Assessing of Thermal Conductivity, Physical and Mechanical Properties of Building Insulation Materials Prepared From Waste Materials and Gypsum

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***Abstract*--** In **this work, thermal insulation, physical and mechanical properties are investigated to develop samples with lightweight from waste materials and gypsum. This technique is proposed to improve building insulation by utilizing sawdust, polyethylene and waste paper separately added to gypsum in different added ratio of 6%, 12% and 24% respectively. Samples for these combinations are prepared in order to perform and evaluate the mentioned properties. Experiments results have shown a discrepancy in the behaviors of the prepared samples. It is found, for samples of sawdust and waste paper, that the thermal conductivity decrease with increasing of added ratio while their water absorption content level is high which makes them unsuitable to be used in humid environments. Also, it is observed from the results of compression strength test that failures are obtained for all samples especially for sawdust and waste paper with added ratio greater 24% due to problem of brittle behavior. In general, as a comparison among the tests results of the three samples, it can be concluded that polyethylene added sample provides the suitable thermal insulation, physical and mechanical properties for different environment conditions. The results obtained show the feasibility of the proposed technique which may find a wide range of applications such as an insulator in civil engineering and cooling systems.**

***Index Term*--** **saw-dust, polyethylene, waste paper, building insulation, thermal conductivity, Compressive strength.**

I. INTRODUCTION

Improvement of building insulation against environment temperature variation plays an important role in the design of buildings structures and other applications. The cost of power rising and energy conservation over the past years concerns have prompted the building industry to improve the efficiency of newly built constructions. Since each site has its own unique climatic and topographic characteristics, a considerate response to the site limitations which utilize the natural resources and integrate them into the design will bring about an energy efficient building by insulation technique which minimizes the transfer of heat energy from inside to outside of the building and vice versa, by reducing the conduction, convection and radiation effects [1]-[3]. In this regard, the most important parameter that should be considered in calculating and designing energy consuming of a building is thermal conductivity of building materials. Thus, studying thermal conductivity and other physical and mechanical properties of such materials is of great importance to satisfy above mentioned conditions [4].

Many waste materials such as sawdust, polyethylene and waste paper have hazardous effects on living environmental. For example most of these materials are burnt in open air, resulting toxic gases such CO which is harmful to people health. One of the techniques used to reduce these effects on environment and health risks is to effectively recycle these materials in order to be beneficial in many applications [5][6]. Several researchers have investigated different techniques to develop and fabricate insulating materials using different waste materials. Faiza *et all* [7] investigates the improvement of the physical, mechanical and thermal conductivity properties to produce gypsum boards by using waste materials. Ogunwusi [8] uses wood waste for industrial utilization. In this regards, the main goal is to increase thermal insulation in building construction. Hanifi *et all* [9] investigates using of sawdust and other materials with gypsum to produce engineering composite materials. The purpose is to study the radiation absorption, ultrasonic pulse velocities, and thermal insulation coefficients properties of specimen's structures of these materials. Obam [4] studies the properties of waste materials such as sawdust and waste paper added to starch to produce composite materials used as insulation materials. Recently, solid wastes are utilized in manufacturing building construction materials to reduce the cost and to avoid the harmfulness of waste materials on environment [10].

In this paper, a technique is suggested to prepare materials with low cost and high thermal insulation factors to be used in engineering applications by recycling waste materials such as sawdust, polyethylene (plastic bottles) and waste papers mixed with gypsum. The goal is to reduce energy consuming that may occur with using traditional insulating materials. The materials are prepared using different added ratios of these waste materials compared to reference pure gypsum. Both physical and mechanical properties and thermal conductivity coefficient are investigated experimentally to verify the feasibility of the prepared materials.

II. EXPERIMENTAL PROCEDURE

A series of experiments are conducted to prepare three samples of sawdust with gypsum, polyethylene with gypsum and waste paper with gypsum. Each sample prepared with three different added ratios resulting in three specimens with added ratio of 6%, 12% and 24% respectively. The waste materials used in this research work are available in the local environment as a result of daily people use of disposable materials. Hence efforts are spent to convert sawdust, polyethylene (plastic bottles), and waste paper into the production of materials suitable for walls and ceiling construction and other applications. The experimental procedure is described in the following subsections.

A. Materials

The materials used in this work are described as follows:

1**.** Gypsum is a building material usually manufactured as a dry powder and mixed with water to produce paste which in turn used for coating walls and ceilings. The process of mixing produce heat through crystallization and the hydrated gypsum then hardens in mold. Gypsum has advantages of easy fabrication features, excellent fire properties, cheap in price and environmental friendliness. For these reasons, gypsum is used as matrix material in these mixtures.

