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Experimental and Theoretical Analysis to Determine the Radiation Shielding Properties of Mortar Samples Prepared with Different Mineral Additives

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Different Mortar Types,
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Abstract: In this study, the Radiation Shielding properties of reinforced mortars whose matrices were made with different mineral materials were investigated. In order to predict the behavior of the mortar specimens against radiation, productions were made with using mineral additives of different properties in the mortar specimens. Perlite, colemanite, pumice, silica fume, fly ash, and ground blast furnace slag, which are widely used in the construction industry, were preferred. In order to study the radiation shielding properties of the prepared samples, the mass attenuation coefficients (cm^2 /g) were determined using the XCOM program at an energy of 59.543 keV. The rays were detected with a high resolution Si(Li) detector. Experimental results were compared with theoretical values.The comparison of the experimental results with the theoretical results, it was found that there was a satisfactory agreement between the two methods. In general, the calculated values differ by 4% from the experimental values.

Farklı Mineral Katkı Oranlarına Göre Üretilen Harç Numunelerin Radyasyon Zırhlama Özelliklerinin Belirlenmesinde Deneysel ve Teorik Analiz

Anahtar Kelimeler
Farklı Harç Türleri,
Mineral Katkılar,
XCOM, Radyasyon Zırhlama

Öz: Bu çalışmada farklı mineral malzemelerle matrisleri hazırlanan takviyeli harçların radyasyon zırhlama özellikleri incelenmiştir. Harç numunelerinin radyasyona karşı gösterecekleri davranışı belirleyemek için harç numunelerinde farklı özelliklere sahip mineral katkılar kullanılarak üretimler yapılmıştır. Yapı sektöründe yaygın kullanılan perlit, kolemanit, pomza, silis dumanı, uçucu kül, öğütülmüş yüksek fırın cürufu tercih edilmiştir. Üretilen numunelerin radyasyon zırhlama özelliklerini araştırabilmek için ise kütle azaltma katsayıları (zırh) XCOM programında 59.543 keV enerjide hesaplanmıştır. Işınlar Yüksek çözünürlüklü bir Si(Li) dedektörü ile dedekte edildi. Deneysel sonuçlarla teorik sonuçlar karşılaştırıldığında ise iki yöntem arasında iyi bir uyum olduğu elde edilmiştir. Hesaplanan değerler ile deneysel veriler arasında ortalama %4 fark vardır.

1. INTRODUCTION

All living and non-living things on earth are exposed to natural radiation sources in the air, water, soil, and even within their own bodies, as well as artificial radiation sources produced by humans every day. In particular, it is necessary to develop radiation shields in order to adequately protect the bodies of employees and patients. Permanent tissue damage, acute radiation syndromes, cancers, and deaths have been observed in living beings exposed to radiation for a long time [1] [2]. To be protected from the harmful effects of radiation, three basic issues should be considered: time, distance and shielding. The longer the exposure time to the radiation

from the radioactive source or the closer to the radiating source, the higher the radiation dose to be received.
The radiation efficiency by certain radionuclides is so powerful that it can be exposed even when it is invisible even from miles away. The effects of such strong radioactive materials can only be protected by shielding. The parts that are included in the structure of the design that provides the formation of that design and its shaping in the process of use and that regulate the health and comfort of the person using the design are called building materials. After the nineteenth century, as a result of economic and social changes, material technology gained more importance, and solutions in the form of material combinations emerged in all designs instead of a single material [3].

Lead, iron, and materials containing both elements are the best examples of high-intensity radiation shields. Although these materials offer the desired protective feature, they are not preferred in the construction of buildings due to their durability and high costs. Also, lead is toxic to humans and the environment, making it less ideal. For this reason, inexpensive protective materials containing brick, concrete, cement, and sand are used, although they seem less effective. In studies, improving these materials or which ones are better were compared [4] [5]. Due to the popularity of the most widely used concrete building material in construction, studies have been carried out by changing factors such as the effect of aggregate types used in concrete production and the concentration amounts of chemical compounds of cement and water. In most studies, experimental and theoretical evaluation of radiation shielding properties of building materials has been made. Radiation attenuation coefficients were determined to estimate the radiation shielding properties of building materials and more commonly used materials.Thus, it is important to choose building materials that will reduce the effect of radiation on living things [6] [7] [8] [9].

