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Waste Epoxy Moulding Compound as a Composite Gypsum Ceiling Board for a Sustainable Potential

Wee Pi Boon[1], **Hasnida Harun**[1]*,

[1]Department of Civil Engineering Technology,
Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Muar, Johor, MALAYSIA

*Corresponding Author Designation

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Abstract: Epoxy moulding compounds are polymer-based encapsulation materials often used in electronic packaging. In recent years, the increasing electronic component output has resulted in a significant rise in the production of epoxy moulding compounds as industrial waste from the moulding process of electronic components packages. Therefore, this study investigated the potential of the waste epoxy moulding compounds as a composite gypsum ceiling board to reduce gypsum use. It is in conjunction with the concept of a circular economy, which focuses on optimizing resources, reducing the consumption of raw materials, and recovering waste by recycling by giving it a second life as a new product. The composite materials were developed by a mixing method according to the proportion of the epoxy moulding compounds and the gypsum. Mixed proportions with five different percentages of epoxy moulding compounds, which are 0%, 5%, 10%, 15%, and 20%, were prepared and cast in an aluminium mould size of 10cm x 10cm x 1.27cm. The sample's properties were analyzed for thermal conductivity, sound absorption, and water absorption. Hence, the optimum proportion of the composite gypsum ceiling board was identified, and the best results were 20% waste epoxy moulding compound and 80% gypsum for the better value of physio-mechanical properties of the composite materials. The result showed that the good thermal conductivity is 0.21W/m˚C, the maximum sound adsorption coefficient is 0.483 at 2000Hz, and the minimum water absorbency is 31.4%. Therefore, exploring innovative recycling approaches might reduce material waste and repurpose them as beneficial secondary products.

Keywords: Epoxy Moulding Compound, Gypsum Ceiling, Circular Economy, Composite Ceiling Board, Electronic Waste

1. Introduction

Electronic components, such as integrated circuits and microelectronic devices, are the building blocks for almost all electronic goods and are generally encapsulated by epoxy moulding compounds

**Corresponding author: hasnidah@uthm.edu.my*

(EMC). EMC is among the most often utilized materials in the electronic packaging sector among all the many types of polymer-based encapsulation materials due to their exceptional performance in adhesion, chemical resistance, and modulus. Compared to traditional encapsulating materials like metals and ceramics, the advantage of polymer materials is their low cost and suitability for mass production. The reliability of polymer encapsulating materials is no longer a key concern because of advancements in polymer technology. In microelectronics encapsulation, EMC contains more than ten ingredients. EMCs typically have 10–20% epoxy and hardener, strengthening the adhesion and creating a crosslinking polymer network. A significant loading of filler, typically more than 70%, is added to EMCs to lower the thermal expansion coefficient, which offers a greater modulus, and reduces the compounds' moisture absorption. [1]

Additionally, the finished items contain a variety of additional additives. For instance, silane coupling agents are frequently utilized to enhance the interface between the polymer matrix and the filler. It improves the compatibility of the silica filler in the compounds. Flame retardants are used to reduce the overall flammability of the compounds, whereas catalysts are employed to encourage the curing process of epoxy and hardeners. EMC is cured at an elevated temperature during the encapsulation process and enclosed in the integrated circuit chip with EMC residue produced. Furthermore, since the EMC residue is non-consumable and non-recycle materials for the process, it is very important to find ways to recycle them besides directly disposing of them in landfills. Increased electronic component output in recent years has resulted in a significant rise in the amount of EMC produced as industrial waste in the moulding process of electronic component packages. However, reusing this residue has proven problematic because the epoxy resin has a network structure that prevents remoulding [2].

Traditionally, most of the residue is disposed of in landfills or incinerated without reusing, polluting the environment and wasting resources. In recent years, significant efforts have been made in waste electric and electronic equipment disposal, particularly nonmetal recycling research.

