

*Original Article*

## Recycling of melamine formaldehyde waste as fine aggregate in lightweight concrete

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### Abstract

Lightweight concrete production using melamine formaldehyde (MF) waste as fine aggregate by partially replacing river sand was investigated. Two forms of MF waste, granules and waste powder, were employed to produce the concrete of 1,000 and 1,300 kg/m<sup>3</sup>. The replacements were 0%, 15%, 25% and 35% by weight with constant water-to-cement and cement-to-fine aggregate ratios of 0.5 and 1.0, respectively. The concrete containing 25% waste powder was found to achieve the highest compressive strength and comply with the ASTM standard for non-load-bearing lightweight concrete. The results revealed the potential of MF waste recycling as fine aggregate in lightweight concrete.

**Keywords:** recycling, melamine formaldehyde, waste, fine aggregate, lightweight concrete

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### 1. Introduction

Plastic is known as one of the most important innovations of 20<sup>th</sup> century. A rapid growth in plastic consumption has been seen worldwide in recent years. Many industries have used plastic in various functions and in many aspects, which also increase the production of plastic-related waste. Plastic waste management of both thermoplastic and thermosetting plastics has become a major concern in the world. Thermoplastic can be re-melted and easier to recycle in the plastic industry, such as polyethylene terephthalate. On the other hand, thermosetting plastic, such as melamine formaldehyde, cannot be re-melted by heating. Therefore, thermosetting plastic waste were disposed by either burning or landfilling, which leads to environmental problems due to the fact that plastic waste contains various toxic elements, which can pollute soil and water. Thus, this research describes the

recycling melamine formaldehyde waste as aggregate in lightweight concrete by retaining the waste in the concrete.

In Thailand, lightweight concrete is popular for construction of both interior and exterior walls for building. Lightweight concrete is an important building material in reducing of the load on the structure due to its acceptable strength with a low load. Lightweight concrete can be classified into various types by their method of production. In this study, the technique of cellular concrete was employed to produce lightweight concrete in the laboratory.

In the past decade, several studies have been reported on the utilization of plastic waste in concrete and construction materials especially solid waste from waste polyethylene terephthalate (PET) bottles (Albano *et al.*, 2009; Choi *et al.*, 2005; Choi *et al.*, 2009; Frigione, 2010; Ismail *et al.*, 2008; Marzouk *et al.*, 2007; Remadnia *et al.*, 2009; Saikia *et al.*, 2014; Yesilata *et al.*, 2009). According to the authors, the compressive strength of concrete containing PET aggregate is lower than reference concrete. The reduction in compressive strength was observable in a higher degree when using larger flaky PET aggregate. Also, experiments have

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been carried out by using melamine debris mixed with marginal lateritic soil for the improvement of engineering fill materials. (Donrak *et al.*, 2016). The results indicate that melamine debris reduces plasticity, unit weight and particle breakage of lateritic soil. Melamine debris can be used as a replacement material in lateritic soil improvement for engineering fill materials.

In addition, also previous research has been done utilizing other plastic waste in concrete (Asokan *et al.*, 2010; Fraj *et al.*, 2010; Hannawi *et al.*, 2010; Kou *et al.*, 2009; Panyakapo *et al.*, 2008). These researchers studied concrete containing glass fiber reinforced plastic, polyurethane (PUR) foam, polycarbonate (PC), polyvinyl chloride (PVC), melamine, respectively. However, few studies have been reported on the recycling of thermosetting plastic waste in lightweight concrete. Thus, it would be very interesting to recycle thermosetting plastic waste to produce cement composites, which might be one of the best solutions for disposing of plastic waste of economic advantages and environmentally friendly methods.

Therefore in this study, melamine formaldehyde (MF) waste has been recycled as fine aggregate for partially replacing river sand in lightweight concrete. This study has investigated the possibilities for the recycling of MF waste in the lightweight concrete. Density and mechanical properties were analyzed to achieve the purpose. The application of the lightweight concrete was the focus, particularly, for the non-load-bearing concrete wall in buildings.