The aim of this study is to compare the radiation protection capability of the produced mortars with the theoretical data in order to investigate the effects of different mineral solids, which are widely used in mortar production, on radiation shielding. For the theoretical calculation, the analysis made using XCOM was performed.

2. MATERIAL AND METHOD

2.1. Materials

2.1.1. Cement

Chemical properties of CEM I 42.5R Portland Cement produced in Mersin Cement factory were used. The chemical analysis of the cement used is given in Table 1.

Table 1. Cement sample chemical analysis

Chemical Test Results	
Constituents Parts	%
SiO_2	20.02
Al_2O_3	4.87
Fe_2O_3	3.44
CaO	62.49
MgO	2.81
Na_2O+K_2O	0.91
SO_3	2.86
Free CaO	0.48
Loss on Ignition	2.12

2.1.2. Aggregate

0-4 mm Aksu sand, 4-16 mm and 16-32 mm crushed stone gravel, which was extracted from the Aksu river bed and sieved, was used. The maximum grain diameter of the aggregate used in the mortar samples was 32 mm, washed and used after drying in the drying-oven.

In this study, acidic pumice (AP), basic pumice (BP), blast furnace slag (Y), fly ash (U), silica fume (S), colemanite (K) and perlite (P) ground minerals were used. Materials used in the experimental study; ground blast furnace slag and ground basaltic pumice from Iskenderun Adana cement factory, ground colemanite Etimaden A.Ş. Bigadiç boron facility, perlite from Saftaş Mining, fly ash from Elbistan Thermal Power Station. The chemical analysis values of the mineral additives used in the study are given in Table 2.

Table 2 . Chemical analysis of mineral additives

Constituents Parts (%)	Asidic Pumice	Basic Pumice	B. Furnuce Slag	Fly Ash	Silica Fume	Colemanite	Perlite
SiO_2	66.12	47.63	43.71	35.84	79.62	4.00	72.93
Al_2O_3	15.23	15.99	11.14	15.90	2.01	0.40	13.98
Fe_2O_3	3.18	11.24	1.21	5.67	0.70	0.08	0.60
CaO	4.98	9.65	32.28	20.93	0.56	26.00	0.81
MgO	2.13	8.05	8.42	5.83	8.66	3.00	0.43
SO_3	0.38	-	-	3.31	0.23	-	0.03
Na_2O+K_2O	5.85	6.51	-	5.00	3.69	0.35	8.43
TiO_2	0.40	0.2		0.64	0.30		0.11
MnO	0.10						
SO_3			1.33	2.85	0.42		
SrSO	-	-	-		-	1.50	-
B_2O_3	-	-	-	-	-	40.00	-
Loss on Ignition	1.63	0.73	1.91	4.03	3.81	24.67	2.68

2.2. Method

2.2.1. The method for preparing mortar samples

In this study, mineral additives, which are preferred in research and generally in mortar production, were used. In the production of mortar, mineral additives in different proportions were used instead of reducing the amount of cement. In the study, the preparation of mortar was made according to TS 802. Silica fume (S), perlite (P), blast furnace slag (Y), acidic pumice (AP), basaltic pumice (BP) and colemanite (K) were used as mineral additives.

Instead of cement in the mortar mix, silica fume (S), perlite (P) at the rates of 5, 10, 15, 20 and 25%, blast furnace slag (Y) at the rates of 10, 20, 30, 40, 50 percent, acidic pumice (AP), fly ash (U) and basaltic pumice (BP) and colemanite (K) at 0.5, 1.0, 1.5, 2.0 and 2.5 % were used. Mixture calculations were made for 36 types of mortar samples, including the control sample.The components used in 36 types of sample contents are given in Table 3.

Table 3. Mixing quantities of different types of mortars for 1 m^3[10]

