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Effect of magnetic field treated water on mortar and concrete containing fly ash

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Abstract

This research investigates the workability and compressive strength of mortar and concrete, which were mixed with magnetic field treated water (MFTW) and contained fly ash. MFTW was obtained by passing tap water through a magnetic field. Test variables included the magnetic strength of water, fly ash content in place of cement, water-to-cementitious material ratio (W/CM) and curing age.

Results show that the compressive strength of mortar samples mixed with MFTW is higher than those prepared with tap water. The best compressive strength increase of concrete is achieved when the magnetic strength of treated water is of 0.8 and 1.2 T. The compressive strength increase of concrete prepared with MFTW is more significant at early age.

Keywords: Magnetic field treated water; Fly ash; Compressive strength; Workability; Mortar

1. Introduction

Water after passing through a magnetic field of certain strength is called magnetic field treated water (MFTW) or magnetized water. In 1962, Wulachoufuski and Alnanina in Russia started researches on using MFTW to mix concrete [1]. Similar researches were also conducted in Japan, Europe and China confirming that MFTW could improve concrete strength as much as 10% [2,3]. Hence, it can save 5% of cement dosage, decrease bleeding of concrete and improve resistance to freezing [1,4]. The reason why MFTW can improve characteristics of concrete can be explained by the molecular structure of water. Water is a polar substance, which tends to be attracted to each other by hydrogen bonding and forms clusters as illustrated in Fig. 1(a) [5]. These associations and disassociations of water molecules are in thermodynamic equilibrium. In general, each cluster contains about 100 water molecules at room temperature as shown in Fig. 2 [6,7]. In a magnetic field, magnetic force can break apart water clusters into single molecules or smaller ones as shown in Fig. 1(b), therefore, the activity of water is improved [8]. While hydration of cement particles is in progress, the MFTW can penetrate the core region of cement particles more easily. Hence, hydration can be done more efficiently which in turn improves concrete strength. When cement particles are surrounded by MFTW of same electrical charges, these particles will repel each other and thus disperse cement clusters which facilitates the flow of entrapped mixing water. In addition, when hydration takes place, it forms hydration layer on the cement exterior, which prevents further penetration of other water molecules. As magnetized water molecules are rather dispersed or of small clusters, they can penetrate through the hydration layer more easily and therefore, hydration is more complete. A Japanese patent claimed that when concrete is cured in a magnetic field, its hydration substance would tend to orient along the magnetic field, which results in increased compressive strength. A report on the use of MFTW in concrete mixing is also available [9]. The magnetized water can be kept in a reservoir for 0–12 h, over this range, its advantage may be lost [1,9]. Some other authors reported that water usually does not pick up magnetism easily. It becomes magnetized only temporary [1,4]. Once it leaves

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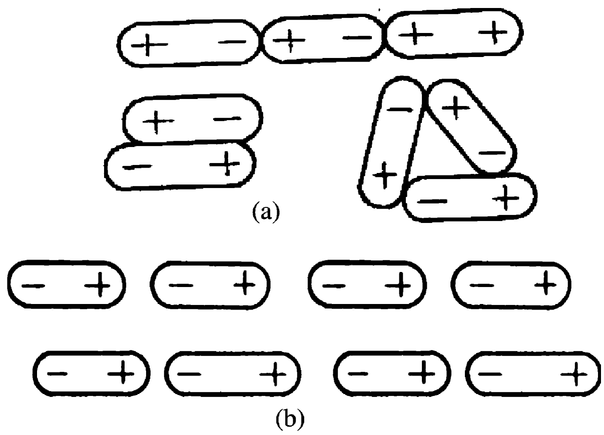

Fig. 1. Effect of magnetic field on water molecules: (a) thermodynamically stable water clusters, (b) water molecules after passing through a magnetic field.