2. Sawdust consists of small particles of wood with different sizes. Its properties (both physical and chemical) depend on different parameters such as environment and the way by which it processed. Sawdust particles are collected from saw mill and wood wastes. Also, it can be obtained from carpentry and wood- working. Both physical and chemical tests are performed on sawdust to estimate its suitability for samples preparation. Before mixing, the sawdust is subjected to dry process in the air at room temperature. After that the process of sieving is performed using 1 mm mesh sieve. This is done to remove any undesirable materials in the matrix. The sawdust used in this work is in the range of (4– 16 mm). The usages of sawdust as a partial mixture provides an economic use of the product and consequently produce cheaper materials for low cost building materials as well as light weight [11].

3. Polyethylene is the most common plastic. Plastic bottles are collected as disposable wastes of water and refreshments drinks bottles. Before mixing, they are carefully washed and cut into pieces with dimensions of 1-2 mm. Sometimes it is written poly ethylene terephthalate, commonly abbreviated PET is a thermoplastic polymer resin of the polyester family and is used in synthetic fibers; food and other liquid containers, thermoforming applications. It is a long-chain polymer ($C_{10}H_8O_4$) belongs to the polyesters family Bottles [12].

4. Waste paper**s** are obtained from different resources such as used newspapers and scratch papers. The paper samples are shredded manually and cutting the prepared sampled with dimensions of 2-4 mm. To make waste paper samples smooth and soft, they are immersed into water for a time of one hour at room temperature after dried the water out of the paper by manually squeezing them.

5. Water is used as a liquid to mix gypsum with added waste materials to prepare the pastes. In this work distil water is used for this purpose.

B. The Process for Specimen's Production

Three samples are prepared each with three specimens having different added ratio. These samples are gypsum-sawdust, gypsum-polyethylene, and gypsum-waste paper. Each specimen in the sample is with added ratio of 6%, 12%, and 24% respectively. Hence, a total of 9 specimens are prepared to perform three tests for each specimen of the samples. These tests are thermal conductivity coefficient, compression strength and water content. Gypsum is mixed with each one of the waste materials in the dry state for a given added ratio to prepare the required material by hand, then distil water is added with fixed amount until we obtain paste. The paste is well mixed and casted in cylindrical molds prepared previously, clean and well-oiled in order to prevent sticking of the prepared paste, especially at the edge. The cylindrical mold dimensions are of 2 cm radius and 12 cm length. It should be noted that the entire samples are dried at temperature of 45 ˚C for one day before performing these tests and until constant weight is obtained.

C. Tests Implementation

1. Thermal Conductivity Test

To perform this test, Thermal Conductivity Meter (KD2 Pro Thermal properties analyzer) with sensor probe as shown in Fig.1 is used to study thermal conductivity of each specimen. The dimensions of the prepared samples with hallow cylindrical shape of radius 2 cm and 12 cm in length while the internal diameter of hallow is 0.2 cm. The results of thermal conductivities of the samples for different added rates are displayed in Fig. 2.

Fig. 1. Thermal conductivity measuring device

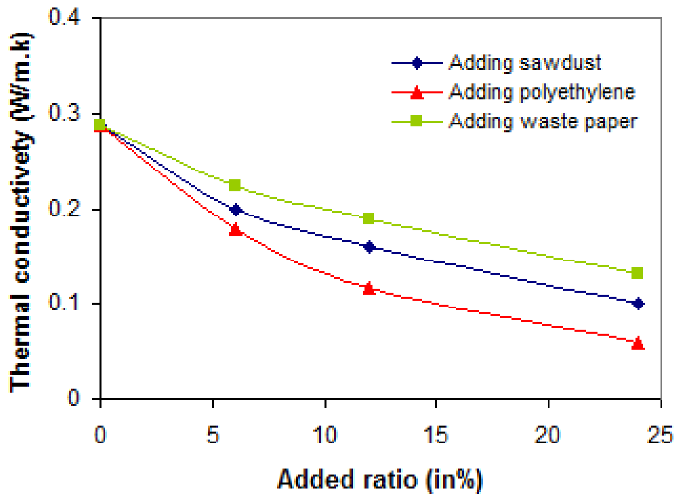

Fig. 2. Variation of thermal conductivity with additive ratio for prepared samples

2. Compression Strength Test

This test is necessary to be performed in order to investigate the compression strength of the prepared samples. In this test the specimens are prepared with solid cylindrical shape of radius 2 cm and length of 7 cm. The load is applied and increased gradually until the specimen fails and record the maximum load carried by the specimen. The test pieces are placed between a supporting base and a flat steel plate. The machine applied a uniform load until the maximum failure load is reached. The maximum load (in Newton) is automatically recorded and the compressive strength is calculated as maximum failure stress per unit area. The results obtained for different rate of adding are displayed in Fig. 3.