## 2. Experimental Details

### 2.1 Materials

#### 2.1.1 Cement

Type I Portland cement conforming to ASTM C150-12 was used in the concrete mixtures with a specific gravity of 3.15 (technical data from manufacturer). The chemical composition of the cement is given in Table 1.

Table 1. Chemical composition of cement.

Components	Mass%
Calcium oxide (CaO)	66.33
Silica (SiO <sub>2</sub> )	18.6
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )	4.03
Alumina (Al <sub>2</sub> O <sub>3</sub> )	3.77
Sulphuric anhydride (SO <sub>3</sub> )	2.67
Magnesium oxide (MgO)	2.13
Sodium oxide (Na <sub>2</sub> O)	1.39
Potassium oxide (K <sub>2</sub> O)	0.46

#### 2.1.2 Sand

River sand was used as the fine aggregate in the concrete mixes with 1.97 fineness modules (FM), 2.52 average values of bulk specific gravity and 0.33% water

absorption are given in Table 2. Its particle size distribution, obtained from sieving according to ASTM C33-13 is provided on Figure 1.

Table 2. Physical and mechanical properties of lightweight aggregate (LWA) and MF waste.

Aggregate	Shape	FM/particle size*	Specific gravity	Water absorption (%)
Sand	Round and smooth	1.97	2.52	0.33
MF waste granules	Flaky and rough	3.98	1.50	5.51
MF waste powders	Powder	*34 micrometer	1.50	-

A mark "\*" is an average particle size of aggregate.

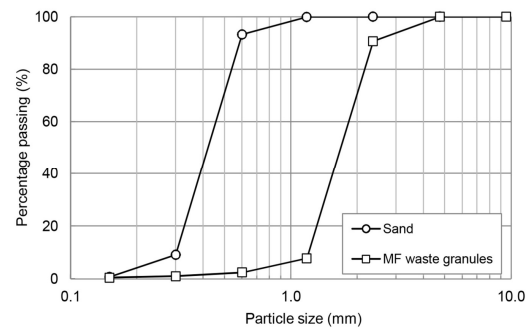


Figure 1. Gradation of sand and MF waste granules.

#### 2.1.3 MF waste

Melamine formaldehyde (MF) waste was used as fine aggregate, supplied from a Srithai Superware Public Company Limited, in Thailand. It was obtained by collecting discarded waste from the forming process of melamine products. Two different forms of MF waste, granule and powder, are shown in Figure 2 and 3. The crushed MF waste granules were separated under sieve no. 8 (pass in the 2.38 mm sieve) with 3.98 fineness modules (Figure 1), 1.50 specific gravity and 5.51% water absorption (Table 2). The MF waste powder was separated under sieve no. 140 (pass in the 0.105 mm sieve) for removal of impurities. Average and standard deviation sizes of MF waste powder were 34 and 29 micrometer (Figure 4), respectively. The MF waste was used to replace river sand by weight fraction in the concrete mixtures.

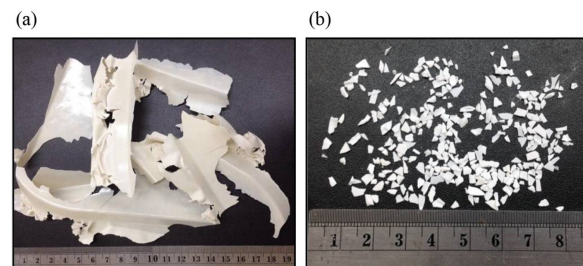


Figure 2. Recycled MF waste (a) before crushing and (b) after crushing.