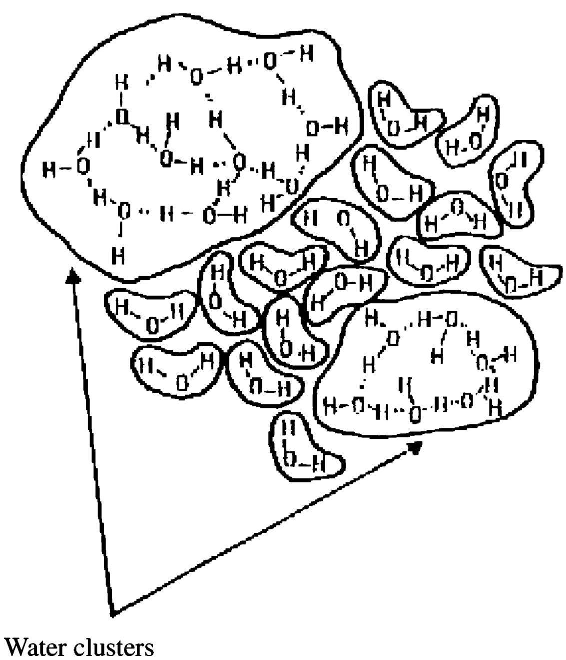

Fig. 2. Structure of molecule clusters of water.

the magnetic field, it returns to its original state. Therefore, calling it magnetized water is rather inappropriate and should be addressed as MFTW [10]. To know how the magnetic field affects water, Raychoukin pointed out that it affected water's hydrogen bonding and Pekercarki said it brought about structural and charge changes of ions in water [9]. The true mechanism still remains to be solved since many phenomena in liquid state have not been satisfactorily explained yet. Furthermore, studies on the effect of MFTW on concrete containing fly ash have also been rare. It is well known that fly ash is a pozzolanic material. Concrete with fly ash will decrease the waste pollution and enhance the engineering properties such as workability, long-term mechanical strength, and durability [11,12].

This study investigates the workability and compressive strength of cement mortar and concrete mixed with MFTW after different curing ages. Moreover, the effect of MFTW and microstructure of different magnetic strengths on the engineering properties and microstructure of fresh concrete prepared with fly ash substituting part of the cement is also examined.

2. Experimental design

2.1. Materials

The cement used is Portland cement Type I produced by Taiwan Cement Company. Indigenous fine and coarse aggregates are obtained from Tsuo-Shui River in Central Taiwan. Their physical properties and size gradation are shown in Tables 1 and 2, respectively. The standard sand for making the cement mortar samples is Ottawa sand with grading that meets the requirement of ASTM C788. The water used in the mixing and with

Table 1
Physical properties of coarse and fine aggregates

Properties	Type	
	Coarse aggregate	Fine aggregate
Specific gravity	2.65	2.63
Absorption (%)	0.89	1.18
Modulus of fineness	–	2.92

Table 2
Size gradation of coarse and fine aggregates

Coarse aggregate			Fine aggregate		
Sieve size	Pass (%)	ASTM C136 regulation (%)	Sieve size	Pass (%)	ASTM C136 regulation (%)
25 mm	100.0	100–90	4.75 mm	98.9	100–95
19 mm	81.8	–	2.36 mm	82.4	100–80
13.5 mm	30.0	60–25	1.18 mm	60.2	85–50
9.5 mm	16.1	–	600 μm	36.7	60–25
4.75 mm	1.1	10–0	300 μm	18.8	30–10
			150 μm	9.55	10–2

Table 3
Quality test of mixing water

Test item	Result	Regulatory standard for tap water
pH value	6.81	5–9
SO_4 salt (ppm)	134	<3000
Turbidity (NTU)	0.04	<4
Residue after evaporation (g/l)	2.3	<30
$KMnO_4$ consumed (mg/l)	~0	<10
Suspended solid (g/l)	~0	<2
Dissolved solid (g/l)	~0	<2
Cl (ppm)	11.5	<200

quality shown in Table 3 is produced by the Taiwan Tap Water Company in Touliu. Magnetization is carried out by passing the tap water through a magnetic field at 1350 l/h. Class F fly ash is obtained from a power plant of Taipower. Its physical and chemical properties are listed in Table 4. In this study, fly ash is used to substitute cement of equal weight in the mixing process.