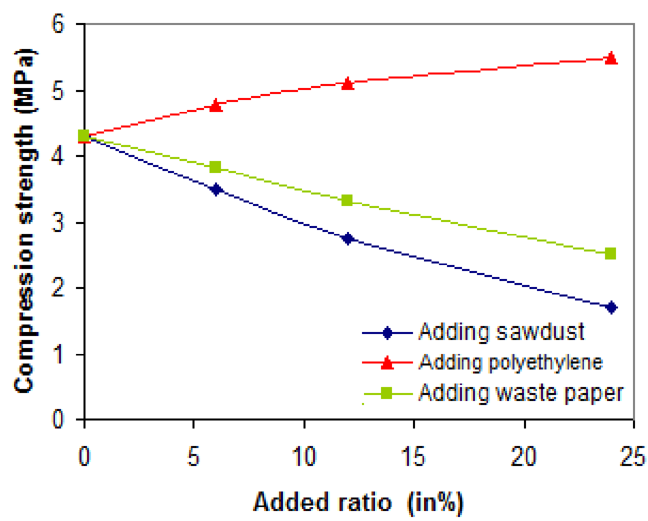

Fig. 3. Variation of compression strength with added ratio for prepared samples

3. Water Absorption Test

This test is carried out to measure water content in the prepared samples. After the specimens are prepared, they are dried using oven at temperature of 45 ˚C for one day (24 hours). The dry specimens are weighed and immersed in water for 24 hours. They are allowed to surface dry then weighed. The moisture content in the specimen is calculated using (1):

$$\%p = \frac{(w_w - w_d)100}{w_w} \qquad (1)$$

Where:

P is the percentage water absorption
Ww weight of wet sample
Wd weigh of dried sample

The results of water absorption test for different added rates of suggested materials are plotted in Fig. 4.

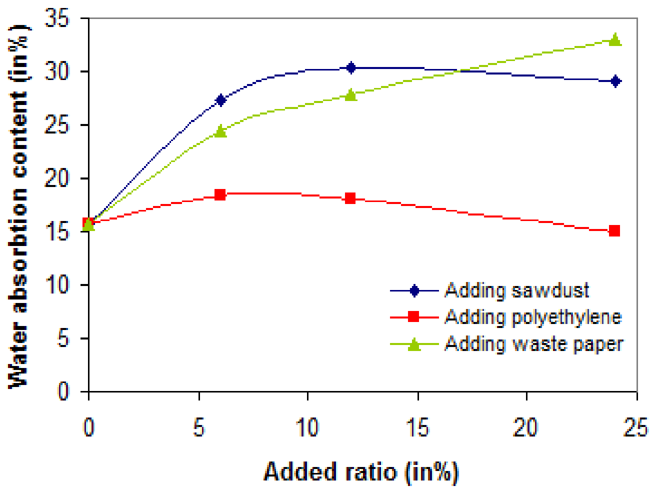

Fig. 4. Variation of water content (in %) with added ratio for prepared samples

4. Density Test

Another test performed on the prepared samples is density test. This test is necessary since the density is a measure of how the material is compact which in turn affects thermal insulation. In general, the density of each sample is determined by its volume and mass. The sample overall dimensions are measured using a digital vernier caliper. Before performing density measurements, samples are dried at 45 ˚C until weight becomes constant. Measurements are made on (9) specimens and their masses are measured. The density of each specimen is calculated using (2)

$$D = \frac{m}{v} \qquad (2)$$

Where:

