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Investigation of Neutron Shielding Behaviour of Unreinforced and Calcite Reinforced Concrete Samples

Kalsit Katkılı ve Kalsit Katkılı Olmayan Beton Numunelerde Nötron Zırhlama Davranışının İncelenmesi

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Abstract

Neutron particles are different, due to their nature of interacting directly with the atomic nucleus and making indirect ionization. In this study calcite containing and non-calcite containing concrete samples neutron shielding capabilities was compared with each other. $CaCO_3$ (calcite) added concrete and pure concrete was experimentally compared against an isotropic Am-Be neutron source. Naturally, calcite containing concrete was in heavy form in comparison with pure concrete, means that the aim of these experiment is comparing neutron shielding properties of heavy and light concrete. In both samples, thickness of the samples was started with 2 cm and reach to 10 cm with 2 cm increases.

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The effect of thickness and the effect of material type on neutron shielding was investigated. According to the test results, pure concrete samples shows better shielding characteristics.

Keywords: Neutron, concrete, shielding, radiation, calcite

Öz

Nötron parçacıkları, atom çekirdeği ile doğrudan etkileşime girme ve dolaylı iyonizasyon yapma yapıları nedeniyle diğer radyasyon türlerinin oluşturduğu etkilerden farklı etkiler oluştururlar. Bu çalışmada kalsit içeren ve içermeyen beton numunelerin nötron zırhlama yetenekleri birbirleriyle karşılaştırılmıştır. $CaCO_3$ (kalsit) katkılı beton ve saf beton deneysel olarak izotropik Am-Be nötron kaynağı karşısında karşılaştırılmıştır. Doğal olarak kalsit içeren betonun saf betona göre ağır formda olması, bu çalışmanın amacının ağır ve hafif betonun nötron radyasyonuna karşı koruyuculuk özelliklerini karşılaştırmak olduğu anlamına gelir. Her iki örnekte de örneklerin kalınlığı 2 cm ile başlamış ve 2 cm'lik artışlarla 10 cm'ye ulaşmıştır. Kalınlığın etkisi ve malzeme tipinin nötron zırhlama davranışı üzerine etkisi araştırılmıştır. Deney sonuçlarına göre, saf beton numunelerinin daha üstün özellik gösterdiği görülmüştür.

Anahtar Kelimeler: Nötron, beton, zırhlama, radyasyon, kalsit

INTRODUCTION

Radiation is a phenomenon that arises from natural and artificial sources and has been found since the existence of the world. Radiation in the form of photons and particles is an energy transport, cosmic radiation is naturally found in the universe and artificial radiation sources are used in many different fields, especially in medicine, industry and research and development activities (Aboelezz and Hassan, 2018; Başyiğit at al. 2011; Biarrotte at al. 2004; Ipe, 2010; Sariyer at al., 2015; Singh and Badiger, 2014). The type of radiation that is dangerous for living tissues is ionizing radiation, which can cause permanent damage to the tissues on a cellular scale by causing ionization in material. X-rays and gamma rays are types of radiation in the form of photons, while alpha and beta particles and neutrons are in the form of particles. Although the damage caused by each radiation in living tissue or organ is different, neutrons are considered as a severe and dangerous type of radiation for living tissues, since they interact directly with the nucleus of the atom and also cause indirect ionization (Gökoğlan at al., 2020; Nami, 2015). In order to prevent uncontrolled exposure to radiation, precautions such as shielding of radiation sources and adjusting the distance between the source and the living beings are used (Başyiğit at al., 2011; Dees, 2017; Rwashdy at al., 2016; Tesch and Zazula, 1991).