2.2. Mixture proportioning of samples

2.2.1. Concrete samples

Cement, fly ash, water, as well as coarse and fine aggregates are mixed according to the proportions listed in Table 5 to produce cylindrical concrete samples ($\oint = 100$ mm, $h = 200$ mm). Compressive strength of concrete is measured after the samples have been cured at 23 ± 1 °C and 100% R.H. for 7, 28 and 56 days.

2.2.2. Mortar samples

Cubic samples (50 mm × 50 mm × 50 mm) are made by mixing cementitious materials (cement and fly ash) and standard sand according to the proportions shown in Table 6. The compressive strength of mortars is assessed after the samples have been cured at 23 ± 1 °C and 100% R.H. for 7, 28 and 56 days.

Table 4
Physical and chemical properties of fly ash

Test item	Test result	ASTM 618 (F class)
Physical properties		
Soundness (%)	0.021	<0.8
After #325 sieve (%)	13.05	<34
Multiple factor (%)	35.10	<255
Specific gravity	2.27	–
Chemical properties		
TiO_2 (%)	1.37	–
SiO_2 (%)	50.43	–
Al_2O_3 (%)	27.28	–
Fe_2O_3 (%)	3.73	–
CaO (%)	3.65	–
MgO (%)	1.23	–
SO_3 (%)	0.52	–
K_2O (%)	2.03	–
Na_2O (%)	0.49	–
pH value	9.20	–
Loss on ignition (%)	9.0	<12

Table 5
Mixture proportioning of concrete samples (W/CM = 0.485), unit: kg/m^3

Materials	Cement substitution by fly ash (%)			
	0	5	10	15
Cement	349	331	314	297
Mixing water	192	192	192	192
Coarse aggregate	969	969	969	969
Fine aggregate	784	784	784	784
Fly ash	0	18	35	52

2.3. Experimental variables

Tap water is treated by flowing through the magnetic field of 0.2, 0.4, 0.6, 0.8, 1.2 and 1.35 Tesla (T) while 0 T denotes plain tap water. Fig. 3 shows the magnetic-field-generating machine developed for this research. The size of this machine is 120 × 60 × 72 cm^3, and the weight is about 250 kg. The diameter of flow pipe is 25 mm. The magnetic field strength of this machine ranges from 0 to 5 T. The electric current at full load is 15 A. The water flow rate can be adjusted by a proportional integral differential (PID) controller in the range of 0 to 2000 l/h. The electromagnetic induction is generated by the N and S poles of magnet, which are made of copper induction coils. The water flow pipe is installed between two poles as show in Fig. 3. When tap water flows through this magnetic field, it turned into MFTW.

The water-to-cementitious ratio (W/CM) of concrete samples is 0.485, while those of mortar samples are 0.35, 0.4 and 0.485, respectively. For mortar samples, the percentages of cement substituted by fly ash include

Table 6
Mixture proportioning of mortar samples

Materials (g)	Cement substitution by fly ash (%)				W/CM
	0	5	15	25	
Mixing water	0.35	0.35	0.35	0.35	0.35
Standard sand	2.75	2.75	2.75	2.75	
Cement	1.00	0.95	0.85	0.75	
Fly ash	0	0.05	0.15	0.25	
Mixing water	0.40	0.40	0.40	0.40	0.40
Standard sand	2.75	2.75	2.75	2.75	
Cement	1.00	0.95	0.85	0.75	
Fly ash	0	0.05	0.15	0.25	
Mixing water	0.485	0.485	0.485	0.485	0.485
Standard sand	2.75	2.75	2.75	2.75	
Cement	1.00	0.95	0.85	0.75	
Fly ash	0	0.05	0.15	0.25	