Samples	Mixture Quatities			
	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Minerals (kg/m^3)
R	450	225	1350	0
AP10	405	225	1350	45
AP20	360	225	1350	90
AP30	315	225	1350	135
AP40	270	225	1350	180
AP50	225	225	1350	225
BP10	405	225	1350	45
BP20	360	225	1350	90
BP30	315	225	1350	135
BP40	270	225	1350	180
BP50	225	225	1350	225
Y10	405	225	1350	45
Y20	360	225	1350	90
Y30	315	225	1350	135
Y40	270	225	1350	180
Y50	225	225	1350	225
U10	405	225	1350	45
U20	360	225	1350	90
U30	315	225	1350	135
U40	270	225	1350	180
U50	225	225	1350	225
S5	427.5	225	1350	22.5
S10	405	225	1350	45
S15	382.5	225	1350	67.5
S20	360	225	1350	90
S25	337.5	225	1350	112.5
K0.5	447.5	225	1350	2.25
K1	445.5	225	1350	4.5
K1.5	443.25	225	1350	6.75
K2	441	225	1350	9
K2.5	438.75	225	1350	11.25
P5	427.5	225	1350	22.5
P10	405	225	1350	45
P15	382.5	225	1350	67.5
P20	360	225	1350	90
P25	337.5	225	1350	112.5

2.2.2. Experimental process for radiation shielding

In the experiment system, Canberra brand Si (Li) semiconductor solid-state detector preamplifier, ADC (Analog-Digital Converter), system 100 computer board with a resolution of 155eV at 5.9 keV was used. Ring sources of ^{241}Am (59.543 keV) and ^{55}Fe (5.9 keV) were used as radiation sources. S_i (L_i) semiconductor solid-state detector is a detector with 2 mm thickness, 12.5 mm² active area, and 500 volts reverse supply voltage, with Lithium atoms diffusing into the lattice spaces of the semiconductor silicon crystal, and it is under vacuum (Canberra, 1995) [11].

It was immersed in liquid nitrogen (-196 ºC) in order to reduce electronic noise and to prevent the evaporation of conductivity-enhancing Lithium, which can evaporate at room temperature, and thermal equilibrium was achieved.

The pre-amplifier converts the characteristic X-rays reaching the detector into electrical pulses in the order of a few millivolts. From here, the electrical pulses reaching the amplifier are amplified to the order of 0-10 volts. These electrical pulses are converted to numerical values in the ADC. These values form peaks in channels suitable for their energies on the 4096-channel screen, depending on their size. In this way, pulses coming in different numbers and energies are displayed on the screen.gives the characteristic X-ray spectrum of the samples. (Figure 1).

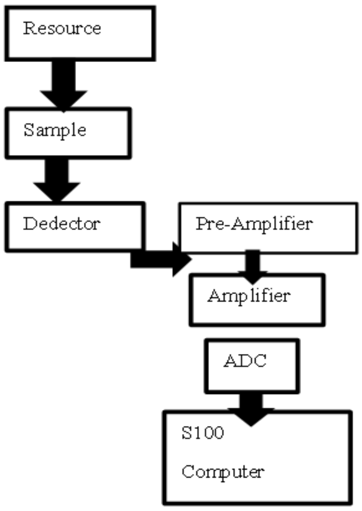

Figure 1. Experimental Setups

Using equation 1, radiation attenuation coefficients of the mortars were obtained using X-Ray fluorescence ^{241}Am (59.543 keV) gamma beam sources.

$$\mu = \frac{\log_e \frac{I_o}{I}}{t} \quad ,\mu_m = \frac{\mu}{\rho}\frac{cm^2}{g} \qquad (1)$$

After the 28-day strength of the mortar samples prepared as 12x12x2 cm^3, the radiation shielding test of the mortar samples was determineted.. By using 36 different mortar samples, ^{241}Am (59.543 keV) source, linear attenuation coefficients (μ) and mass attenuation coefficients (μ_m) of AP, BP, Y, U, S, K and P added mortar samples were obtained. The samples were weighed with precision scales and the mass amounts of the samples were obtained. The densities (ρ) of the samples were calculated based on the sample weights. The thickness of each of the samples was measured with the help of the caliper (t). Before starting the experiment, when the system was empty, counting was made with a γ source of 59.543 keV for 1000 seconds and I_0 was found. Afterwards, the samples were placed in the sample holder, counted again at the same time and recorded (I).

I_o = Incoming photon intensity with no sample
I = Incoming photon intensity with sample
t = Thickness of the sample
μ = Linear attenuation coefficient
ρ = Density
μ_m = Mass attenuation coefficient

2.3. XCOM Program Analysis

In the XCOM program, mass attenuation coefficients were found according to the radiation transmittance of the samples exposed to 59.543 keV energy. I/I_0 was found using the Beer-Lambert equation. This equation is as follows.

$$\mu = \frac{1}{x} In\frac{Io}{I} \quad (2)$$

x sample thickness

I_0 the peak area recorded with no sample between the source and the detector.

