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IMPACT OF STEEL FIBERS ADDITIVES ON PHOTON ATTENUATION COEFFICIENT OF CONCRETE

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ABSTRACT
Commercial steel fibers were added to concrete and photon attenuation coefficients of the composite were evaluated using MCNP5. Steel fibers were added at 1, 2, 3, and 4 $^{w}/_{o}$ to concrete, and attenuation coefficient was evaluated for 0.511, 0.662, 1.170, 1.274, and 1.330 MeV photons. All composites showed slight increase of attenuation coefficient compared to simple concrete at all photon energies. Increase of steel fibers percentage in concrete had little effect on photon attenuation coefficient of the composite concrete. Conclusively, adding steel fibers to concrete to increase its photon attenuation coefficient proved only minimal success. Photon attenuation coefficient at most increased by 5% at 0.511 MeV photon energy. Also, the tenth value layer was at most decreased by 10% also at 0.511 MeV photon energy. The slight reduction in concrete shield thickness is outweighed by the increase in shield mass due to the added steel fibers.

KEYWORDS:
Steel Fibers, Concrete, Photon Attenuation Coefficient, Tenth Value Layer

INTRODUCTION

Concrete is a common photon (X-or gamma rays) shield due to its low cost and convenient mechanical properties. However, due to its relative low density compared to most common metals, its photon attenuation coefficient is accordingly relatively low. It is anticipated that increasing the density of the concrete shield by adding a heavy material to it such as steel fibers will improve its photon attenuation coefficient (Makarious, 1996). Several works have been carried out to determine the attenuation properties of shielding materials (Bashter, 1992, 1997, 1997, El-Bakkoush, 2000, Bashter, 2001, Salinas, 2006).

OBJECTIVES

This work investigated the improvement in photon attenuation coefficient of concrete on reinforcing it with commercial steel fibers at different weight percentages.

MATERIALS

MCNP5 code was used to model conventional experimental set up for estimating photon's linear attenuation coefficient (μ) of a concrete block. This composed of an isotropic point photon source inside a thick Pb shield, with a narrow ray exit tunnel. Rays were received into a completely shielded detector except for a narrow tunnel facing and in line with the ray exit tunnel from the source. The concrete block was located in-between the source ray tunnel, and the detector ray tunnel. To tally the unshielded photon flux inside the detector (Φ_o), one model had no concrete block, see figure 1.

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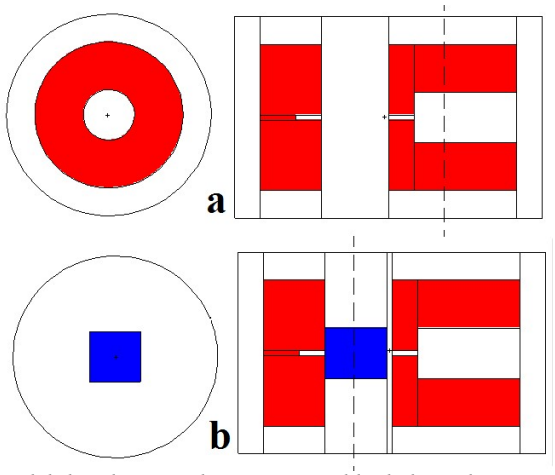

Fig. 1. *Model details; a: without concrete block, b: with concrete block.*

Photon Source

The photon source was located at the dead end of the source tunnel, shielded by a thick Pb shield. It emitted photons at energies 0.511, 0.662, 1.170, 1.274, and 1.330 MeV, each in an individual model. Rays were allowed out in only one direction through a narrow collimator tunnel heading onto the investigated concrete block.

Detector

The detector was located on the other side of the concrete block, defined as a right cylinder enclosed in a thick Pb shield. Photons reach the detector volume only through a long narrow tunnel in its shield facing and in line with the source exit tunnel. See figure 1.

The Concrete Block

The concrete block was modeled as a cuboid 10 × 10 × 12 cm. Its material was as in table 1.

Table 1. *Concrete sample element composition. (Density = 2.3 g·cm^{-3}) (Tekin, 2016).*

Element	Mass fraction (%)
H	1
C	0.1
O	52.9107
Na	1.6
Mg	0.2
Al	3.3872
Si	33.7021
K	1.3
Ca	4.4
Fe	1.4

In other models, steel fibers were added to concrete at mass percentages of 1, 2, 3, and 4%. Each steel fiber was 1.0 cm long, and 0.04 cm in diameter. Its material was as in table 2.

Table 2: *Steel fiber element composition. (Density = 7.9 g·cm^{-3}) (CCTTC - 08X18H10T Datasheet).*

Element	Mass fraction (%)
Fe	68.22
Cr	18
Ni	10
Mn	2
Si	0.8
Ti	0.6
Cu	0.3
C	0.08

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Steel fibers were dispersed evenly within the concrete matrix. In MCNP, the concrete matrix was divided into similar repeated cubic based prisms of length = 1cm. The steel fiber was modeled as an axial cylinder of diameter = 0.04 cm, 1 cm long (Henan Zhancheng Trading Co., Ltd). The base side length (L) of the prism was calculated according to the percentage of steel fibers, such that the steel fibers percentages were 1, 2, 3, and 4 % in mass relative to concrete, see figure 2. To mimic reality, the steel fibers orientations were twice perpendicular to the photon rays, and once aligned with them, to avoid any possible tunneling effect.