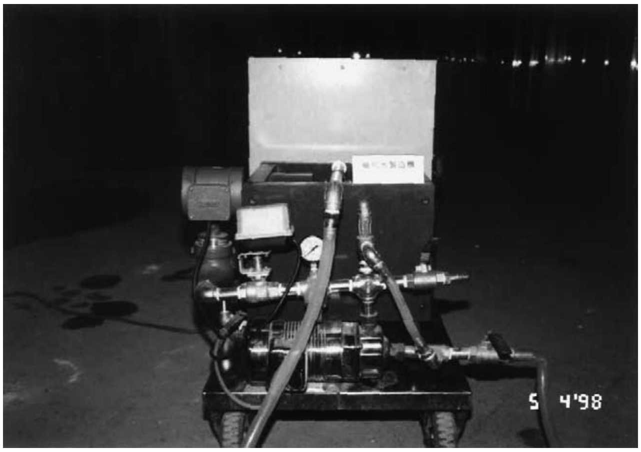

Fig. 3. The picture of magnetic-field-generating machine.

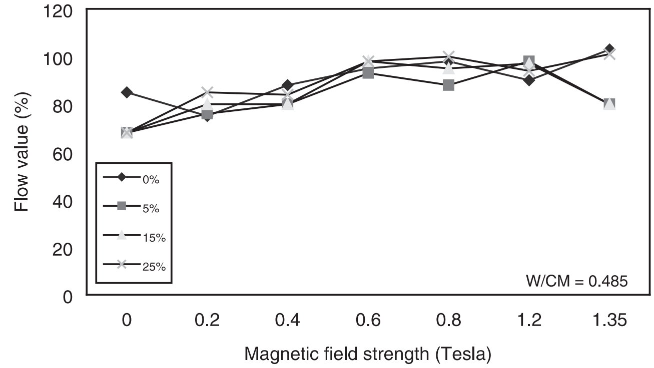

Fig. 4. Effect of MFTW on the flowability of fresh mortars.

5%, 15% and 25% while 0% indicates no substitution. Fly ash also replaces cement in concrete samples at 0%, 5%, 10% and 15%.

2.4. Experimental procedures

The ELE 1960 kN compressive test machine is used to test concrete and mortar samples according to ASTM C31 and C109, respectively. Fresh concrete undergoes the slump test according to ASTM C143. The flow value of fresh mortar samples is measured according to ASTM C230. The hydration products of mortars mixed using MFTW are analyzed by a scanning electron microscope (JEOL, JSF-35-CF).

3. Results and discussion

3.1. The effects of MFTW on mortar samples

As seen in Fig. 4, the flow value (ASTM C230) of fresh mortars prepared with MFTW is slightly higher than that mixed with tap water. This is because the dispersion effect of MFTW on cement clusters in mortars is more efficient than that of tap water. In this study, the result indicates the amount of fly ash added in place of cement would not significantly increase the flow value of fresh mortar. This result is different from other authors [13]. This is because the fly ash used in this study contains up to 9% unburnt carbon (loss on ignition), which is generally present in the form of cellar particles. The large amount of carbon in fly ash is harmful to flowability of mortars because the cellar particles of carbon tend to adsorb some mixing water.

Fig. 5 shows the compressive strength of mortar samples cured for 7, 28 and 56 days. The relative compressive strength of mortar samples at 7 days is shown in Table 7. Despite being prepared with different W/CM ratios and various percentages of cement substitution by fly ash, all mortar samples exhibit a similar trend, indicating that the effect of magnetic field strength of MFTW on the compressive strength of different mortar samples is almost the same. As can be seen, whether fly ash is used in place of cement and irrespective of the fly ash content, the compressive strength of samples mixed with MFTW is higher than that of the control one (tap water represented by 0 T). In other words, MFTW is more effective than tap water during the hydration process. Besides, the effect of MFTW on compressive strength varies with the magnetic field strength. The most significant increase is observed when the MFTW is of 0.8 and 1.2 T.

As can be seen in Table 5, the effects of curing age on the compressive strength of mortar samples mixed with tap water and with MFTW are quite similar. An increase in compressive strength can be observed when curing age becomes longer. Samples with $W/CM = 0.35$ and with 0%, 5%, 15% and 25% of fly ash substitution show the same trend of increase. In other words, a consistent pattern of increase in strength can be found in all samples mixed with tap water and MFTW as well as samples containing different amounts of fly ash. In particular, the increase in compressive strength becomes more significant with longer curing age and at greater amount of fly ash added.