Depending on the type and energy of the radiation sources, the shielding materials to be used should also different (Jumpee and Wongsawaeng, 2015; Tesch and Zazula, 1991). X-rays and gamma rays interact predominantly with the electron shell of the atom, so that if an atom has more electrons (i.e. with increasing atomic number Z), probability of interaction is getting higher, while heavy materials with higher atomic number should be used for shielding. On the other hand, the situation is completely different for neutrons (Adeli at al., 2016; Soltani at al., 2016). Neutrons have no net electric charge, so they are not affected by electric forces and act directly on the nucleus of the atom, not on the electron shell. Therefore, they are highly sensitive to light atoms such as hydrogen, oxygen, etc., which have a higher probability of interaction with neutrons (Rwashdy at al., 2016; Sarıyer and Küçer, 2015). In contrast, metals show a relatively lower probability of interaction with neutrons which means a fairly high depth of penetration. For this reason, it is desirable that the material to be used for shielding should be rich in light elements such as hydrogen (Araz at al., 2021; Piotrowski, 2021). After thermalizing the neutrons with this light atomic nuclei, neutrons can easily absorbed by elements with high thermal neutron cross sections (Özcan at al., 2022; Özdemir at al., 2016). Shielding characteristics of many different materials have investigated yet. Gamma and neutron shielding properties of zinc extraction residue containing bricks were analyzed and its stated that gamma shielding capabilities of materials were higher than neutrons

(Gencel at al., 2021). In another study, investigation of the shielding ability of a composite material, concrete matrixed colemanite, was performed and effect of sample thicknesses was revealed as the thickness of the shielding material increases, the neutron shielding ratio of the composite material increases (Tuna and Bayrak, 2017). Different ratios of boron carbide added to polyester matrix in a novel study with different thicknesses and both the effects of boron carbide amount and sample thicknesses were investigated by Tuna at al. (2021)

In this study, concrete mixtures created with two different contents were discussed. While one of the mixtures is concrete with calcite (CaCO3) additives distinctively from other studies, the other is pure concrete mixture. While calcite-added concrete is heavy concrete, pure concrete is lightweight. Thus, it is aimed to compare the neutron shielding properties of heavy and light concrete. The effect of thickness on neutron shielding was also investigated by preparing samples of different thicknesses in both mixtures.

MATERIALS AND METHOD

Calcite material ($CaCO_3$), known as marble powder after the supply of sea sand and cement was obtained from a local marble factory in Turkey.

During the preparation of the samples, to get pure concrete samples, materials was mixed by mechanical mixing for five minutes to ensure homogeneity by setting the cement/sand ratio to 1. Then, this mixture was poured into wooden molds prepared in five different thicknesses 2-4 6-8-10 cm and molded (Figure 1a-b). In second mixture, the calcite and concrete mixture, the Calcite/(Cement+Sand) ratio was adjusted to 1 and mixed mechanically for five minutes and the molding processes were repeated with the same thicknesses (Figure 2a-b). All samples were kept for a week at room temperature in order to ensure sufficient drying and solidification. All samples possess integrity with chosen cement/sand ratios. Further investigations could be targeted to get samples with different ratios and analyze the cement/sand ratio effect in our experimental perspective.

Figure 1a-b

Pure concrete samples

Figure 2a-b

Calcite added concretes

In the study, an Am-Be isotropic neutron source with 2 Ci activity was used as a neutron source. Firstly, background values were determined by taking blank counts just by removing the paraffin blocks in front of the outlet beam of the source in the Howitzer, (I_0) without samples.

Then, each of the prepared samples was placed in front of the source and 5 measurements of 60 seconds were taken from each sample (I). A Radeye NL brand He-3 detector was used as a neutron detector (Figure 3).

Figure 3

Neutron shielding test system with Am-Be neutron source and He-3 detector

In Table 1, the counting results from pure concrete samples are given. Permeability rates (I/I_0) in Table 2 permeability percentages in Figure 4, are given.