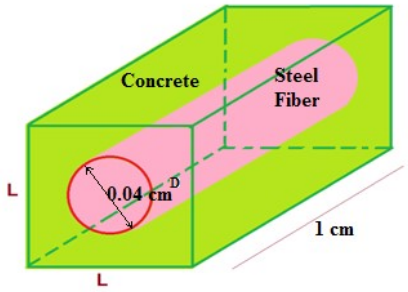

Fig. 2. *Lattice unit; cube based prism of concrete with an axial steel fiber.*

METHODOLOGY

MCNP5 code was used to tally the un-attenuated (Φ_o) and un-collided (Φ) photon fluxes inside the detector without and with the concrete block respectively, for all photon energies and all steel fiber percentages investigated. Hence, photon linear attenuation coefficients (μ) of the concrete blocks were calculated, at the all investigated energies. Calculated photon linear attenuation coefficients (μ) were used to calculate the tenth value layer for the concrete blocks.

RESULTS AND DISCUSSION

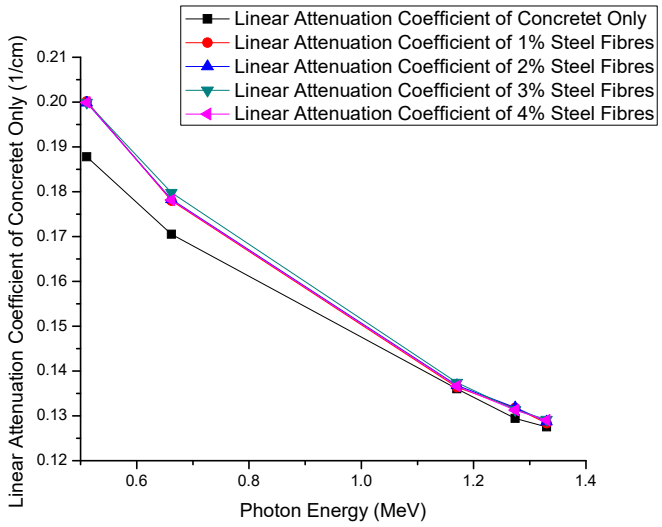

Fig. 3. *Linear attenuation coefficients (μ) for concrete blocks containing 0, 1, 2, 3, and 4 % steel fibers in mass vs. photon energy.*

Figure 3 illustrates that all composites containing steel fibers had greater linear attenuation coefficients (μ) compared to simple concrete; at all photon energies. However, the differences between linear attenuation coefficients (μ) of composites with different percentages of steel fibers were small. Increase in linear attenuation coefficients (μ) was more at photon energies < 1.17 MeV.

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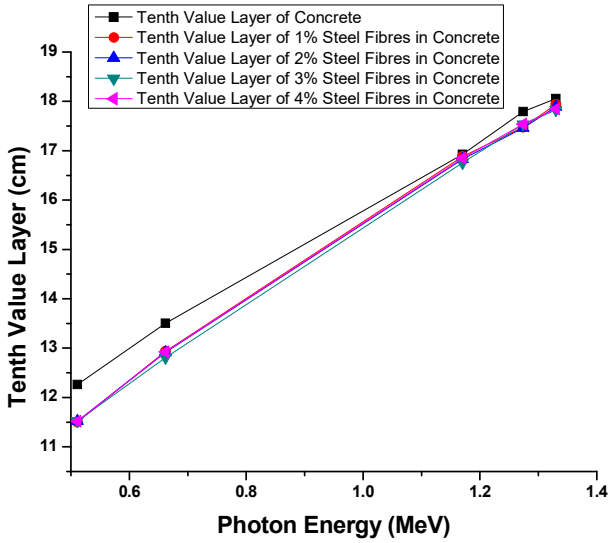

Fig. 4. *Tenth value layer of the concrete blocks containing 0, 1, 2, 3, and 4 % steel fibers in mass. vs. photon energy.*

Figure 4 illustrates that below 1.17 MeV photon energy, all composites containing steel fibers had slightly smaller tenth value layer (TVL) compared to simple concrete. However, the differences in TVL were small.

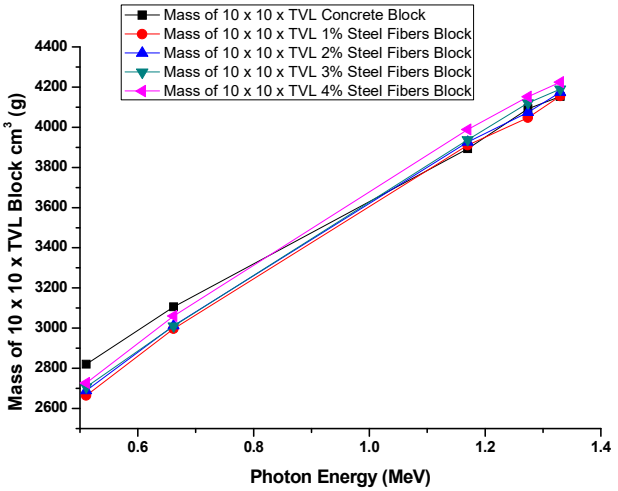

Fig. 5. Mass of 10 × 10 × TVL (cm^3) concrete blocks containing 0, 1, 2, 3, and 4 % steel fibers in mass. vs. photon energy.

Figure 5 shows that the masses of TVL concrete blocks containing 0, 1, 2, 3, and 4 % steel fibers were closely equal. This implies that there's no significant weight reduction of the concrete shield block if it was reinforced by steel fibers

CONCLUSION

Adding steel fibers at mass percentages of 1, 2, 3, and 4 % to concrete on purpose of increasing its photon attenuation coefficient proved only minimal success. Photon attenuation coefficient wasn't increased by more than 5% at best, which was achieved at 0.511 MeV photon energy. Tenth value layer wasn't reduced by more

than 10% at best, which was also achieved at 0.511 MeV photon energy. Such slight reduction in concrete shield thickness is outweighed by the increase in shield mass due to the added steel fibers. So, it can be concluded that adding steel fibers to concrete on purpose of increasing its photon attenuation coefficient is not practical.

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