Fig. 5 shows the changes in the average compressive strength of mortars aged of 7, 28 and 56 days as a result of different quantities of fly ash used in place of cement. Regardless of the W/CM value, all the samples containing fly ash, show a lower compressive strength than those without fly ash substitution. In other words, the higher the fly ash contents, the lower the compressive strength of mortar. Therefore, we can conclude that the addition of fly ash will bring a decrease in compressive strength and such effect becomes less significant with longer curing age. This is easily explained by the

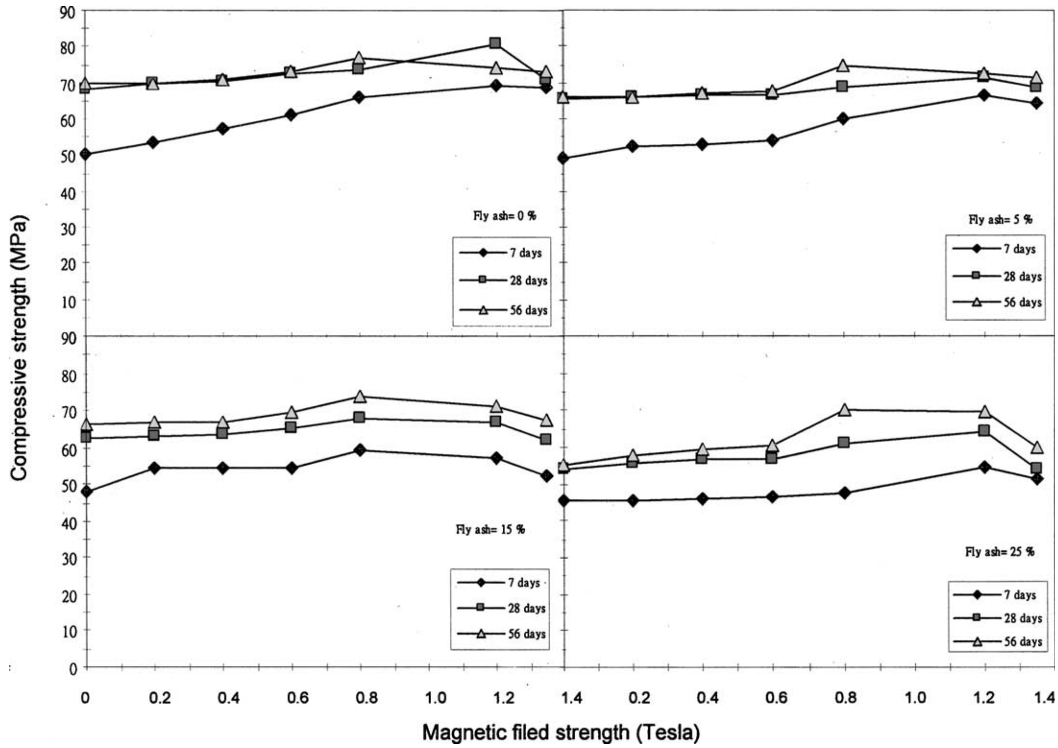

Fig. 5. Effect of MFTW on the compressive strength of mortars (W/CM = 0.35).

Table 7
Relative compressive strength of mortar samples at 7 days (unit: %)

Cement substitution by fly ash (%)	Magnetic field treated water (T)							W/CM
	0	0.2	0.4	0.6	0.8	1.2	1.35	
0	100	107	115	122	132	138	137	0.35
5	100	106	107	110	121	135	131	
15	100	114	114	114	123	120	110	
25	100	100	101	102	104	120	112	
0	100	109	115	137	153	131	130	0.40
5	100	115	124	131	148	146	135	
15	100	124	127	138	141	124	114	
25	100	111	127	131	139	134	118	
0	100	103	113	115	115	118	125	0.485
5	100	109	115	133	137	135	132	
15	100	151	153	167	173	162	154	
25	100	118	129	130	135	140	107	

pozzolanic reaction between cement and fly ash, which occurs at later age.