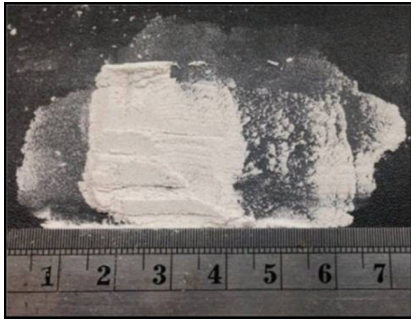


Figure 3. MF waste powders.

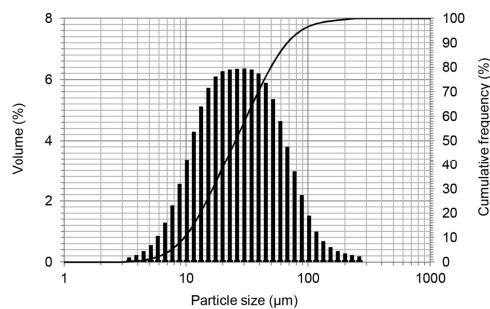


Figure 4. Particle size distribution of MF waste powders.

#### 2.1.4 Foaming agent

A foaming agent was used to produce foam. The foaming agent was diluted, 1:40 with water by weight, and then aerated by a foam generator to a density of 50 kg/m<sup>3</sup> according to ASTM C796-12. The mixing of water and chemical liquid created small air bubbles with sizes in the range of 0.1-1.0 mm. These small air bubbles were entrained in the fresh concrete, leading to an expansion of concrete volume. Thus, the foaming agent was used for controlling the density of the concrete mixes. This type of lightweight concrete is called cellular lightweight concrete (CLC).

#### 2.2 Sample preparation

The mixing of the concrete and molding of specimens were performed in accordance with ASTM C109-13. The constituent was proportioned by weight 1:1:0.5 (cement : fine aggregate : water). The MF waste was used to replace 0%, 15%, 25% and 35% by weight of river sand. The mix proportion and code of concrete mixtures are indicated in Table 3 and 4.

The wet density of the concrete mixtures was measured before casting. For the cube concrete specimen, 50 x 50 x 50 mm and 100 x 100 x 100 mm were casted for the determination of the compressive strength and the water absorption, respectively. A 65 mm high x 69 mm diameter cylindrical specimen was casted for measurement of the thermal conductivity. All the specimens were then de-molded, 24 hours after casting, and immediately covered with plastic film to prevent water loss. The specimens were air cured at room temperature and wrapped with plastic until the ages of testing.

Table 3. Mix proportions of concrete mixture.

Mixcode	MF0	MF15	MF25	MF35
Replacement (%)	0	15	25	35
Cement (ratio)	1	1	1	1
Sand (ratio)	1	0.85	0.75	0.65
MF (ratio)	0	0.15	0.25	0.35
Water (ratio)	0.5	0.5	0.5	0.5

Table 4. Code of concrete mixtures.

Code	MF waste form	Density (kg/m <sup>3</sup> )
Mix I	MF waste granules	1,000
Mix II	MF waste powders	1,000
Mix III	MF waste granules	1,300
Mix IV	MF waste powders	1,300

#### 2.3 Test methods

For each mixture, five samples were taken for the compressive strength testing, three samples for the water absorption testing and two samples for thermal conductivity testing. The test method and the related specifications of the properties determine are reported in Table 5. The wet density of the concrete was calculated by measuring the volume and weight of the fresh concrete before casting the molds. The dry density of the concrete was measured for the cubes taken from the mold prior to compressive strength testing according to ASTM C138-14. Five cubic specimens of each mixture were used to determine the compressive strength of the concrete at the ages of 3, 7, 14, 28, and 60 days. The cubes were tested immediately after being taken out of plastic film. The compressive testing machine was employed with a loading capacity of 2000 kN, according to ASTM C109-13. The load was applied continuously (0.40 MPa/sec) until the specimen failed. Three 28-day cubic specimens of each mixture were used for the water absorption test, according to ASTM D6489-12. Two cylindrical specimens, aged 28 and 60 days, of each mixture were used for the determination of thermal conductivity, according to ASTM E1225-13.

