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Investigating the Physical Properties (Density and Profile Density Distribution) of Gypsum Samples Using CT scan Technique

A graduation project submitted to the Department of Physics in partial fulfillment of the requirements for the degree of Science in Applied Physics

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μ : linear attenuation coefficient

μ_w: the linear attenuation coefficient of water.

CT: Computed Tomography .

HU: the Hounsfield unit of CT.

ρ: Density.

K: is a magnification contrast (=1000) .

I: initial intensity.

I: its intensity after passing

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ABSTRACT

The profile density distribution has such a significant impact on gypsum board performance that characterizing it is still difficult in many ways. Currently, industry procedures for quality control rely on destructive evaluation techniques which are inefficient and costly. Therefore, it is important need a reliable and fast means to assess the quality of each gypsum board without affecting the structural integrity of the material. In this work, the profile density distribution was estimated using an X-ray computed tomography (CT) scanner. The nine different types of gypsum board samples were prepared for this study. The CT results indicated that there is difference in the density distribution of the samples. The results showed that sample S1 (Water proof, Saudi Arabia), and S3 (Fire proof, Saudi Arabia) are more homogeneous in term of density distribution with coefficient of variation (COV) of 2.778 % and 2.776 %, respectively. In addition, the linear attenuation coefficient of test samples in the CT scan photon energy was calculated and within the range of (0.432 cm^{-1} – 0.341 cm^{-1}). This indicates that CT scan has possibility to measure the attenuation property at specific diagnostic energy.

دراسة الخواص الفيزيائية (الكثافة وتوزيع كثافة المقطع) لعينات الجبس باستخدام تقنية التصوير المقطعي المحوسب

الملخص

التوزيع الكثافي للمادة له تأثير كبير على اداء لوح المادة، توصيف هذه الخاصية ما زالت صعبة في نواح كثيرة. حاليا، الإجراءات المستخدمة لمراقبة الجودة في صناعة تعتمد على تقنيات التقييم المدمرة التي هي غير فعالة ومكلفة. و بالتالي، فإنه بحاجة الى وسيلة مهمة موثوقة وسريعة لتقييم جودة كل عينة من دون التأثير على السلامة الهيكلية للمادة. في هذا العمل، اختلاف التوزيع الكثافي قد قدر بإستخدام الأشعة السينية التصوير المقطعي (CT). بالنسبة للعينات أستخدمت تسع انواع من عينات الجبس. أشارت نتائج التصوير للاشعة المقطعية ان هناك اختلاف في تباين التوزيع الكثافي للعينات. . أظهرت النتائج أن العينة (S1مقاومة للماء، المملكة العربية السعودية)، (وعينة S3 مقاومة للحريق، المملكة العربية السعودية) أكثر تجانسًا من حيث توزيع الكثافة مع معامل التباين (COV) 2.778% و 2.776 ٪ على التوالي. كما حسبت معامل التوهين الخطي لعينات الاختبار في طاقة فوتون المسح المقطعي المحوسب وفي حدود (0.432 سم$^{-1}$ – 0.341 سم$^{-1}$) وهذا يدل على أن المسح المقطعي المحوسب لديه القدرة على قياس خاصية التوهين عند طاقة تشخيصية محددة.

CHAPTER 1
INTRODUCTION

1.1 Introduction

Density is a characteristic of materials. Density is defined as the mass of a substance per unit volume, given in measurements such as kilograms per cubic meter (kg/m^3) or grams per cubic centimeter (g/cm^3). The significance of density in material characterization lies in its ability to distinguish materials and compounds. Designing and optimizing compounds Understanding density is important for improving material quality [1]. Density is essential for assessing the strength and stability of solid materials and serves as a fundamental component in the advancement of scientific and commercial applications. Methods for calculating density include direct measurement, Archimedes' principle, density measuring techniques, and X-ray or neutron diffraction. The process is selected depending on many parameters, including the material type and the necessary precision [2].

The density profile is one of the key characteristics used to assess the quality of material processing. It indicates how symmetrical the material is and how evenly it is distributed, showing whether it is homogeneous. Even though the variation in profile density significantly influences the board's performance, determining this variation remains challenging in many aspects. The quality control procedures currently used in the industry depend on destructive evaluation techniques, which are not only ineffective but also costly and require a lot of labor. It's vital to have a reliable and quick way to check the quality of each board while maintaining the material's structural integrity [3]. X-ray scanning technology seems to have a lot of potential for offering a reliable and efficient way to continuously evaluate boards during production. However, the use of this technique to measure the profile density of board samples is relatively new and requires further research and analysis.

A CT scan helps doctors look inside the body. It combines X-rays with a computer to produce images of organs, bones, and other tissues. It provides more detail compared to a standard X-ray. A narrow X-ray beam is used that circles around a specific part of the body (Figure 1.1). This shows a collection of images taken from various perspectives. A computer takes this information to produce a cross-sectional image and to create a representation of the tissue density in a “slice” through the inside of the patient's body [4].