A transition to environmentally friendly industrial and economic development and sustainable sociotechnical systems has become urgently necessary in recent decades. The unsustainable use of natural resources and the current state of the ecosystem have significantly stressed the Earth's life-support systems. Some of the most serious environmental issues encountered and extensively researched in recent decades include biodiversity loss, resource waste, soil desertification from excessive land use for food production, rising urban air pollution, ocean plastic pollution, and dramatic climate changes. A circular economy becomes a tool for sustainable development if circular initiatives improve sustainability outcomes. The shortage of natural resources necessitates the switch from a linear to a circular economy. This transformation in perspective mostly affects the industrial sector, which bears a heavy burden in creating new goods and machinery that must be recycled or recovered at the end of their useful lives. As a result, researchers are intensifying their work on waste streams from industries to repurpose them as secondary raw materials in production processes. Political, social, environmental, economic, and technical actions that are targeted and courageous are required. The circular economy is a model for new economic development and proposes a shift from the current model of production and consumption, which is based on "end-of-life" principles, to the new model. The new model aims to reduce resource use while recycling and reusing different materials and products throughout all production, distribution, and consumption stages [3].

Gypsum is a substance that is commonly used in civil engineering. It is often applied in the form of plasterboards without any reinforcement. It is most frequently used for ceilings because it is lightweight, flexible, fireproof, and moisture-resistant. Gypsum board, a widely used ceiling material, has existed since the 1960s. Gypsum is a mineral classified as calcium sulfate dehydrate $CaSO_4{}^2H_2O$ found in sedimentary rock formations.

Moreover, gypsum board is often called drywall or plasterboard and is distinguished from materials like plywood, hardboard, and fiberboard by its noncombustible core. When placed with standard treatment compounds, it gives a monolithic surface. The building material gypsum board is incredibly light, low density, simple to install, and has strong mechanical and thermal properties. Nowadays, gypsum boards are taking place of traditional plaster since they are a practical option. In offices and homes, they are frequently utilized to cover the interior walls and ceilings. Gypsum board offers several advantageous qualities, such as being fire and water-resistant and acting as heat and sound insulation. Therefore, this study intends to explore the utilization of EMC, an abundant residue from the electronic industry in a widely used gypsum, into useful production of composite gypsum ceiling boards, thereby converting waste to wealth and improving the properties of existing gypsum boards. [4]

2. Materials and Methods

2.1 Materials

Epoxy Moulding Compounds (EMC) residue was collected from a semiconductor company, ST Microelectronics Sdn. Bhd., Muar, Johor, Malaysia. The EMC residues are in a crushed form with a 0.3 to 0.5cm size and black in color. Indeed, based on the result from Energy dispersive X-ray (EDX) had shown in Table 1, the chemical composition of EMC is a good result for functioning as a filler to replace gypsum and could strengthen the properties of composite materials. Meanwhile, the gypsum powder was manufactured by PYE Products (M) Sdn Bhd and was purchased from a local supplier was used.

Table 1: Chemical composition of EMC

Chemical composition	Percentage, %
Oxygen, O	44.79
Carbon, C	29.06
Silica, Si	25.87
Sodium, Na	0.14

2.2 Method

In this study, the crushed EMC is ground into powder form to ensure good workability during the mixing process to develop the composite material. Meanwhile, for the mixture of gypsum, a 2:1 ratio of gypsum to water is used as the ratio was tested to have good workability and strength. A square aluminium plate mould is used to cast the composite gypsum ceiling board. The aluminium mould is designed with a size of 10cm x 10cm x 1.27cm as illustrated in Figure 1.

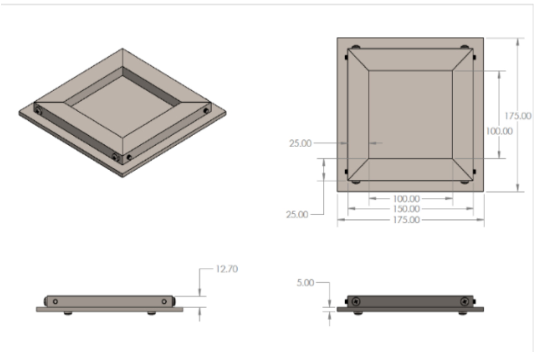

Figure 1: The schematic diagram of the design of the square aluminium plate mould

The mixing process of the composite materials is shown in Figure 2. After the casting process, the mixture of gypsum and EMC is rested at room temperature until the mixture hardens. As the EMC is used to replace the gypsum in the composite gypsum ceiling board, the best mixture between gypsum and EMC is determined. Then the developed composite by the mixing method is examined for water absorption, thermal conductivity, and sound absorption based on the American Society for Testing and Materials (ASTM) procedures and International Organization for Standardization (ISO).