### 3. Results and Discussion

#### 3.1 Density

The dry densities of the different concrete mixtures at 28 and 60 days are reported in Figure 5. The dry density of all specimens slightly decreased with time due to the evaporation of water. The results indicated that the dry density of the control concrete (MF0) had little deviation from the designed density (1,000 and 1,300 kg/m<sup>3</sup>). On the other hand, values of dry density were slightly fluctuated from the design density for mixtures containing MF waste aggregate due to the influence of the MF waste during blending. The flow properties and homogeneity of the blend containing MF waste

were altered. The MF waste might yield a decrease of plasticity and compaction when compared with the control concrete.

### 3.2 Compressive strength

For specification of non-load-bearing lightweight concrete according to ASTM C129-11 type II standard, the compressive strength should be higher than 4.14 MPa and dry density lower than 1,680 kg/m<sup>3</sup>. The compressive strength results of the concrete mixtures are illustrated in Table 6 and

Figure 6. It was found that, the compressive strength developed rapidly at an early age up to 14 days because of a hydration reaction between the cement and water. However, after 14 days the compressive strength developments slowed down due to the decreasing amount of water in concrete CLC, which also confirmed similar results reported by Jitchaiyaphum *et al.* (2011). The compressive strengths were found to increase with the increase of MF waste content (both granules and powder MF wastes) and it was also found that the concrete containing MF waste showed the highest compressive strength at 25% MF waste content. It could be

Table 5. Methods of testing.

Properties	Detail of test	Specification
Dry density	50 x 50 x 50 mm cubic specimens were used to determine the dry density by measuring $D_d = (M_d / V_d)$ of dry concrete at the age of 28 and 60 days.	ASTM C138-14
Compressive strength	50 x 50 x 50 mm cubic specimens were used to determine the compressive strength of concrete at the age of 3, 7, 14, 28 and 60 days. A compressive testing machine with a loading capacity of 200 kN was used for the experiment. The load was applied continuously (0.40 MPa/sec.) until the specimen failed.	ASTM C109-13
Water absorption	100 x 100 x 100 mm cubic specimens were used to determine the water absorption by measuring $W_a = ((M_{sat} - M_d) / M_d)$ of concrete at the age of 28 days.	ASTM D6489-12
Thermal conductivity	65 x $\Phi$ 69 mm cylinder specimens were used to determine the thermal conductivity by measuring $K = (Q/A) / (\Delta T / \Delta L)$ of concrete at the ages of 28 and 60 days.	ASTM E1225-13

where:  $D_d$  (kg/m<sup>3</sup>)=the dry density of concrete,  $M_d$  (kg)= the mass of concrete,  $V_d$  (m<sup>3</sup>) =the volume of concrete,  $W_a$  (%)=the water absorption,  $M_{sat}$  (kg)=the mass of the sample in saturated surface dry state,  $M_d$  (kg)=the mass of the sample in a dry state,  $K$  (W/m.°C)=the thermal conductivity,  $Q$  (W)=the amount of heat passing through a cross section,  $A$  (m<sup>2</sup>)=the cross section,  $\Delta T$  (°C)=the temperature difference,  $\Delta L$  (m)=the distance of temperature difference.

Table 6. Compressive strength of concrete mixture.