3.2. The effects of MFTW on concrete samples

Fig. 6 shows the effect of magnetic field strength of water on the compressive strength of concrete. It can be seen that with the same fly ash content and same curing age, the compressive strength of concrete prepared with tap water is lower than that mixed with MFTW of 0.2–1.35 T. Moreover, the greatest increase in compressive strength can be achieved using MFTW of 0.8 and 1.2 T.

The effect of curing age on the compressive strength of concrete with W/CM = 0.485 can be seen in Table 8. All concrete samples prepared with tap water and MFTW show a similar trend of compressive strength increase with longer curing age.

As seen in Fig. 7, the compressive strength of concrete containing fly ash at 7 days is lower than that of plain concrete. Moreover, with increasing fly ash content, the average compressive strength of concrete

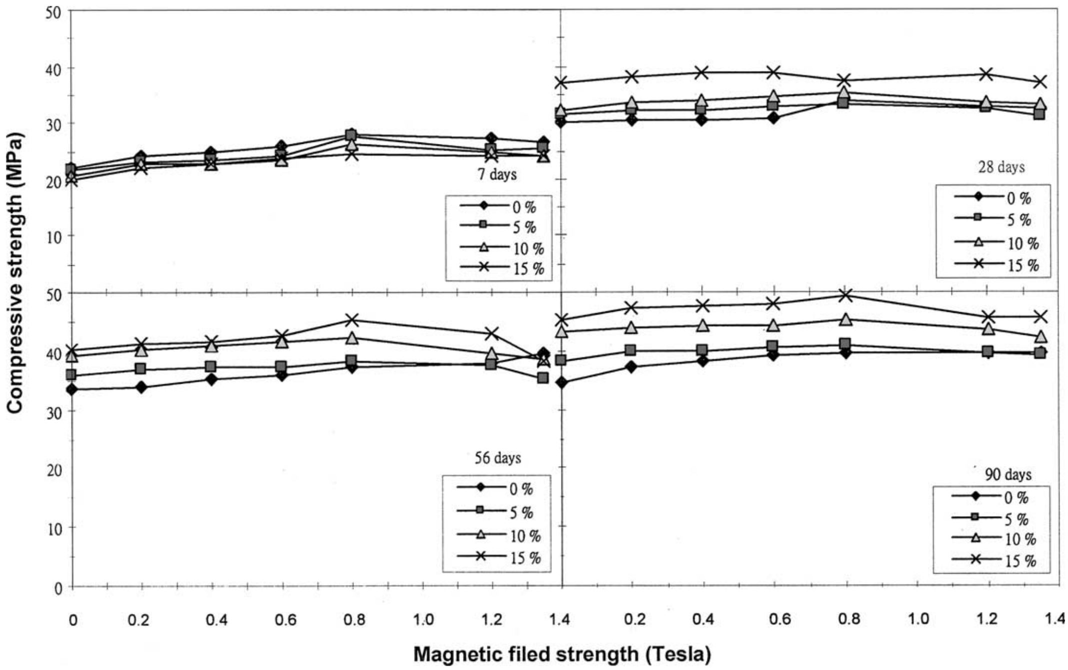

Fig. 6. Effect of MFTW on the compressive strength of concrete.

Table 8
Effect of curing age on compressive strength of concrete sample (unit: %)