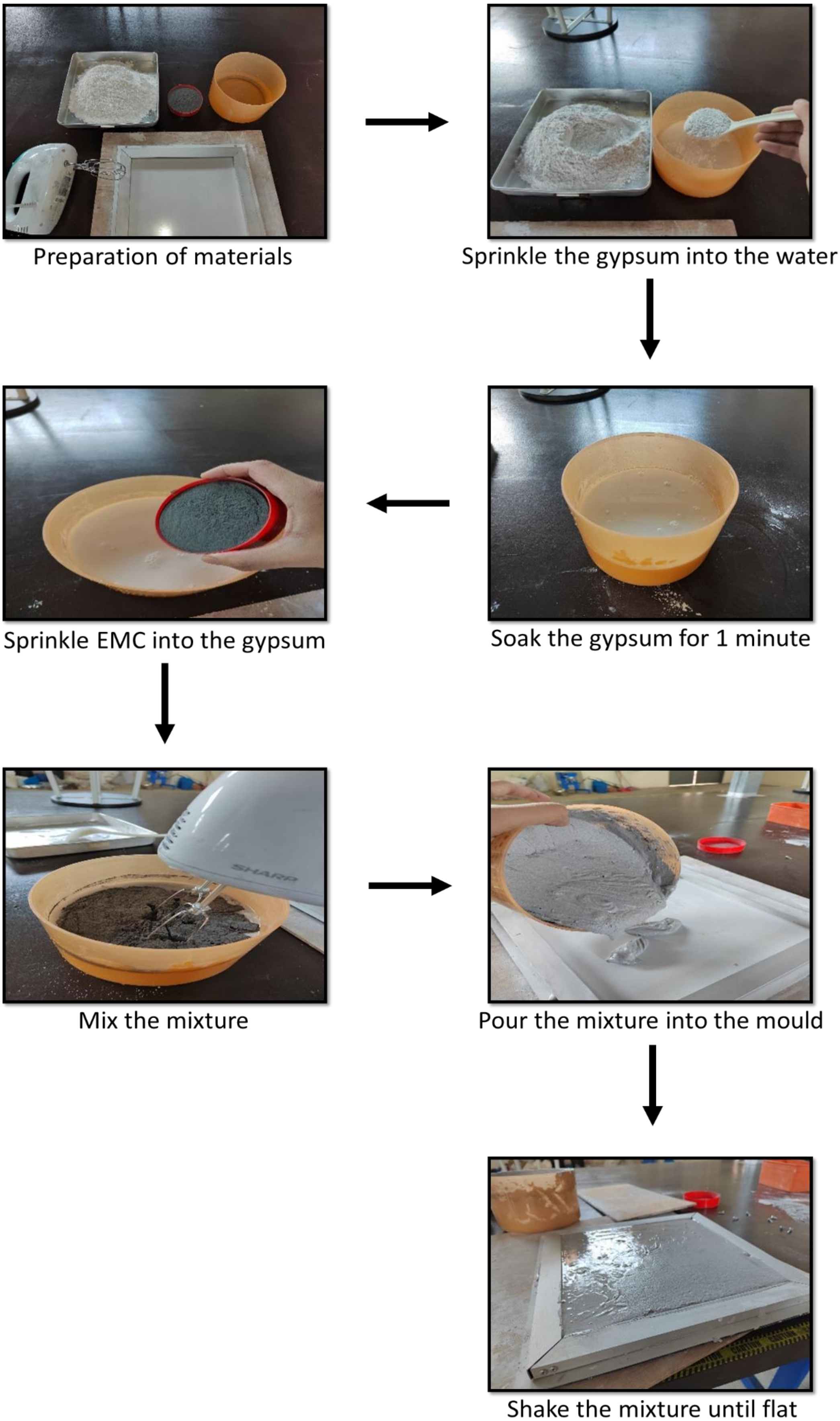

Figure 2: The mixing process of the composite gypsum ceiling board

2.3 Optimization of Composite Gypsum Ceiling Board Composition

The EMC and gypsum are mixed in a prescribed proportion by percentages. The mixing process is carried out in a plastic container and stirred until achieved a homogenous state before the moulding process. The composite materials are mixed according to the five different percentages of gypsum and EMC where 0%, 5%, 10%, 15%, and 20% of EMC. Table 2 shows the details percentage proportion of gypsum and EMC used in determining the best proportion of the composite materials.