Code	MF waste form	Density (kg/m <sup>3</sup> )	Mix code	Fine aggregates (100%)		Compressive strength (MPa)				
				Sand content	MF waste content	3 days	7 days	14 days	28 days	60 days
				(wt%)	(wt%)					
Mix I	MF waste granules	1,000	MF0D10	100	0	0.95	1.15	1.21	1.21	1.49
			MFG15D10	85	15	1.03	1.44	1.48	2.17	2.29
			MFG25D10	75	25	1.11	1.79	2.00	2.09	2.41
			MFG35D10	65	35	0.84	1.30	1.32	1.74	1.89
Mix II	MF waste powders	1,000	MF0D10	100	0	0.95	1.15	1.21	1.21	1.49
			MFP15D10	85	15	1.33	1.62	2.05	2.16	2.18
			MFP25D10	75	25	1.86	2.12	2.42	2.65	2.78
			MFP35D10	65	35	1.25	1.59	1.92	2.20	2.40
Mix III	MF waste granules	1,300	MF0D13	100	0	1.56	1.83	2.61	2.74	3.14
			MFG15D13	85	15	2.53	3.34	3.53	4.26	4.40
			MFG25D13	75	25	2.76	3.95	4.11	4.12	4.70
			MFG35D13	65	35	1.63	2.17	2.78	3.11	3.24
Mix IV	MF waste powders	1,300	MF0D13	100	0	1.56	1.83	2.61	2.74	3.14
			MFP15D13	85	15	1.79	2.09	3.27	3.54	3.73
			MFP25D13	75	25	2.78	3.42	4.90	5.65	5.74
			MFP35D13	65	35	1.72	2.42	2.99	3.30	3.44

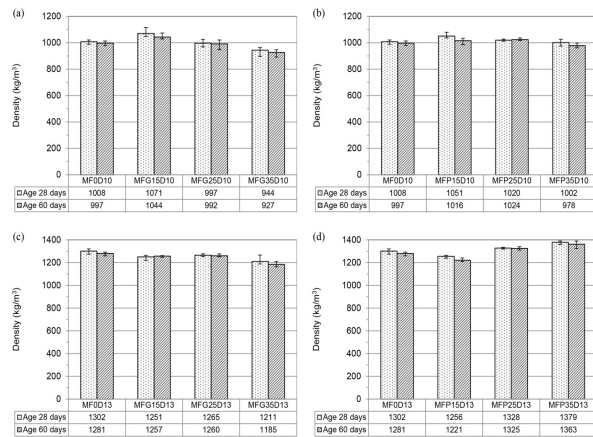


Figure 5. Dry density of concrete mixtures (a) Mix I, (b) Mix II, (c) Mix III, and (d) Mix IV.

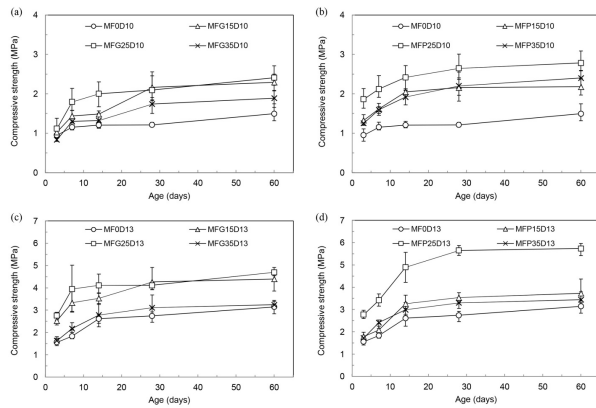


Figure 6. Compressive strength of concrete mixtures (a) Mix I, (b) Mix II, (c) Mix III, and (d) Mix IV.

explained that this is due to the influence of the w/c ratios on the compressive strength of concrete at various proportions of MF waste. Then, while increasing the MF waste content (both granules and powder MF wastes), the compressive strengths were increased due to the MF waste having high water absorption and leading to w/c ratios that were relatively reduced. This behavior might affect the amount of hydration reaction between cement and water, especially, the appropriate concrete mixtures with 25% of MF waste. Similar behavior was also observed by Dweik *et al.* (2008), the test results revealed that MF waste had a considerable influence on concrete strength. The same author also reported the best compressive strength with 0.6:1 w/c ratio of 30 wt% MF waste mixture.

