For a material to be classified as heat insulator, its thermal conductivity (λ) should be less than 0.065 W/mK as indicated in TS 825 (Anonymous, 2008b). According to this classification, among cement-bound samples, serials-Ib3 and Ic3 with 1/9 mixing ratio; among gypsum-bound samples, serials-IIb2 and IIc2 with 1/6 mixing ratio and seri-IIb3 and IIc3 with 1/9 mixing ratio may be defined as thermal insulation material.

7. In practice, as an alternative to the other insulation material, thermal insulation plates form RH and SS can be manufactured in the thickness equivalent to 1.0 cm thick glass wool and may be applied easily and economically in the buildings of rural areas where heat insulation is required.

8. Since the effectiveness of thermal insulation is related to moisture insulation to a large extent, moisture insulation should also be done properly with thermal insulation. Vapour is transported continuously from the cool side to the warm side, due to the differences in outside and inside temperatures of the buildings, particularly in winters.

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