Table 2: Percentage proportion of gypsum and EMC

Percentage of Gypsum (%)	Percentage of EMC (%)
100	0
95	5
90	10
85	15
80	20

2.3.1 Water Absorption

ASTM C 473, the standard test method for the physical testing of gypsum panel products is referred to for water adsorption testing procedures [5]. The composite materials with a size of 10cm x 10cm x 1.27cm are submerged in a water tank for two hours at room temperature. The percentage of water absorption was determined by using Equation 1 where W_t and W_o represent the final and initial weight of the sample respectively.

$$\%W= \frac{W_t - W_o}{W_o} \times 100\ \% \qquad \text{Eq (1)}$$

2.3.2 Sound Absorption Coefficient

According to ISO 10534, a standard to determine sound absorption coefficient, a sample is mounted at one end of a straight, stiff, smooth, and airtight impedance tube [6]. A tube size of 100mm is used to test the absorption for a low frequency (600Hz and below) and for high frequency (1000Hz and above), a tube size of 28mm is used. A sound source produces plane waves inside the tube, and the sound pressures are measured at two points close to the sample. The normal-incidence complex reflection factor, the normal-incidence absorption coefficient, and the impedance ratio of the test material is calculated using the complex acoustic transfer functions of the two microphone signals.

2.3.3 Thermal Conductivity

The SOLTEQ thermal conductivity (Model: HE110) of the building materials apparatus has been used to identify the thermal conductivity of the composite gypsum ceiling board. The square plate test materials are put between the electrically heated heating plate and the water-cooled cooling plate. All measurement is presented on digital indicators. The heat transfer rate is measured using a thermal sensor. The heat transfer rate and temperature differential are used to calculate thermal conductivity as shown in Equation 2.

$$k = \frac{qx}{A(T_1 - T_o)}, \qquad \text{Eq (2)}$$

where q is the heat flow density (W/m^2); x is the thickness of the samples (m); A is the area of the sample (m^2); T_1 is the hot plate temperature (˚C), and T_o is the cool plate temperature (˚C).

3. Results and Discussion

3.1 Water Absorption Test

Based on Figure 3, it can be observed that the percentage of water absorption decreases as the amount of the EMC mixed into the gypsum increase. The sample with 100% gypsum obtains the highest percentage of water absorption which is 37%. Besides, for the gypsum mixed with 5%, 10% and 15% of EMC, the percentage of water absorption is 35.0%, 32.9%, and 31.8% respectively. While gypsum which mixes with the highest percentage of EMC, 20%, hits the lowest percentage of water absorbed, 31.4%.

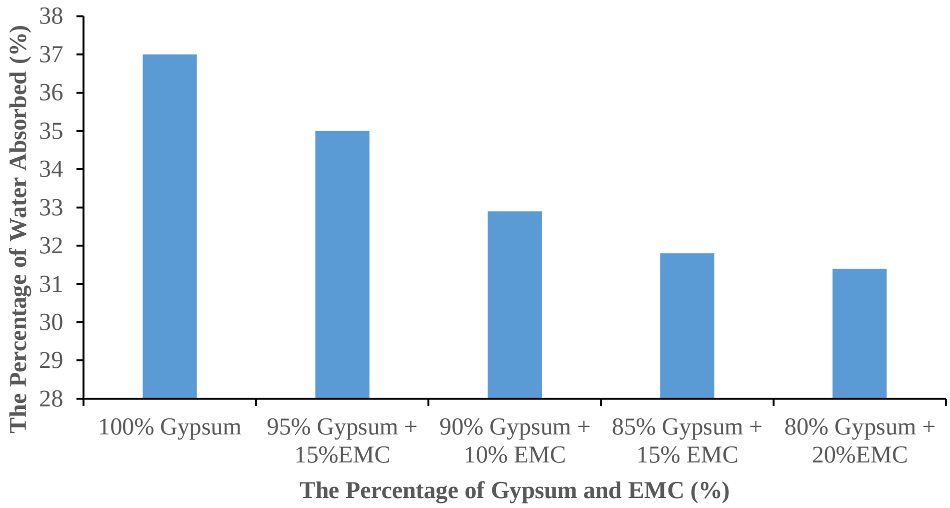

Figure 3: The percentage of water absorption at different percentages proportion of gypsum and EMC

The decreased percentage of water absorption when EMC is mixed might be due to the number of voids decreasing. Gypsum might have a porous property due to the mixing method, water-powder ratio, evacuation of air during or shortly after mixing, and the process of dihydrate. [7] As a result, when the samples are submerged in a water tank, the water will seep into the pores and result in a high percentage of water absorption. It is proven that the sample with 100 % gypsum has a lot of air bubble pop up as shown in Figure 4. When EMC is added to the gypsum, it decreases the quantity of porous water because EMC can act as a filler and occupy the pore in the gypsum mixture. It can be seen by less burble popping out at the surrounding of the samples. As a result, the existence of EMC in the gypsum could decrease the water absorption of the samples.

