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Mini Review

Recent Developments in Concrete as a Gamma Ray Shielding Material

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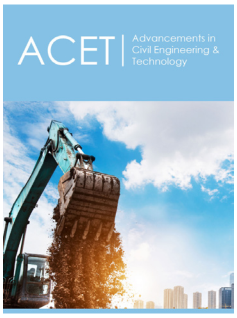

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Abstract

Concrete with fillers can serve as a shield material against harmful radiation effects due to availability of materials, low cost, high strength, and adaptability in various environments. An overview of the recent developments in concrete as a gamma ray shielding material along with important aspects of aggregates in various nuclear isotope applications in presented.

Abbreviations: HDC: Heavy Density Concrete; GSC: Grit Scale Concrete; LAC: Linear Attenuation Coefficient; MAC: Mass Attenuation Coefficient; EBF: Exposure Buildup Factor; MFP: Mean Free Path; BC: Barite Concrete; DC: Dolomite Concrete; RPC: Reactive Powder Concrete; OC: Ordinary Concrete; HWUHPC: Heavyweight Ultra-high-performance Concrete; UHPC: Ultra High-performance Concrete; Bi-GGBS: Bismuth Ground Granulated Blast Furnace Slag

Introduction

Due to the increase in nuclear technology sector, it is of prime importance to improve the isolation of harmful effects of radiation on the environment and humans in gamma irradiation facilities [1-4]. The applications of nuclear radiation are in nuclear power plants [5], cancer therapy rooms [6], nuclear medicine, food preservations, agriculture, archaeology, insect control, space exploration inspection and instrumentation [7-9]. However, its shielding is evitable due to the accompanied harmful effects on the environment and the living things.

Gamma-ray shields can be made out of a variety of engineering materials. Lead, for instance, is commonly used as a radiation shield because of its high density and high atomic number [10]. However, due to its high weight, expensive, and molding constraints, its utilization as a construction material is limited [11]. Interconnected graphite bricks are widely used in UK gas-cooled nuclear reactors not only to counter radiation effects but also thermal stresses due to high temperatures [12]. Iron slag added to cement mortars improves their ability to absorb gamma rays and significantly impacts shielding efficiency [13]. PbO/nano-clay composites are appropriate materials for shielding applications due to their ability to attenuate low-energy gamma rays [14].

Concrete has received considerable attention as a gamma-ray shielding material in nuclear facilities due to its low cost, high strength, adaptability, and ease of molding techniques [15-17]. Concrete as shielding material has been utilized in nuclear facilities, casks, vaults, and as storage for Spent Nuclear Fuel (SNF) where it is exposed to severe conditions such as cracks, thermal loads, freeze & thaw, acids, radiation, and other environmental aspects [18-19]. Therefore, concrete has been a subject of interest since many decades to attenuate harmful radiation along with structural integrity.

Recent developments

Several studies have been conducted to understand the applications of concrete in nuclear power plants and installations related to radioactive materials considering its structural and protective properties [20-23]. Some of the heavyweight concrete incorporating different fillers in various radiation applications are given in the Table 1.

Table 1: Gamma ray shielding properties of different concreates

Concrete Type	Aggregates/Fillers	Application	Shielding Characteristic	Buildup
Grit iron scale HDC [24]	Grit scale iron aggregate	4th generation NPPs	LAC (cm^{-1}) OC = 0.177, GSC = 0.172 MAC (cm2/g) OC = 0.074 , GSC = 0.035	-
Modified HWC [25]	dolomite, barite, ilmenite, and celestite	Nuclear dry storage cask	LAC (cm^{-1}) Dolomite = 0.183, Barite = 0.230, Ilmenite = 0.217 and Celesite = 0.217	EBF Calculated upto 40 MFP for BC and DC
RPC [26]	Steel fibers (1, 2, and 3%)	Resistant against thermal temp. (25-700 °C) & gamma exposure	MAC (cm^2/g) OC = 0.0696, RPC1 = 0.0732 RPC2 = 0.0779, RPC3 = 0.073	
HWC incorporated with minerals [27]	Bi-GGBS	Nuclear radiation shielding and protection	LAC (cm^{-1}) 0.1430 for 20% Bi-GGBS 0.1446 for 40% Bi-GGBS MAC (cm^2/g) 0.0568 for 20% Bi-GGBS 0.0577 for 40% Bi-GGBS	
HWUHPC [28]	Hematite powder	Radiation shielding	HWUHPC showed 40% more shielding than HWCC	
UHPC [29]	Fiber reinforced	Concrete nuclear waste container	UHPC showed 60% less weight. Wall thickness reduced from 550 mm to 300 mm	
HWC with Fe [30]	Fe traces	Nuclear radiation shielding at high temperature	MAC (cm^2/g) OC = 0.033 Before heating & 0.0327 after heating HWC = 0.0334 before heating & 0.0329 after heating	EBF for OC, HDC for large energy range
Boron oxide concrete composite [31]	12-20% basalt fibers	Fast fission spectrum and thermal LWR	LAC (cm^{-1}) 12% of B_2O_3 Concrete = 0.18 30 % of B_2O_3 Concrete =0.19	
HDC [32]	Magnetite, iron scale and barite	Containment vessel nuclear power plant	Long term irradiation using Sc-46, Cr-51, Mn-54, Co-58, Fe-59 in MBq range	

Summary and Conclusion

Concreates with different fillers like Grit iron scale HDC (with Grit scale iron aggregates), Modified HWC (with dolomite, barite, ilmenite, and celestite), HWUHPC (with Hematite powder), UHPC (with Fiber reinforced), and HDC (with Magnetite, iron scale and barite) etc. can be used for gamma-ray shielding, NPPPs containment, spent fuel storage etc. in the field of nuclear engineering. The advantages of using concrete as shielding material include low cost, high strength, and adaptability in various environments which makes it an important nuclear shielding material even at elevated temperature and harsh radiation environment.

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