The compressive strength values of the concrete containing 25% MF waste granules (Mix I and Mix III) at 28 days were 2.09 and 4.12 MPa and reached 2.41 and 4.70 MPa at 60 days, respectively. The compressive strength of the concrete containing 25% MF waste powders (Mix II and Mix IV) at 28 days were 2.65 and 5.65 MPa at 28 days. At 60 days, their levels rose to 2.78 and 5.74 MPa, respectively. It could be suggested that the compressive strength of the MF waste powder containing mixtures, Mix IV, could be classified as a non-load-bearing lightweight concrete.

Based on understanding, an increasing of the compressive strength could be concluded as followed: The MF wastes both granule and powder can absorb water, hydration reaction between cement and water does occur on their surfaces. Therefore, bonding between cement paste and MF waste aggregate is quite strong. The rough surface texture and flaky shape of the MF waste provides more surface area (Figure 7) which led to an increased bond strength between the MF waste and cement. The compressive strength of concrete containing melamine waste powder is higher than that of the melamine waste granules. A blending of the fine aggregates (MF waste and sand) have a better gradation result to increase compressive strength of the concrete. Especially, the replacement of river sand by melamine waste of 25% showed the highest compressive strength. Figure 8 shows the scanning electron microscopy analysis between cement paste and river sand (a), MF granule (b) and powder (c) wastes in mortar at the age of 28 days. The result reveals that adhesion between cement paste and MF granule waste is quite good with no gap at the edge of the granule. Thus, there could be a similar function considered for replacing sand aggregate because the physical characteristics of the MF waste, which have a flaky shape and rough surface texture. Similar behavior was observed by Marzouk *et al.* (2007). Figure 8(c) also indicated the better blend of the MF powder with sand and cement paste, which led to higher compressive strength of the MF powder mixture than that of the granule.

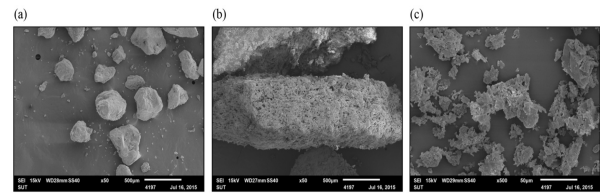


Figure 7. Scanning electron micrographs showing surface of fine aggregates (a) river sand, (b) MF waste granules, and (c) MF waste powders.

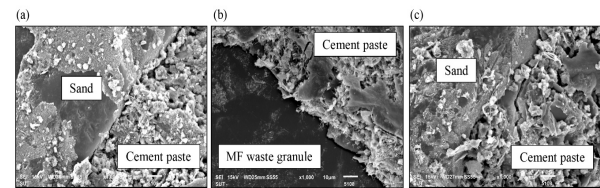


Figure 8. Scanning electron micrographs showing fracture surface of concrete mixture (a) MF0D10, (b) MFG25D10, and (c) MFP25D10.

### 3.3 Comparison between standards and test results

Based on the results, described above, the appropriate proportions of MF waste powder was 25%, which yielded the compressive strength of 5.65 MPa and dry density of 1,328 kg/m<sup>3</sup>. These could be comparable to the specifications according to ASTM C129-11 Type II standard for non-load-bearing lightweight concrete, as shown in Table 7. The compressive strength of MF waste containing lightweight concrete, found in this study, was higher than that of the non-load-bearing lightweight concrete Type II standard (ASTM C129-11).

Table 7. Specification of non-load-bearing lightweight concrete (ASTM C129-11).

Type	Compressive strength (MPa)		Density (kg/m <sup>3</sup> )
	Average of three units	Individual unit	
II	4.14	3.45	1,680

### 3.4 Water absorption

Water absorption of different concrete mixtures at 28 days is given in Figure 9. The experimental results revealed that the water absorption of concrete containing MF waste tended to be increased with an increase of MF waste contents (both granules and powder MF waste). The melamine debris is able to absorb water better than sand due to the water absorption of MF waste (5.51%) is higher than that of river sand (0.33%).