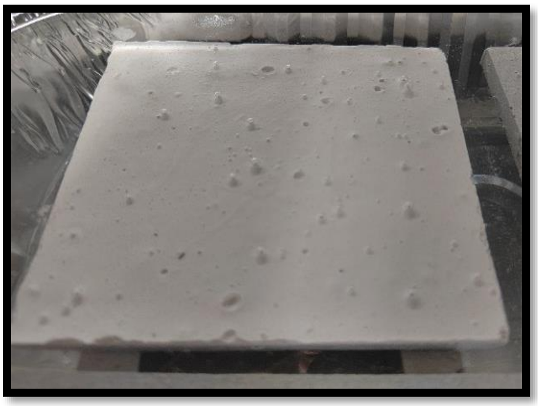

Figure 4: Observation of air burbles that pop out from the 100% gypsum sample

According to ASTM Test 1396, actual testing has shown that water absorption rates of about 40% are typical when gypsum board core material is submerged in water for two hours [8]. Therefore, it shows that the percentage of water absorption for our sample with 100% gypsum is 37%. Hence, we can conclude that the water absorption of gypsum samples was good. That is because the lower the water absorption the better the sample is.

According to the physical properties of other types of ceiling board materials [9], the percentage water absorption for the sample with 80% gypsum and 20% of EMC is 31.4% which is above the standard for asbestos ceiling boards. Therefore, it represents a bad result but it is a good result when compared with fiber cement flat sheet and trilite board ceiling board, and WP/RH composite ceiling board.

3.2 Sound Absorption Test

Figure 5 shows the sound absorption coefficient for different percentages of gypsum and EMC at different frequencies. The sample with 100% gypsum had the lowest sound absorption coefficient at the frequency 125 Hz and 2000 Hz while the sample with 80% gypsum and 20% EMC had the highest sound absorption at the frequency 125 Hz and 2000 Hz.

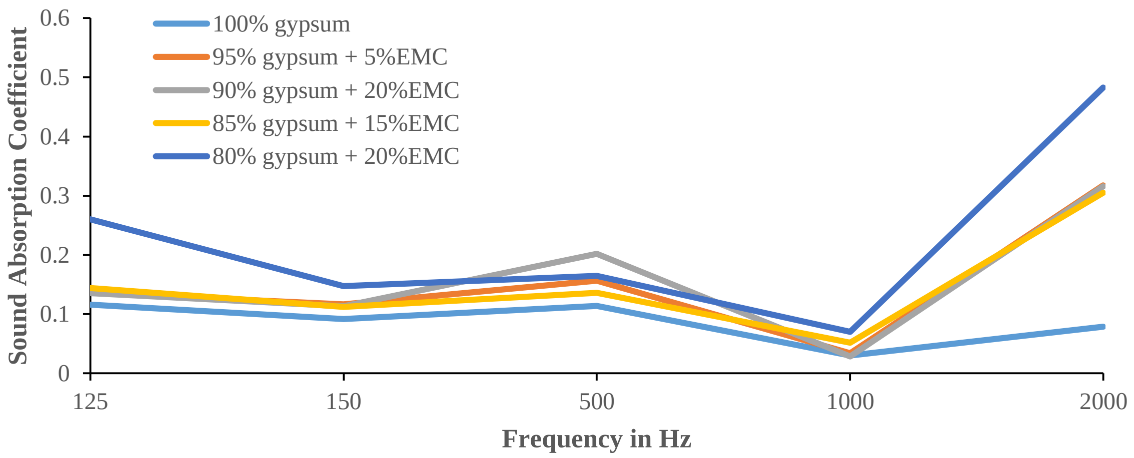

Figure 5. The sound absorption coefficient with different percentages of gypsum and EMC at different frequencies.