Age (days)	Magnetic field treated water (T)							Cement substitution by fly ash (%)
	0	0.2	0.4	0.6	0.8	1.2	1.35	
7	74	80	82	84	82	82	82	0
28	100	100	100	100	100	100	100	
56	111	112	116	116	109	116	109	
90	115	123	126	110	116	121	122	
7	68	72	72	73	83	78	83	5
28	100	100	100	100	100	100	100	
56	113	114	115	113	116	115	113	
90	122	124	123	123	123	121	126	
7	64	67	67	67	74	73	72	10
28	100	100	100	100	100	100	100	
56	122	120	121	120	119	118	117	
90	134	130	131	128	127	130	128	
7	54	57	58	62	66	62	65	15
28	100	100	100	100	100	100	100	
56	109	108	107	109	121	111	102	
90	122	124	123	124	132	118	123	

samples with 5%, 10% and 15% fly ash substitution shows a decrease of 5%, 8% and 9%. As curing age was further extended to 90 days, concrete samples containing 5%, 10% and 15% fly ash showed compressive strength 4%, 14% and 23% higher than those without substitution. Therefore, it is only at early age that the compressive strength of concrete containing fly ash is lower than that of concrete without substitution. With longer curing age, the higher the percentage of cement substitution by fly ash, the higher the compressive strength of concrete.

3.3. The effects of MFTW on the microstructure of cement paste

Figs. 8 and 9 show calcium hydroxide (CH) crystals in cement pastes prepared with tap water and MFTW, respectively. The morphology of hydration products

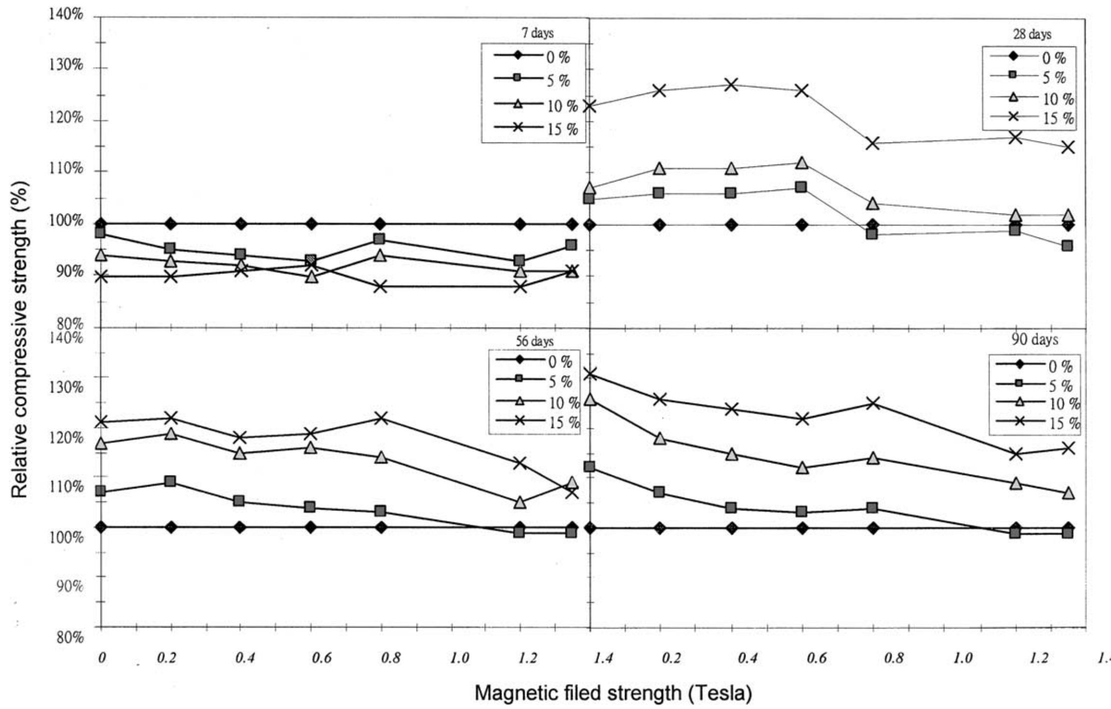

Fig. 7. Effect of fly ash on the compressive strength of concrete.