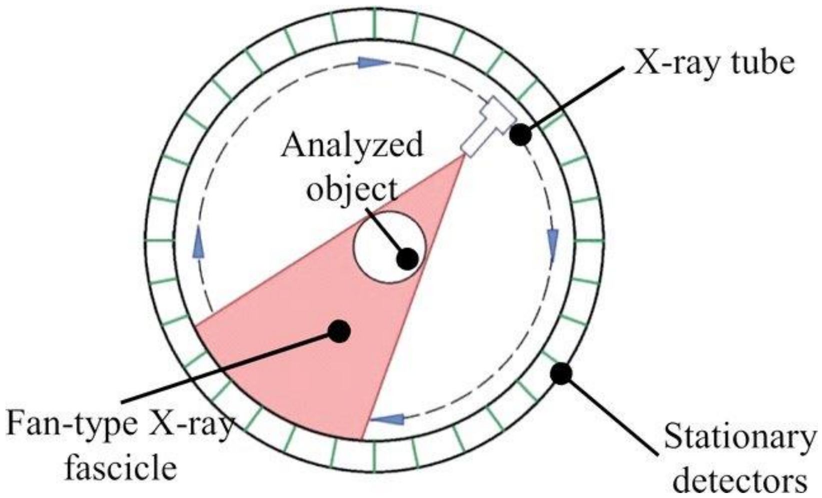

Figure.1.1 Working principle of the CT scan [5]

According to Fromm et al. [6], X-ray CT can measure the internal properties of wood in plants. Some authors [7, 8] have discussed CT scanning of wood, indicating that the CT system has the ability of identifying defects in logs and measuring wood density without causing damage. This study involved the use of nine different types of gypsum board samples that are commonly used in wall construction. In this experiment, we created a density distribution plot using an X-ray computed tomography (CT) scanner. The linear attenuation coefficients of the gypsum bared samples were also measured using CT data.

1.2 Objectives

The aim of this study is to show that the Computed tomography (CT) scan has good potential to provide reliable and effective evaluation of the profile density distribution.

The specific objectives of this study were:

1- To measure the density of gypsum board sample with different types and prepared in the form of cubes.
2- To study the profile density distribution of gypsum samples with different types using CT scan.
3- To calculate the linear attenuation coefficient of samples by using CT scan data.

1.3 Structure of project

Chapter 1 provided a brief introduction to the concept of profile density, as well as an overview of the significance of utilizing computed tomography (CT) in the process of evaluating profile density. In addition, the objectives of this project are outlined in the following paragraphs. The theoretical background, which is connected to the interactions of radiation with matter, is presented in Chapter 2. In addition, each and every formula and unit of measurement for the linear attenuation coefficient that is utilized in this investigation will be described individually. Subsequently, the materials and technique utilized in this study will be addressed in Chapter 3, which will follow. This chapter covers the broad concepts of the characterization and the details of the simulation for the CT scan experiment. Examples are provided throughout the chapter. The density measurement, the profile density distribution, and the attenuation property tests are all included in these testing procedures. In Chapter 4, the findings of the profile density distribution for gypsum-bared samples of various kinds are provided, along with a discussion of the results. In addition, the findings of the density and linear attenuation measurements applied to the test materials will be discussed in this chapter. Finally, the conclusion of this project is offered in Chapter 5.

CHAPTER 2
THEORETICAL BACKGROUND

2.1 X-ray and Gamma ray

Radiation refers to the transfer of energy through waves or particles. It is typically categorized by its energy levels as either ionizing or non-ionizing. Ionizing radiation has enough energy to remove electrons from atoms or molecules. This category includes gamma rays, X-rays, and the higher-energy portion of ultraviolet radiation within the electromagnetic spectrum. Gamma rays (γ) are highly penetrating electromagnetic radiation emitted from the decay of radioactive atomic nuclei. X-rays consist of photons with energies ranging from approximately 10 eV to 100 keV. They can be produced naturally when electrons transition from higher-energy orbits to lower ones (characteristic X-ray emission) or through Bremsstrahlung interactions between electrons and nuclei [9].

2.2 Photoelectric Effect

When electromagnetic radiation (X-ray) is incident on metal, there will be an interaction between the atom and X-ray. This interaction will give me three phenomena: the photoelectric effect, Compton scattering, and pair-production. As a CT scan was used in the study, the effect is dominant at low photon energies; the interaction is a photoelectric effect. Thus, surface electrons are bound to metals with a small amount of energy. Some of the incident photons enter the surface, collide with atoms of the metal, and are totally absorbed. They give their energy to an electron, which, if the absorbed energy was substantial enough, then breaks free from the atom. The photoelectric effect is the result of collisions between photons and electrons that knock the electrons out of the metal, as shown in Figure 2.1 [10].

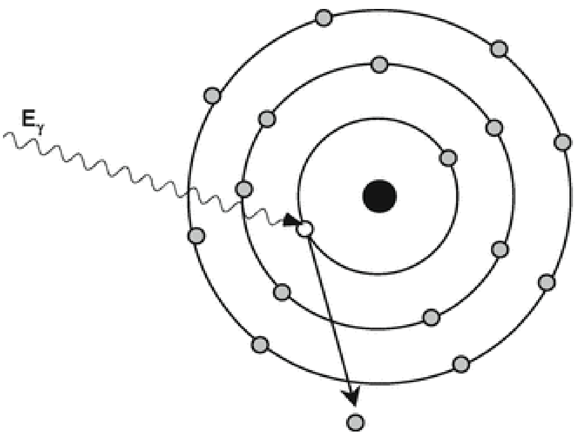

Figure 2.1: Photoelectric Effect [10].