I peak area recorded with sample between source and detector.

The linear attenuation coefficients measured from the experiment and the mass attenuation coefficients finded out using the XCOM program were compared.References in sample thickness (*t*) and density (*ρ*) experiments were chosen as references for using XCOM.

3. DISCUSSION AND RESULTS

The data used to interpret the radiation shielding properties of 36 different mortar samples and the data obtained from the experiment are given in Table 4.

Table 4. Experimental data of samples according to 59.543 keV (Linear attenuation, mass attenuation coefficients) [10].

Simples	t(cm)	ρ(g/cm³)	μ(cm⁻¹)	μm(cm² /g)	I/I₀
R	2.10	2.02	0.54	0.27	0.32
AP10	2.10	2.01	0.59	0.29	0.29
AP20	2.20	1.92	0.56	0.29	0.29
AP30	2.20	1.94	0.54	0.29	0.30
AP40	2.20	1.84	0.53	0.29	0.31
AP50	2.20	1.86	0.51	0.27	0.32
BP10	2.20	1.39	0.44	0.32	0.38
BP20	2.10	1.27	0.41	0.32	0.42
BP30	2.05	1.30	0.42	0.32	0.42
BP40	2.10	1.30	0.42	0.32	0.41
BP50	2.10	1.29	0.42	0.33	0.41
Y10	2.00	2.00	0.58	0.29	0.31
Y20	2.10	2.00	0.57	0.29	0.30
Y30	2.15	1.98	0.56	0.28	0.30
Y40	2.20	1.82	0.55	0.30	0.30
Y50	2.10	1.87	0.54	0.29	0.32
U10	2.10	1.37	0.41	0.30	0.42
U20	2.20	1.56	0.47	0.30	0.35
U30	2.20	1.73	0.49	0.28	0.34
U40	2.05	1.80	0.53	0.29	0.33
U50	2.10	1.87	0.56	0.30	0.31
S5	2.00	2.00	0.55	0.28	0.33
S10	2.10	1.97	0.55	0.28	0.32
S15	2.20	1.92	0.54	0.28	0.31
S20	2.20	1.88	0.54	0.29	0.30
S25	2.20	1.95	0.52	0.27	0.32
K0.5	2.05	2.00	0.59	0.30	0.30
K1.0	2.10	1.96	0.57	0.29	0.30
K1.5	2.20	1.86	0.55	0.30	0.30
K2.0	2.20	1.82	0.54	0.30	0.30
K2.5	2.20	1.83	0.53	0.29	0.31
P5	2.20	1.94	0.55	0.28	0.30
P10	2.10	1.79	0.52	0.29	0.33
P15	2.20	1.76	0.51	0.29	0.32
P20	2.10	1.62	0.50	0.30	0.35
P25	2.10	1.55	0.47	0.30	0.37

The linear attenuation coefficient at 59.543 keV was obtained at most from AP10 (0.59) and K0.5 (0.59), and at least from BP20(0.41) and U10 (0.41) samples. It was determined that the linear attenuation coefficient increased as the amount of fly ash increased in the mortar produced with the fly ash (U) mortar sample. In the samples of acidic pumice (AP), basic pumice (BP), blast furnace slag (Y), fly ash (U) silica fume (S), colemanite (K) and perlite (P) added additives, the energy rays of 59.543 keV are reduced by It has been obtained that it has undergone 20% of the radiation. It was found that the AP20 sample passed 28% radiation, while the BP30 sample passed 42% radiation. The mass attenuation coefficient is the highest in the BP50 (0.33) sample and the least in the S25 and AP50 (0.27) sample.

A theoretical study was created by adhering to the data in the experimental process. The theoretical mass absorption coefficients were obtained with the XCOM program. The experimental and theoretical mass absorption coefficients were compared. As can be seen in Figure 2, the experimental measurement results of the samples and the theorical/computed results are in good agreement. There is an average of 4% difference between the calculated values and the experimental data.
Once the experimental and theoretical mass attenuation coefficients are compared, the closest average to each other is in the U mineral added samples at the rate of 0.3%. Whenever the experimental and theoretical data of the samples produced with P and S were compared, an average of 0.6% was estimanted, the samples produced with Y were compared, an average of 0.9% difference was obtained. As compared to the serial samples produced with A, an average difference of 1.5% was resuting. The difference in the average comparison rate of the serial samples produced with K is 9%. The experimental and theoretical data of the samples produced with BP were compared, a difference of 12% was obtained. In this case, the experimental and theoretical mass attenuation coefficients were compared, the greatest difference was found in the AP samples.