Table 1

Counting Results of Pure Concrete Samples

Sample Thicknesses	Blank Count	2 cm	4 cm	6 cm	8 cm	10 cm
Concrete	941	520	390	191	149	127
	902	511	329	191	165	124
	891	527	368	207	167	120
	906	603	334	206	154	126
	876	561	383	206	172	124
Average	903	544.4	360.8	200.2	161.4	124.2

Table 2

Permeability rate of pure concrete samples

Sample Thicknesses	2 cm	4 cm	6 cm	8 cm	10 cm
The Rate of Permeability (I/I_o)	55.14	41.36	20.25	15.80	13.47
	52.25	33.64	20.25	16.87	12.68
	52.86	36.91	20.76	16.75	12.04
	64.29	35.61	21.96	16.42	13.43
	60.58	41.36	22.25	18.57	13.39
Average	57.02	37.78	21.10	16.88	13.00

Figure 4

Permeability percentages of pure concrete samples

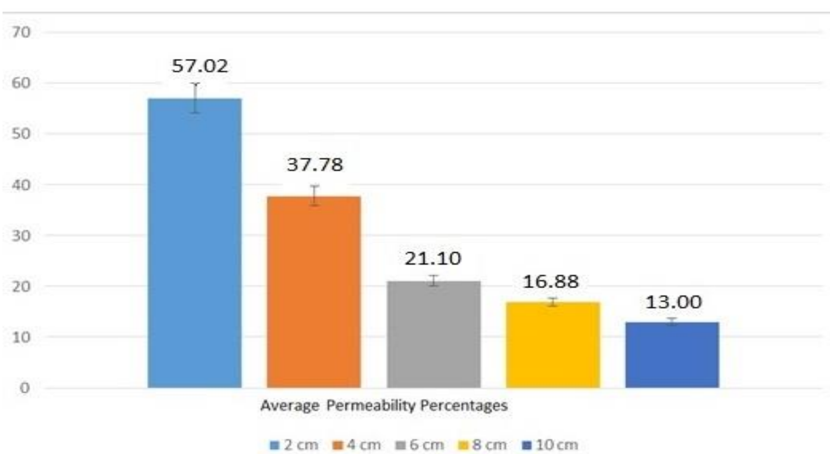


Table 3 shows the I and I_0 values obtained from the measurements for calcite concrete samples. Permeability rates (I/I_0) are given in Table 4. In Figure 5, the graph of the permeability percentages is given.

Table 3

Counting Results of Calcite-Concrete Mixed Samples

Sample Thicknesses	Blank Count	2 cm	4 cm	6 cm	8 cm	10 cm
Calcite+Concrete Mixture	941	715	392	238	192	135
	902	679	413	267	181	144
	891	723	413	252	200	144
	906	701	391	251	179	132
	876	705	397	270	179	137
Average	903	704.6	401.2	255.6	186.2	138.4