2.3 Linear Attenuation Coefficient

The probability that a photon will pass through a medium without interaction of any kind is the product of the probabilities of survival of each interaction. Hence, if is the initial intensity (I_o) of a narrow beam of gamma-ray, its intensity after passing (I) through an attenuator with thickness (l) is given by equation:

$$I = I_o e^{-\mu l} \tag{2.1}$$

where μ : total linear attenuation coefficient.

The ratio I/I_o is called the gamma-ray transmission. Figure 2.2 illustrates the exponential attenuation of three different gamma-ray energies. It also shows that transmission increases with increasing gamma-ray energy and decreases with increasing absorber thickness. Measurements with different sources and absorbers show that the total linear attenuation coefficient μ depends on the gamma-ray energy and atomic number (Z) and density (ρ) of the absorber [11].

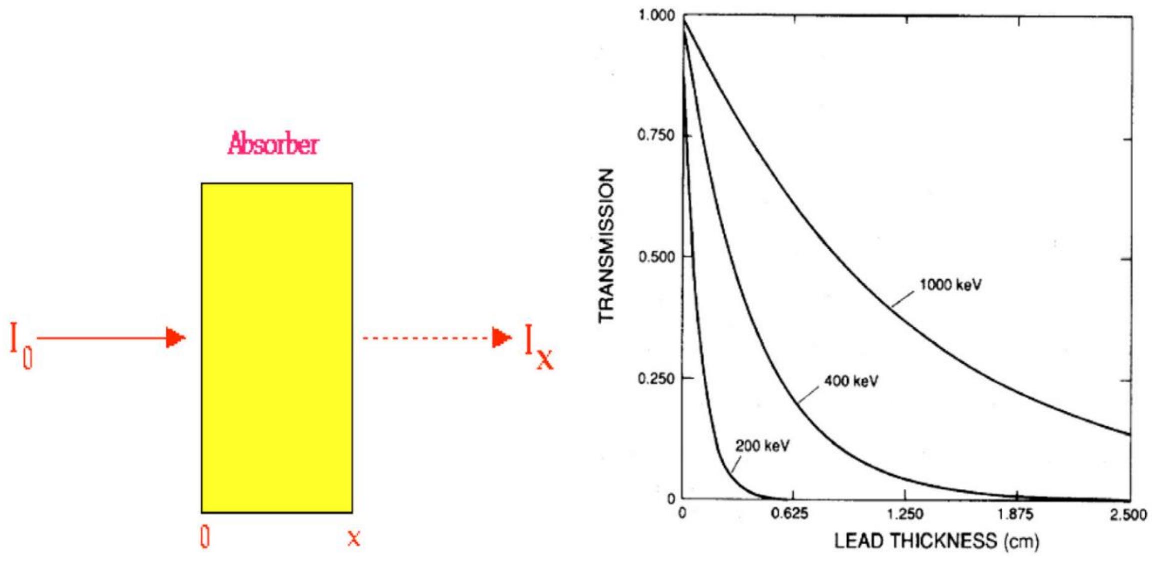

Figure 2.2 Transmission of gamma rays through lead with different energies [11]

CHAPTER 3
MATERIALS AND METHODS

3.1 Density Measurement

The density of the material samples was determined by weighing and measuring the external dimensions, assuming that the sample has a uniform density. Density is determined, ρ was the ratio of mass to volume, expressed in International System (SI) in grams per unit cubic centimeter (g /cm^3). Ruler were used to measure the length, width and thickness of each test sample, while an electronic balance was found to measure the mass. From the measured lengths, width and thickness of the test samples, the sizes of each were calculated and the density was calculated by dividing the mass by volume (m /v) to the nearest 0.01 g/cm^3. Average values of three test reading were taken from each sample to achieve higher accuracy the density was calculated by dividing the mass of each button by its volume. However, nine samples of gypsum board were divided from the same size of (length and width) (17 x 10 cm^2) as shown in Figure 3.1. The information about the samples in terms of source of samples origin and type of material were shown in the Table 3.1.

Figure 3.1: Gypsum board samples used in the experiment

Table 3.1: Type and source of gypsum samples

SAMPLE	Type of Sample	Source of the sample	Usage
S1	Gypsum board	Saudi Arabia	Water proof
S2	Gypsum board	Saudi Arabia	Partition Walls
S3	Gypsum board	Saudi Arabia	Fire proof
S4	Gypsum board	Saudi Arabia	Partition Walls
S5	Gypsum board	Saudi Arabia	Sound Insulation
S6	Gypsum board	Saudi Arabia	Moisture proof
S7	Gypsum board	Bangladesh	Partition Walls
S8	Gypsum board	Bangladesh	Partition Walls
S9	Gypsum board	UAE	Moisture proof

3.2 X-ray computed tomography (CT) scanner

The CT number values inside Gypsum board samples were examined using an X-ray computed tomography scanner (SOMATOM-SIEMENS CT scan, German). Tungsten acted as the X-ray target. A CT number, or image pixel value, is provided by X-ray CT scans. The CT number is defined as

$$\text{CT number} = \text{K}\ \frac{\mu - \mu_w}{\mu_w} \qquad (3.1)$$

where μ, μ_w is the linear attenuation coefficient of the sample and linear attenuation coefficient of water, respectively. In addition, K is a magnification contrast (=1000) [12]. The CT number is represented as the Hounsfield unit (HU), which is number related to the density. Water and air corresponding to HU values of 0 and -1000, respectively.