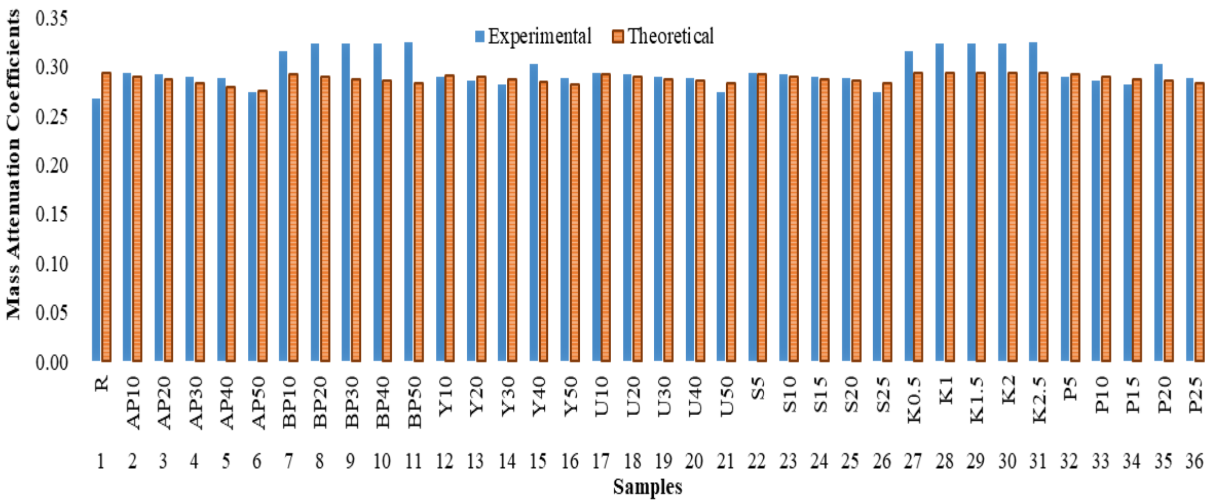

Figure 2. Experimental and theoretical comparison of mass attenuation coefficients of mortar samples

4. CONCLUSION

Radiation shielding properties of 36 different mortar samples produced with different minerals were obtained by experimental and theoretical methods, depending on the mass attenuation coefficients. According to the energy of 59.543 keV, the experimental study results and the theoretical data were compared with the mass attenuation coefficients. The closeness of the obtained theoretical data to the experimental data was determined. According to the study data:

- Silica fume (S), colemanite (K), and perlite (Acidic pumice (AP), basic pumice (BP), blast furnace slag (Y) and fly ash (U) added mortar samples) were analyzed according to 59,543 keV energy beams. In the mortar samples with the P) additive, it was determined that the P5 sample passed 29% of the energy, the P25 sample passed 37% of the energy, the AP20 sample absorbed 72% of the energy, and the BP30 sample absorbed 58% of the energy.

- The linear absorption coefficient at 59.543 keV is the highest in the AP10 sample and the least in the BP20 and U10 samples. It was determined that the linear attenuation absorption coefficient increased depending on the increase in the amount of fly ash (U).

- The linear absorption coefficients of fly ash (U), and basaltic pumice (BP) in mortar samples increased, and the number of additives in colemanite (K), acidic pumice (AP), blast furnace slag (Y), silica fume (S) and perlite (P) samples It was evaluated that as the linear attenuation coefficient increased, the linear absorption coefficients decreased.

- In the theoretical reckon of the samples, an average of 4% difference was obtained compared to the experimental data. Depending on this ratio, it has been determined that the radiation attenuation coefficients can be used in a healthy way when the product is made according to these minerals theoretically.

Considering that it is always difficult to conduct experiments according to the results above, it is obvious that theoretical data will be supported in the determination of radiation amounts of materials in building products with theoretical studies. It will be easier to work with XCOM or other software. Materials in the building can be easily evaluated for radiation-holding properties. As a result, environmental problems can be prevented in the construction industry.

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