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Evaluation of physical characteristics and microscopic structure of mortar containing synthetic resin

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HIGHLIGHTS

- The applicability of synthetic resin as neutron shielding aggregate were evaluated.
- The strengths showed overall reduction regardless of the type of synthetic resin.
- The HDPE and PP appeared that the ITZ was wider than OPC.
- The UPE was the dense than the HDPE and PP.
- The UPE shows even distribution at the whole but the HDPE and PP are not uniform.

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ABSTRACT

This study investigated the applicability of synthetic resin as neutron shielding aggregate provided by its high hydrogen content. The adopted synthetic resin was mixed using quantities of high density polyethylene (HDPE), polypropylene (PP) and ultra-high molecular weight polyethylene (UPE) replacing the fine aggregates by volume ratios of 20%, 40% and 60% converted into weight. Slump flow and tensile and compressive strength tests were conducted to evaluate the physical properties of the mortar, and image analysis, SEM and X-ray CT were performed on the fracture surface to examine the micro-structure inside the specimens. The flow of the mortar containing synthetic resin increased when using HDPE and PP but decreased in the case of UPE. Besides, the tensile and compressive strengths tended to reduce at the whole regardless of the type of resin. The image analysis showed that the strength of mortar containing HDPE and PP was influenced by the fraction of synthetic resin at the fracture surface regardless of the quantities. It seemed that the non-uniform distribution of the materials and faults with the cement matrix inside mortar provoked the loss of strength. On the other hand, larger content in powdered UPE increased the internal porosity. The loss of strength remained insignificant under a definite level but became steep beyond this level and, especially for replacement ratio higher than 60% in the present study.

1. Introduction

During the last 200 years, concrete has been one of the most utilized construction materials owing to its remarkable economy, safety and durability. In a will to supplement the drawbacks of concrete, recent research has focused on solutions admixing steel and glass fibers or impregnating organic compounds like polymers [1].

Especially, the combination of concrete with organic compounds from the polymer technology has found a variety of purposes thanks to its outstanding improving effect on the tensile strength, flexural strength and adhesiveness enabling it to fulfill its role as structural material with durability and stability [2]. For example, it is applied to shield neutrons produced in nuclear reactors, or in the transport and storage of radioactive substances [3,4].

In general, neutron shielding is achieved sequentially by first damping the high speed neutron ray ranging between 0.5 and 10 MeV into thermal and low speed neutron rays through linear and nonlinear dispersion followed by the absorption of the ray [5]. Hydrogen is used to disperse the high speed neutron ray into

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low speed neutron ray and boron to absorb the so-obtained low speed neutron ray.

Recently, neutron shields using polymers and advanced materials were developed by USA and Japan, and benchmarked by Korea, which proposes now diversified products [6–9]. These shields are mainly available in the form of block-type products that can be used as supplemental shields by admixing liquid solutions like epoxy resin, admixtures and boron, or are applied in the form of powdered hydrogen and boron on the concrete surface to generate a thin coating film [10,11]. However, the block-type and coating film shields have limited application since they increase the initial construction cost and are used as a secondary member rather than be exploited directly as material of concrete. Accordingly, this study intends to evaluate the applicability of available synthetic resins as aggregates in neutron shielding concrete without being limited by the size and shape of the members while being economically efficient.

Since synthetic resin is composed mainly of hydrogen and carbon, it is effective for the shielding of fast neutron [12,13]. Therefore, the exploitation of such synthetic resin as substitute to aggregate is likely to not only save significantly the initial construction cost but also to be helpful in further reduction of radioactive wastes. Among the currently available synthetic resins, polypropylene (PP) as a material extensively adopted in construction is used in this study considering its economy, and its composition similar to high-density polyethylene (HDPE) rich in hydrogen and carbon. In addition, ultra-high molecular weight polyethylene (UPE) which has a composition identical to HDPE but different molecular weight and particle size is also selected for the investigation.

With regard to these selected synthetic resins, basic physical tests are conducted on mortars with various contents in synthetic resins to analyze their mechanical characteristics. Moreover, image analysis is also carried out to examine the composition and internal profile of mortar containing synthetic resins. The results are displayed in three-dimensional images to evaluate the applicability of the synthetic resin as aggregate-replacing material.