For demonstrating this linear correlation, water and Perspex materials were scanned and used as a standard material. The density and CT number of standard materials is shown in Table 3.2. The calibration curve for this experiment is shown in Figure 3.2.

Table 3.2: Standard samples used for the calibration curve with their densities and CT numbers.

Sample	Density (g/cm^3)	CT Number
Perspex	1.19	1.16538
Water	1	0.04154
Air	0	-974.26

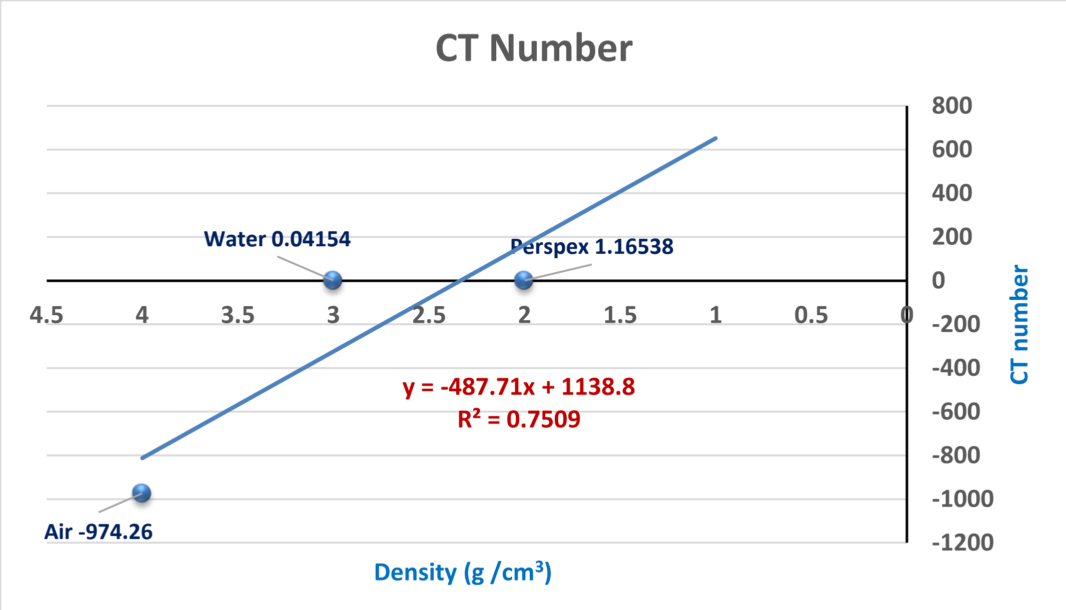

Figure 3.2: Calibration curve between CT numbers and standard sample densities.

The density (ρ) measured according to the calibration curve be obtained by:

$$\rho = (CT-1138.8)/487.71 \qquad (3.2)$$

The nine samples (**S1 , S2 ,S3 ,S4 ,S5 ,S6 ,S7 ,S8 and S9**) with different type of Gypsum board were studied in this experiment as shown in Figure 3.3. The samples were scanned using 80 kV X-ray with about 225 rays which are 5 mm thick. The area of interest is a rectangle area that measures 299.42 mm^2 to occupy about 30 % of the cross-sectional area of the rectangular square cross-section in order to minimize pixel averaging at the edges as shown in Figure 3.4. The average CT number for the interest areas was recorded. The CT number values were not recorded at the beginning and end scans to reduce pixel averaging at the interface of Gypsum board-air on the edge. The 13 average CT number values were computed. The density distribution profile was investigated using calibration equation between density and CT number as will describe later in chapter 4.