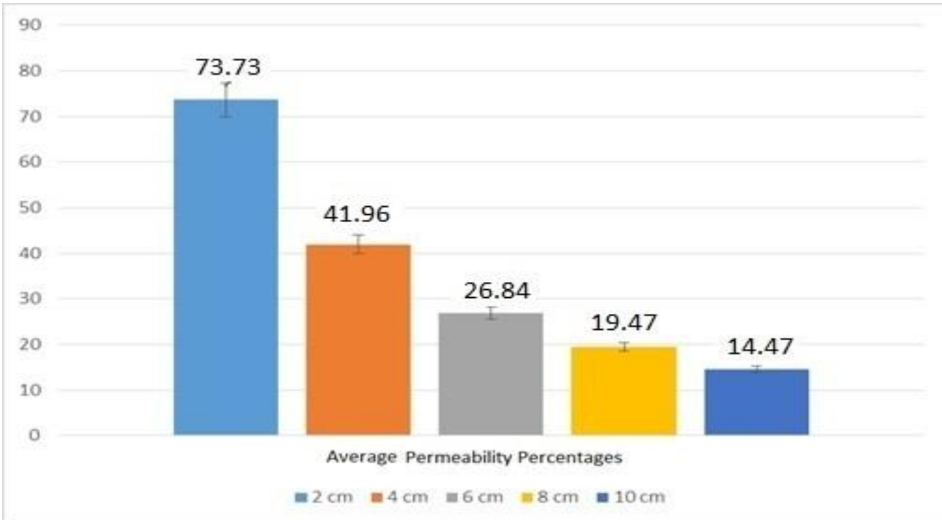
Table 4

Permeability Rate of Calcite-Concrete Mixed Samples

Sample Thicknesses	2 cm	4 cm	6 cm	8 cm	10 cm
The Rate of Permeability (I/Io)	75.82	41.57	25.24	20.36	14.32
	69.43	42.23	27.30	18.51	14.72
	72.52	41.42	25.77	20.06	14.44
	74.73	41.68	26.76	19.08	14.07
	76.13	42.87	29.16	19.33	14.79
Average	73.73	41.96	26.84	19.47	14.47

Figure 5

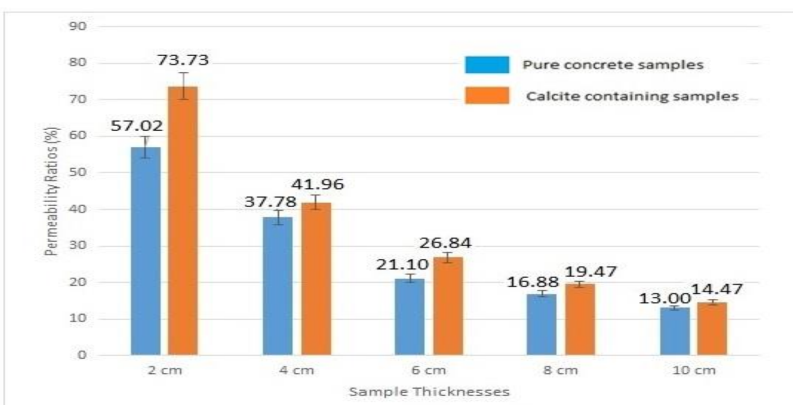
Permeability Percentages of Calcite Concrete Samples



Both types of concretes shielding results can be seen side by side in Figure 6 to be able to make comparison of results of the neutron experiments easier.

Figure 6

Comparison of Permeability Percentages of Samples



RESULTS AND DISCUSSION

As a result of this experiment, it was determined that the neutron shielding of the calcite mixed concrete was weaker than the pure concrete as can be seen obviously from Figure 6 above. Calcite added concrete passes neutrons more (when each thickness value is compared within itself) than normal concrete. Among the most obvious reasons for this, it can be stated that the calcite-added concrete is insufficient in terms of light elements and it is a heavier material than normal concrete. Results that reached from concretes reinforced with high thermal neutron cross section materials as mentioned in Tuna and Bayrak (2017) and Tuna at al. (2021) were satisfying when compared with calcite reinforced samples so that boron like elements could choose for reinforcing concrete like matrixes.

In addition, according to the test results, it was observed that the shielding ratio increased in both concrete types with the increase of the sample thickness (Figure 4-5). At the same time, when evaluated in terms of thickness and holding efficiency, the results show us that the ideal thickness is around 10 cm.

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Author Contributions

All authors conceived of the presented idea and take responsibility in literature review. Planning methodology to reach the conclusion was performed by all authors. İpek Balnan, Melek Gülnur Samur fabricated the samples and carried out the experiments. Tuncay Tuna and Nursel Sezgin processed the experimental data. Tuncay Tuna wrote the manuscript with support from İpek Balnan, Melek Gülnur Samur and Nursel Sezgin. All authors discussed the results, provided critical feedback, helped shape the research and contributed to the final manuscript.

Conflict of Interest

The Authors declare that there is no conflict of interest.

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Notes

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Ethical Statement

There is no requirement of Ethics Committee Approval for review articles.