The increase of the sound absorption coefficient when the existence of EMC in the composite materials mixture was due to the size and quantity of pores in the sample. That is because smaller sizes of pores can improve sound absorption. Material with larger pores, on the other hand, has a poor sound absorption function. Therefore, when the EMC is mixed with gypsum, the pores of the samples will become smaller. Hence, the sound absorption coefficient increases as the amount of the EMC increases in the composite material mixture.

Malaysian standards are based on the Acoustical Society of America (ASA) [10]. Thus, the Acoustical Society of America's data has served as a guideline to produce of all types of panels, including composite panels, whose effectiveness is achievable and can be classified as acoustic material within the building.

Based on ASA, the sound absorption coefficients of the resulting gypsum ceiling board are below the standard of gypsum wallboard at frequencies 125Hz, 500Hz and 1000Hz. Therefore, it represents a bad result because the higher the sound absorption, the better the sample is. In contrast, it is a good result when it comes to 500 and 2000 Hz. The sound absorption coefficients for the sample with 80% gypsum and 20% of EMC have a bad result because it is below the standard when compared to fiberglass wall panels and glass fiber ceiling tiles, but it is a good result when compared to gypsum wallboard, plastic wall and concrete block.

3.3 Thermal Conductivity Test

Figure 6 shows the thermal conductivity of the composite material mixture at 50˚C. The samples with 100% gypsum achieved the highest thermal conductivity which is 0.34W/m˚C. The thermal conductivity of the sample is slightly decreased when the amount of EMC in the mixture increases. The sample with 20% of EMC obtains the lowest value of thermal conductivity which is 0.21W/m˚C.

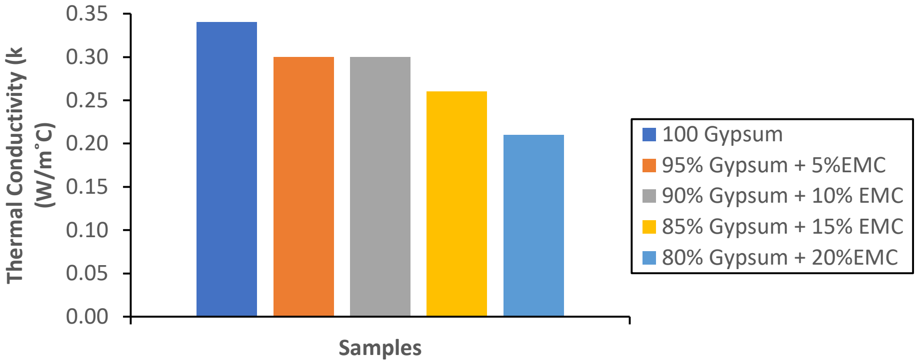

Figure 6: The thermal conductivity with different percentages of gypsum and EMC at 50˚C

The decrease in thermal conductivity when EMC is added is due to the porosity of samples. The number of voids or pores, which is more closely related to the density and the board's assistance in transporting heat to the others, are the factors that affect the thermal conductivity of the materials. Conversely, if the number of voids or pores in the finished board were reduced, the thermal conductivity values of the materials would also be decreased. [11] As a result, we can conclude that when the EMC is mixed into the gypsum, it occupies space and reduces the number of voids. Hence the thermal conductivity of the samples decreases when the amount of EMC increases.

According to the thermal conductivity of gypsum samples at room temperature by other researchers [12], the thermal conductivity for the resulting sample with 100% gypsum, 0.34 W/mK showed a bad performance when compared to Type C (USA), Type X (USA), Type F (Japan) and Type R (Japan) which obtain a thermal conductivity 0.276 W/mK, 0.252 W/mK, 0.238 W/mK, and 0.292 W/mK respectively. That is because, the lower the heat conductivity, the better the sample is.

According to the physical properties of other types of ceiling board materials [9], the thermal conductivity for the sample with 80% gypsum and 20% of EMC is 0.21 W/mK which shows a bad result when compared with asbestos ceiling board, trilite board and WP/RH composite ceiling board. The result 0.21 W/mK only shows a good result when compared with fibre cement flat sheets.

4. Conclusion

Based on the result and discussion, we can notice that the quantity and size of the voids or porous are closely related to the thermal conductivity, sound absorption and water absorption of samples. It is recommended to choose a ceiling board with lower heat conductivity, lower water absorption and higher sound absorption. Therefore, the samples with 20% EMC added to the gypsum showed the best properties for ceiling boards. There also show very strong properties when compare with others ceiling boards.

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