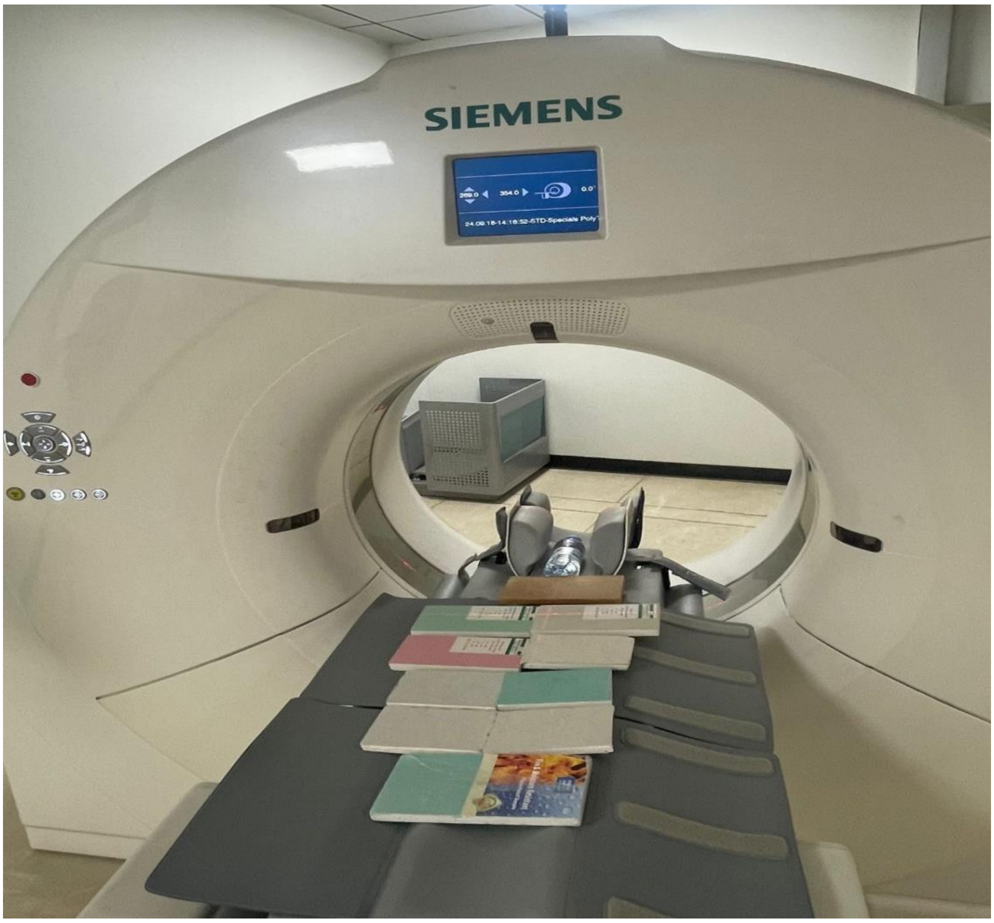

Figure 3.3: CT scan and samples during the experiment

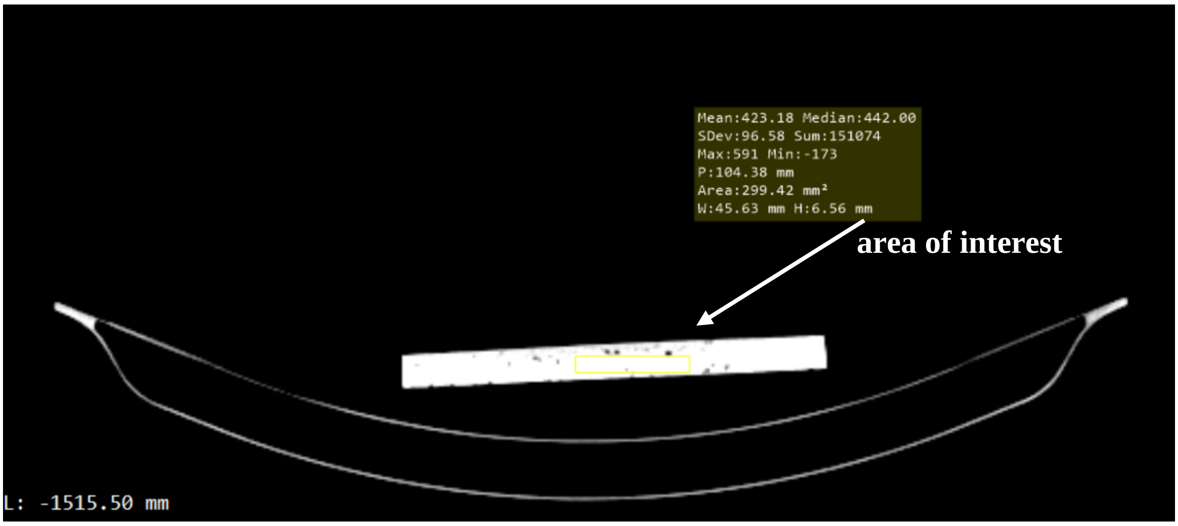

Figure 3.4: CT image of the cross-sectional area of gypsum sample with area of interest.

3.3 Determination of Linear Attenuation Coefficients

The measurement of linear attenuation coefficients (μ) for the test samples was conducted to evaluate their effectiveness in attenuating X-rays. The linear attenuation coefficient is a fundamental parameter that describes how much a material can attenuate or weaken the intensity of the radiation passing through it. The coefficients were determined using Equation 3.1, which provides a quantitative measure of how the material interacts with X-ray radiation.

To establish a reference point, the linear attenuation coefficient of water (μ_w) was calculated theoretically at the energy level used in X-ray CT imaging. Water is often used as a standard reference material due to its well-known properties and consistent behavior in X-ray attenuation. This calculation was performed to ensure accuracy in comparing the attenuation performance of different test samples against a known baseline. For each test sample, multiple measurements were taken, and the average value of the linear attenuation coefficient was determined. This approach minimizes variability and provides a more reliable representation of the material's overall attenuation properties.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 The Gypsum Sample Density Analysis

The density of the test samples was calculated by dividing the sample mass (g) with the volume of the sample (cm^3). Table 4.1 shows the calculated density of the experimental samples. Table 4.2 shows the classification of particleboard test samples based on gypsum`s type and the measured densities.