D is density
m is mass
v is volume

The results of density measurement for 9 specimens are displayed in Fig. 5

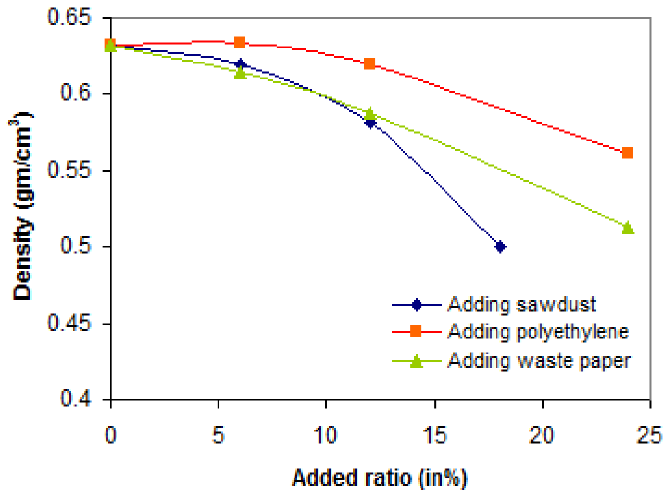

Fig. 5. Variation of density with added ratio for prepared samples

IV. RESULTS AND DISCUSSION

Results of test of different parameters of the prepared samples are plotted in Figures 2, 3, 4, and 5 respectively. Figure 2 shows variations of thermal conductivity of the three samples with waste materials added rate in percent. It is clear from the figure that the thermal conductivity decreases with increasing of the added ratio for the three samples. Also, polyethylene added sample has the lowest thermal conductivity as compared to both sawdust added sample and waste paper added sample respectively. This is due to that the thermal insulation for polyethylene is higher than that for sawdust and waste paper. It is to be noted that the maximum value of added rate for three samples in this work is found to 24%. For more than this rate value, it is found that a failure will happen especially for sawdust and waste paper added samples because that the compaction ratio of these samples is reduced by increasing added ratio over than 24%.

In order to get a better insight into the ability of the prepared samples to different load conditions, compression strength test is performed (in MPa) for three samples and the results are plotted in Fig.3. The figure shows that the compression strength for polyethylene added sample increases with increasing added ratio. Also, the compression strength for polyethylene added sample has behavior better than that for sawdust added sample which in turn provides behavior better than that for waste paper added sample. This is may be due to that the smooth surfaces of polyethylene substance improve the bonding in the network of the materials. This leads to that the compaction density of polyethylene added sample is higher than that for sawdust and waste paper respectively. Moreover, the small pieces of polyethylene may fill many gaps between gypsum and within them each other, thus enhancing compression stress transfer between both materials. Figure 4 shows variations of water absorption for three prepared samples for different added rates in percent. It can be observed that the water absorption rate for sawdust is higher than that for waste paper which in turn higher than that for polyethylene. This may be due to that the absorption rate for sawdust is higher than that for both waste paper and polyethylene added samples especially at small and moderate added rates. For high added rate the absorption rate for waste paper is higher than that for sawdust. This is because that sawdust reaches the saturation limit while the waste paper sample is cellulose material which increases its ability to absorb water. The variations of the calculated density with added rate for the three samples are plotted in Fig. 5. From the figure it can be observed that the density for all samples decreases with increasing added rate because all the added materials have a light weight. Also, it is clear that added polyethylene sample records the highest levels of densities as compared to those of added waste paper and sawdust samples respectively. Moreover, it is clear from the figure that for high added rate (more that 6% added rate) the density of sawdust sample decreases rapidly compared to those of waste paper and sample and polyethylene sample. This is due to that sawdust waste behaves as fibrous substance in the mixed materials and this improves the bonding between sawdust and gypsum whilst reducing density of the samples. It is to be noted that several research works investigated adding of different waste materials with different added rates and test conditions to improve thermal conductivity, physical and mechanical properties of gypsum boards in building among them [4][7][13].

V. CONCLUSION AND RECOMMENDATIONS

With the evident advances in building constructing technology especially in improving energy consuming, makes researchers spend great efforts in order to develop new materials which provide high degree of thermal insulation with low weight and price. This goal is achieved by utilizing waste materials or disposable materials which in turns improve environment health hazards and this is one of the stated goals of this work. In this paper efforts have been made to convert sawdust, polyethylene and waste paper added with gypsum to develop materials with suitable thermal insulation and other physical and mechanical properties as compared with the standard gypsum material (without added). From the results of different tests, it can be concluded that:

1- Gypsum samples can be prepared as light weight by adding of sawdust, polyethylene and waste paper with ratio 6%, 12%, and 24%.of specific weight of gypsum.

2- Thermal conductivity of samples can be decreased when added ratio increased. The lowest rate of thermal conductivity coefficient is at 24% added rate of polyethylene where the thermal conductivity coefficient decreases from 0.287 W/m.K to 0.06 W/m.K.

3- For the waste materials used in this research work, it is found that the compression strength for polyethylene increases with increasing added ratio from 4.77 MPa at added rate of 6% to 5.5 MPa at added rate of 24% while for both sawdust and waste paper the compression strength decreases with increasing added ratio.

4- Water absorption content of both sawdust and waste paper samples can be increased when added ratio increased while for polyethylene water absorption content is decreased when the added ratio increased.

In general, among the three prepared samples, the most suitable sample which provides the required thermal insulation, physical and mechanical properties, is polyethylene. For both sawdust and waste paper samples, although they have low thermal conductivity, but their water absorption contents are high. To solve this problem, it is suggested to perform chemical curing [14]. The results obtained from this study suggest that it is possible to fabricate building materials to any desired thermal insulation factor depending on the waste material used with any added percent for a certain environment. The results obtained in this paper are in close agreement with those obtained in [4][7].

The prepared samples may find a wide range of applications including production of boards to be used for walls and ceilings for the purposes of decoration, Painting and thermal insulation.

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