### 3.5 Thermal conductivity

The test results for the evaluation of thermal conductivity of the concrete mixtures at 28 and 60 days are presented in Figure 10. The experimental results showed that replacing sand with MF waste significantly affect thermal conductivity of the concrete compared with the control concrete (MF0). The thermal conductivity of concrete containing MF waste is slightly higher than that of the control concrete, which was increased with an increase in MF waste content (both granules and powder MF wastes) although the conductivity of sand is higher than that of MF. MF waste replacement significantly influences the thermal conductivity. Packing the two fine aggregates (MF waste and sand) led to an increased transmission of thermal conductivity. However, the conductivity of MF waste containing concrete was lower than that of general lightweight concrete (Sengul *et al.*, 2011).

## 4. Conclusions

MF waste was recycled by replacing river sand in lightweight concrete as a fine aggregate with an increasing replacement ration of the sand by MF waste, it could be concluded as followed: (1) The dry density was slightly fluctuated from design density, not more than  $\pm 90$  kg/m<sup>3</sup>. (2) Compressive strength was increased with an increase in MF waste; the highest compressive strength was at 25 wt% and could be classified as non-load-bearing lightweight concrete according to ASTM C129-11 for 1,300 kg/m<sup>3</sup> mixture powder. (3) The water absorption was increased with an increase in MF waste, since the water absorption of MF waste is higher than that of river sand. (4) The thermal conductivity of concrete containing MF waste is slightly higher than that of the control concrete, because the packing of the two fine aggregates (MF waste and sand) is better than that of concrete containing only river sand.

The results of this study were expected to report the useful finding for recycling scrapped MF wastes by entrapment in lightweight concrete. The MF waste from melamine product manufacturing has a potential to be recycled as fine aggregates for non-load-bearing lightweight concrete. The appropriate sand replacement ratio should be 25 wt%.

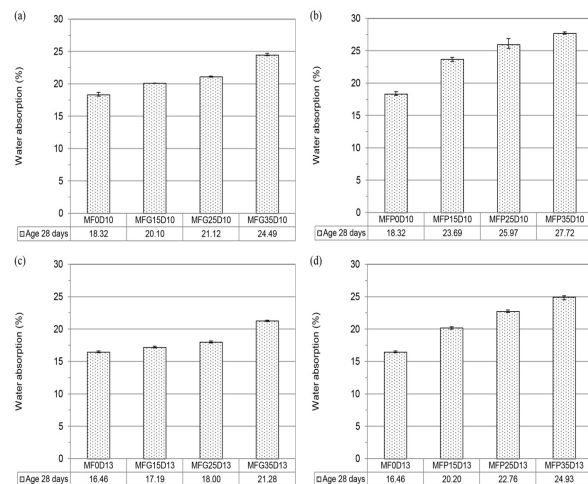


Figure 9. Water absorption of concrete mixtures (a) Mix I, (b) Mix II, (c) Mix III, and (d) Mix IV.

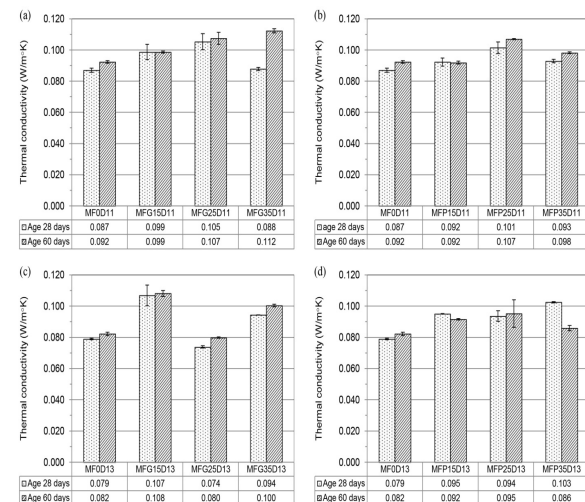


Figure 10. Thermal conductivity of concrete mixtures (a) Mix I, (b) Mix II, (c) Mix III, and (d) Mix IV.

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