Table 4.1: Measured densities of gypsum samples

Sample	Length (cm)				Width (cm)				Thicknesses (cm)				Mass (g)	Density (g/cm^3)
	L1	**L2**	**L3**	**L_{avg}**	**W1**	**W2**	**W3**	**W_{avg}**	**T1**	**T2**	**T3**	**T_{avg}**		
S1	17	17	17	17	9.0	9.0	9.0	9.0	1.1	1.2	1.1	1.13	181.5	**1.046**
S2	17	17	17	17	9.0	9.0	9.0	9.0	1.5	1.5	1.4	1.46	221.4	**0.986**
S3	17	17	16.9	16.97	9.0	9	9.0	9.0	1.5	1.6	1.4	1.5	230.6	**1.006**
S4	13.5	13.4	13.3	13.4	8.8	8.9	9	8.9	1.2	1.0	1.1	1.1	94.9	**0.723**
S5	12.8	12.9	13	12.9	8.7	8.8	8.8	8.77	1.1	1.3	1.2	1.2	95	**0.700**
S6	12.8	13	13	12.93	8.6	8.8	8.9	8.77	1.0	0.9	1.1	1.0	75.9	**0.669**
S7	13.3	13.5	13.6	13.47	8.9	8.8	8.8	8.83	1.1	1.1	1.2	1.13	98.2	**0.728**
S8	13.1	12.9	13	13	8.5	8.5	8.6	8.53	1.1	1.0	1.1	1.06	98.4	**0.831**
S9	20	20	20	20	11	11	11	11	1.2	1.3	1.3	1.26	193.6	**0.694**

From the Table 4.2, it was found that samples **S1** and **S3** have highest density compared with density of samples S2, S4, S5, S6, S7, S8 and S9. Taking into consideration that the gypsum board samples differ from each other in terms of the source and the type of gypsum used in making decoration. Consequently, samples S1and S3 were produced a denser sample with a density of 1.046 g/cm^3 and 1.006 g/cm^3, whereas the densities of the samples S2, S4, S5, S6, S7, S8 and S9 were in the range (0.986-0.669 g/cm^3). This indicate that gypsum materials of the same name differ in term of density according to the source of sample.

Table 4.2: Test gypsum samples with measured densities.

Sample	Measured density (g/cm^3)
S1	1.046
S2	0.986
S3	1.006
S4	0.723
S5	0.700
S6	0.669
S7	0.728
S8	0.831
S9	0.694

4.2 Density Distribution Profile

The density distribution profile of the Gypsum samples was studied. The average, maximum, minimum, and standard deviation of the CT number values for the experimental samples are listed in Table 4.3. Sample S1 had a had the highest CT number value, with a standard deviation of 13.68, as compared with other samples. By considering the variation in the CT numbers among the samples, the type of sample had a considerable effect on the sample density. In general, large CT number value account for the higher density of a sample. Details of the CT number and the measured density of the samples can be found in Appendix I.

The relative density distribution profiles across the test samples are shown in Figure 4.1. The density distribution for each measuring point (in cm) was calculated using Equation 3.2. The CT values at the beginning and end of each scan were not considered to reduce the effect of the density degeneration at the edge of the samples. Therefore, the region of interest across the samples was from 5 cm to 65 cm as shown in Figure 4.1.

Table 4.3 Mean, maximum, minimum and standard deviation of the CT number of samples.

Sample	CT Number			
	Mean	**Maximum**	**Minimum**	**Standard deviation**
S1	492.45	511.28	456.82	13.68
S2	309.61	343.67	287.11	14.63
S3	416.75	436.27	392.6	11.57
S4	237.09	295.3	189.3	39.88
S5	237.72	300.1	198.6	31.73
S6	178.41	232.2	111.7	38.74
S7	292.05	322.8	258.7	21.81
S8	292.98	342.2	243.3	29.28
S9	218.91	262.1	194.8	20.43

From Figure 4.1 analysis of the relative density profiles of the gypsum board samples (S1 to S9) provides valuable insights into the homogeneity and density distribution across the material. Consistency in density is critical to ensuring reliable and uniform attenuation properties, which is essential for the quality of the material.

The results indicate that the samples exhibited varying degrees of homogeneity, with significant differences in how the density was distributed across the material. The data also showed that samples like S1, S2, and S3 had fairly stable density values around 1.0 across a range of thicknesses. They did not have any significant peaks, which suggests that their density distribution was moderate but nearly constant.