2. Test

2.1. Summary of test

Table 1 summarizes the setup of the test for the evaluation of the physical performance and microscopic structure of mortar containing synthetic resin. Three types of synthetic resin that are high density polyethylene (HDPE), polypropylene (PP) and ultra-high molecular weight polyethylene (UPE) are adopted. The quantities of synthetic resin are set with values corresponding to replacement ratios of 20%, 40% and 60% of fine aggregates with reference to HDPE. For comparison with HDPE, mortars were mixed with identical contents in PP and UPE. Moreover, comparison is done with respect to the physical properties of mortar without synthetic resin (MOR). A total of 10 types of mix compositions detailed in Table 2 are considered according to the type of synthetic resin and replacement ratio.

Table 1
Experimental plan.

	Factor	Type
Mixture	W/C	0.485
	Synthetic resin type	HDPE, PP, UPE
	Synthetic resin content (%)	0, 20, 40, 60
Experiment	Fresh mortar	Slump flow
	Hardened mortar	Tensile strength, compressive strength
		Cross section image
		SEM
		X-ray CT

2.2. Materials

The physical properties of the materials used in this study are listed in Tables 3 and 4. Type-1 ordinary Portland cement (specific gravity: 3.15 g/cm^3, fineness: 3800 cm^2/g) and fine aggregates produced by company A in Korea are adopted. The synthetic resins to replace the fine aggregates are HDPE, PP and UPE presenting higher content in hydrogen compared to other high molecular substances and their properties are arranged in Table 5. HDPE is produced by slurry method with particle size of about 5 mm and is a synthetic resin exhibiting a bi-modal molecular weight distribution with a weight-average molecular weight of about 350,000. PP, as a homo propylene made by polymerizing propylene only, shows molecular weight and size similar to HDPE. Finally, UPE presents a weight-average molecular weight of about 5 million with particle size of 120 μm.

2.3. Fabrication of specimens and testing method

The slump of fresh mortar was measured in compliance with KS L 5111. The compressive strength of hardened mortar was measured at 28 days on 50 × 50 × 50 mm cubes fabricated with respect to KS L 5105, and the tensile strength was measured at 28 days on specimens fabricated in compliance with KS L 5104 [21–23].

Besides, the fracture surfaces of the tensile specimens that completed the test were photographed and the images were simplified by distinguishing two zones: the synthetic resin zone and the zone apart. The synthetic resin was figured by pixels of 8-bit images of which each pixel was described by a 256-level value (from 0 to 255 with red color as close to 255) and the images were processed assuming synthetic resin beyond a definite threshold. This threshold was set to delimit a zone for which the brightness of the pixel is larger than 220 by comparing the actual specimen and scanned image.

X-ray CT provided rendering of the internal structure of each specimen using the X-EYE CT system (SEC Corporation) equipped with microfocus X-ray tubes enabling to realize resolution of 6.18 μm^3. The applied voltage and current were 150 kV and 100 mA, and a CCD camera was utilized to collect X-ray attenuation data at scanning. In order to achieve effective analysis of the grains of HDPE and PP in the image device, it was proposed to set the specimens as 50 × 50 × 50 mm cubes. However, since UPE is a powder with particle size of 120 μm, the cuboid were worked to have dimensions of 10 × 10 × 50 mm for UPE to solve the resulting loss of resolution with cubes of 50 × 50 × 50 mm. A total of 1024 images of the incisal surfaces were acquired through

Table 2
Details of mortar mixture specimens.

No.	W/C	Cement [g]	Water [g]	Fine aggregate [g]	Synthetic resin [g]
MOR	0.485	3978.4	1929.5	9747.1	0
H-20 (HDPE)		3978.4	1929.5	7797.7	97.9
H-40 (HDPE)		3978.4	1929.5	5848.3	195.8
H-60 (HDPE)		3978.4	1929.5	3898.9	293.7
P-20 (PP)		3978.4	1929.5	7797.7	97.9
P-40 (PP)		3978.4	1929.5	5848.3	195.8
P-60 (PP)		3978.4	1929.5	3898.9	293.7
U-20 (UPE)		3978.4	1929.5	7797.7	97.9
U-40 (UPE)		3978.4	1929.5	5848.3	195.8
U-60 (UPE)		3978.4	1929.5	3898.9	293.7