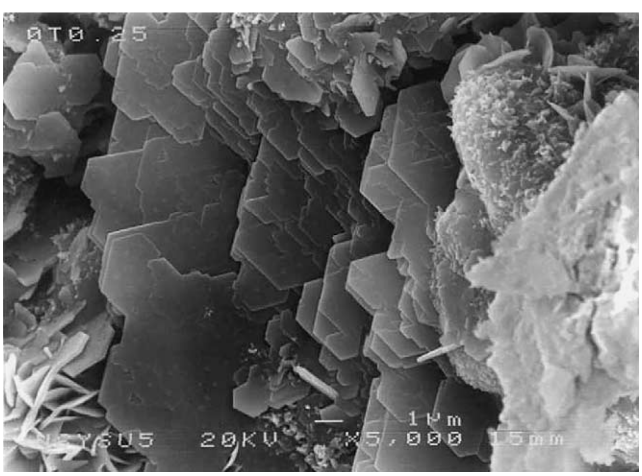

Fig. 8. SEM micrograph of calcium hydroxide crystals in pastes prepared with tap water (5000×).

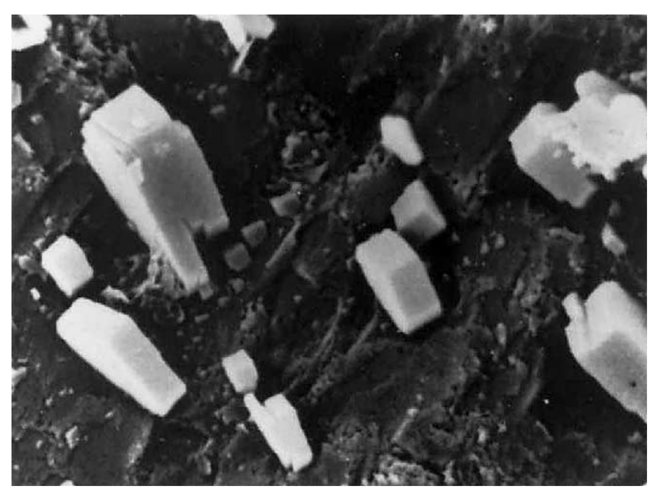

Fig. 9. SEM micrograph of calcium hydroxide crystals in pastes prepared with MFTW (5000×).

such C–S–H gel, ettringite, and monosulfate hydrate of pastes mixed with MFTW is similar to those mixed with tap water. However, larger CH crystals with distinctive hexagonal plates were observed in Fig. 8 for pastes mixed with tap water. The molecules of tap water tend to agglomerate with each other and form clusters. The larger CH plates, which packed in the transition zone, could be produced after cement has reacted with these clustered water molecules. Fig. 9 shows the CH crystals in hydrated paste tend to be smaller and formed separately, because smaller water molecules of MFTW reacted with cement. This difference explains why the compressive strength of cementitious materials with MFTW is higher than those with tap water.

4. Conclusions

1. The use of MFTW can improve the compressive strength of mortar samples containing fly ash. The extent of increase is dependent on the magnetic strength of MFTW. When the magnetic field strength

of water is 0.8 or 1.2 T, the compressive strength of mortar samples increases 15–20%.

2. With longer curing age, the trend of increase in compressive strength of the mortar samples prepared with MFTW is similar to those mixed with tap water.
3. The compressive strength of mortars containing fly ash is lower than that of concrete without substitution. At the same age, the decrease in compressive strength is even more significant as the percentage fly ash substitution increases. However, with the same amount of fly ash added, the decrease in compressive strength will become less prominent with longer curing age.
4. The compressive strength of mortar prepared with MFTW is also affected by the W/CM ratio. The trend of change is similar to that of mortar prepared with tap water.
5. The flowability of fresh mortars prepared with MFTW is slightly higher than that of mortars prepared with tap water.
6. The best increase in compressive strength of concrete is achieved when the magnetic strength of water is of 0.8 and 1.2 T. The increase in compressive strength of concrete due to the use of MFTW is more significant at an early age.
7. All concrete samples prepared with tap water and with MFTW show a similar trend of increase in compressive strength with longer curing age.
8. At 7 days, the compressive strength of concrete partially substituted with fly ash is slightly lower than that of concrete without substitution. Such decrease in compressive strength is more significant with higher fly ash content. However, after 28 days, the compressive strength of concrete is enhanced by greater percentage of cement substitution by fly ash.

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