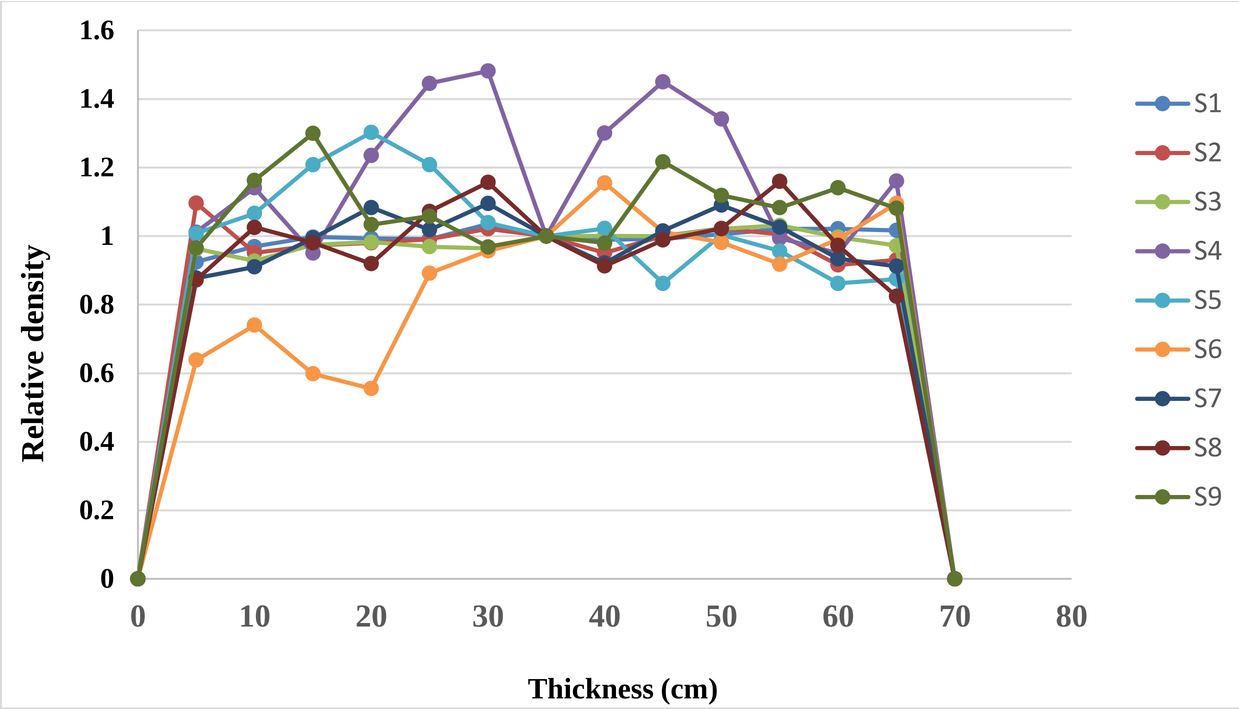

Figure 4.1: Relative density profiles normalize at thickness 35 cm along the test samples S1, S2, S3, S4, S5, S6, S7, S8 and S9.

The coefficient of variation (COV) was used to clarify the ratio of variation in the density distribution of the disk samples. COV is defined as the ratio of the standard deviation of density and its average. The calculated COV values from the samples with the maximum and minimum densities are listed in Table 4.4. The COV values of gypsum samples showed that these samples S1 and S3 had a COV of 2.778 %. Thus, samples S1 and S3 had more uniform density as compared with the samples S2, S4. S5. S6, S7, S8 and S9. Also, the results showed that there is a difference in the dense distribution of samples of the same type, but from different sources, and this is due to the difference in the method of fabrication samples in addition to the difference in the method of fabrication, which leads to the difference in the density distribution of samples. It is also possible to investigate the size of the particles that were made of samples, such as gypsum board sample. Generally, the lower density variations were observed in the particleboard samples with smaller particles than those with larger particles. The number of voids between the particles decreased to a limited area within one layer while the sizes of each void were increased as the particle size increases. Thus, it is possible to know the homogeneity of samples through a CT scan machine without the need to cut or distortion the sample.

Table 4.4: Results of statistical analyses showing the calculated COV, maximum and minimum density values of the gypsum samples by using CT scan for interest region along the samples of 5 cm to 65 cm.

Sample	COV %	Max (g/cm^3)	Min (g/cm^3)
S1	2.778	511.28	456.82
S2	4.725	343.67	287.11
S3	2.776	436.27	392.60
S4	16.820	295.30	189.30
S5	13.347	300.10	198.60
S6	21.715	232.20	111.70
S7	7.467	322.80	258.70
S8	9.993	342.20	243.30
S9	9.335	262.10	194.80

4.3 Linear Attenuation Coefficient Measurements

The linear attenuation coefficients (μ) value of test sample in the CT scan energy is shown in Table 4.5. The linear attenuation was evaluated using Equation 3.1. The results showed that the linear attenuation coefficient for gypsum samples is more than Perspex and water samples at the same X-ray energy. Where the linear attenuation coefficient of gypsum samples within the range of (0.432 cm^{-1} – 0.341 cm^{-1}), while the linear attenuation coefficient of Perspex and water samples 0.2897 cm^{-1} and 0.2894 cm^{-1}. This is due to the general difference in the elemental composition between the three materials, in addition, due to the effect of the photoelectric effect, which is affected by the elemental composition of the material. This indicates that the CT scan has potential to calculate the attenuation property at specific energy in any part of sample depending on the CT scan device and it is always diagnostic energy.

Table 4.5: Results of linear attenuation coefficients (μ) value of gypsum sample.

Linear attenuation coefficients of samples (cm^{-1})											
Samples											
Thickness	**Water**	**Perspex**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
5	0.289	0.290	0.422	0.389	0.407	0.348	0.357	0.327	0.364	0.364	0.346
10	0.289	0.290	0.428	0.376	0.403	0.355	0.360	0.332	0.367	0.377	0.357
15	0.289	0.289	0.432	0.378	0.409	0.344	0.370	0.324	0.374	0.373	0.365
20	0.289	0.290	0.431	0.378	0.410	0.361	0.376	0.322	0.382	0.368	0.350
25	0.289	0.290	0.431	0.379	0.408	0.373	0.370	0.341	0.376	0.381	0.351
30	0.290	0.290	0.437	0.382	0.407	0.375	0.359	0.345	0.383	0.388	0.346
35	0.290	0.290	0.432	0.380	0.412	0.347	0.356	0.348	0.375	0.375	0.348
40	0.289	0.290	0.431	0.376	0.412	0.364	0.358	0.357	0.368	0.367	0.347
45	0.289	0.290	0.431	0.380	0.412	0.373	0.347	0.348	0.376	0.374	0.360
50	0.289	0.290	0.433	0.382	0.414	0.367	0.356	0.347	0.382	0.377	0.355
55	0.289	0.290	0.435	0.381	0.416	0.347	0.353	0.343	0.377	0.388	0.353
60	0.289	0.290	0.435	0.372	0.412	0.344	0.347	0.347	0.369	0.372	0.356
65	0.289	0.290	0.435	0.374	0.408	0.356	0.348	0.353	0.367	0.360	0.353
AVG:	0.289	0.290	0.432	0.379	0.410	0.358	0.358	0.341	0.374	0.374	0.353
MAX:	0.290	0.290	0.437	0.389	0.416	0.375	0.376	0.357	0.383	0.388	0.365
MIN:	0.289	0.289	0.422	0.372	0.403	0.344	0.347	0.322	0.364	0.360	0.346
SD:	0.000	0.000	0.004	0.004	0.003	0.012	0.009	0.011	0.006	0.008	0.006

CHAPTER 5
CONCLUSION

The measured densities of the gypsum board samples revealed significant variations. Samples S1 and S3 had the highest densities at 1.046 g/cm³ and 1.006 g/cm³, respectively. These samples exhibited greater uniformity in density compared to others, indicating that the gypsum type and source play a critical role in determining density. The range of densities across the samples varied from 0.669 g/cm³ to 1.046 g/cm³, showing that the material properties differ even within samples of the same type due to variations in the manufacturing process.

Analyzing the CT number values provided a comprehensive view of the density distribution across the samples. Samples S1, S2, and S3 displayed more consistent density distribution, indicating moderate but nearly constant density values across different thicknesses. The study highlighted that consistency in density is crucial for reliable material performance, as it ensures uniform attenuation properties. These results were supported by the coefficient of variation (COV). Samples S1 and S3 had lower COV values (about 2.78%), which meant they had a more uniform density compared to samples S4, S5, and S6, which had higher variation.

The linear attenuation coefficients (μ) measured for gypsum samples demonstrated their superior attenuation capabilities when compared to Perspex and water samples. The values for gypsum ranged between 0.432 cm^{-1} and 0.341 cm^{-1}, higher than the coefficients for Perspex (0.2897 cm^{-1}) and water (0.2894 cm^{-1}). This suggests that the elemental composition of gypsum, influenced by factors like density and photoelectric effects, enhances its radiation shielding ability. The use of CT scans to determine these properties proved effective, providing detailed insight without damaging the samples.

Overall, the results underline the importance of controlling gypsum board material properties through manufacturing techniques to achieve desired density and attenuation characteristics. Future research could focus on refining the manufacturing process to reduce density variations and improve the overall quality of the gypsum boards for better performance in many applications.

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Appendix I : The CT number of each gypsum sample.

CT scan number											
			Samples								
Thickness	**Water**	**Perspex**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
5	-0.15	1.68	456.82	343.67	407.58	201.60	232.20	128.40	258.70	257.40	194.80
10	0.20	0.80	479.01	298.20	392.60	227.40	245.60	148.90	268.40	302.70	234.50
15	0.05	-1.00	492.83	304.93	412.53	189.40	278.50	120.30	293.10	289.40	262.10
20	-0.57	1.48	490.76	307.38	415.75	246.30	300.10	111.70	319.40	271.30	208.50
25	0.28	0.88	489.87	310.62	410.14	288.10	278.40	179.40	300.20	316.40	213.40
30	0.48	0.50	511.28	320.26	407.94	295.30	239.40	192.40	322.80	341.30	195.40
35	0.53	1.22	494.10	313.50	423.18	199.30	230.40	201.10	294.80	295.10	201.70
40	-0.12	2.50	488.80	298.20	423.31	259.30	235.50	232.20	271.60	269.40	197.60
45	0.20	1.42	490.12	313.73	422.83	289.10	198.60	203.40	299.30	291.70	245.50
50	0.22	1.65	496.77	320.52	432.25	267.50	231.10	197.40	321.50	301.50	225.70
55	0.23	1.25	504.36	315.07	436.27	198.20	220.40	184.60	302.60	342.20	218.40
60	0.07	1.25	504.66	287.11	421.99	189.30	198.60	199.30	275.30	287.10	230.10
65	-0.88	1.52	502.43	291.75	411.37	231.40	201.50	220.20	268.90	243.30	218.10
AVG:	0.04	1.17	492.45	309.61	416.75	237.09	237.72	178.41	292.05	292.98	218.91
MAX:	0.53	2.50	511.28	343.67	436.27	295.30	300.10	232.20	322.80	342.20	262.10
MIN:	-0.88	-1.00	456.82	287.11	392.60	189.30	198.60	111.70	258.70	243.30	194.80
SD:	0.40	0.81	13.68	14.63	11.57	39.88	31.73	38.74	21.81	29.28	20.43
COV%	-	-	2.78	4.72	2.78	16.82	13.35	21.71	7.47	9.99	9.33