Effect of magnetized water on the fresh, hardened and durability properties of mortar mixes with marble waste dust as partial replacement of cement

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Abstract:

In this research, the simultaneous effect of marble waste dust (MWD) and magnetized water (MW) on the fresh, hardened and durability properties of mortar mixes were investigated. A total of 10 mortar mixes using different cement replacement ratios of MWD (0%, 10%, 20%, 30 and 40 %) with regular tap water (RTW) and MW were prepared and tested. The standard consistency and setting characteristics, dry density, compressive and tensile strengths, water absorption and resistance to the acid attack of specimens were examined. The results showed that the fresh, hardened and durability properties of mortar mixes were improved by using MW. The results also revealed that the mortar mixes with either RTW or MW and 10% MWD as cement replacement displayed the most improvement in the hardened and durability performance compared to other mixes. However, using higher amounts of MWD leads to a lower strength and durability performance of the mortar mixes due to more porous microstructure.

Keywords: Magnetized water, Marble waste dust, Mortar, Fresh properties, Hardened properties, Durability.

1. Introduction

Sustainable construction has become an interesting topic in the field of civil and environmental engineering for the past decades since the construction industry, which is recognized as one of the fundamental parts of civilization, is considered as one of the main consumers of raw materials [1, 2]. Construction industry is also considered as one of the most waste generated producers among different industries [3]. Negative impacts of these waste materials on the environment have motivated a lot of researchers around the world for searching a proper solution in eliminating them [4]. Mortars are one of the conventional masonry materials with many diverse applications in the construction industry. Although it has been said that mortars are semi-obsolete material, but they still have retained their suitability features in some cases. Due to the current growth in constructions activities and the social trend for developing, it is predicted that the use of cementitious materials will significantly increase in the future [3]. Therefore, reusing and recycling waste materials in the construction industry can provide a significant environmental and economic contribution [5]. In this regard, researchers have put a great deal of effort through these years to use a wide range of these waste materials such as granular blast furnace slag, bottom ash, rubber tires, fly ash, granite waste dust and MWD for the production of concrete mixes [3, 5-12]. Some industries such as mining and processing of marble stones produce large amounts of MWD, which is spread by the wind in the surrounding area and causes adverse effects on the environment. Therefore, in recent years, MWD and aggregates have been used in several different products such as concrete pavers, infiltration materials and as natural aggregates or cement replacements for producing concrete mixes in order to decrease their environmental impacts [3, 5, 8, 13-17]. An investigation by Khyaliya et.al [18] revealed that substitution of river sand with MWD as fine aggregate at the replacement ratios of 25% and 50% by volume, improves the mechanical and durability properties of mortar mixes. Corinaldesi et al. [19] reported that using up to 10% MWD as partial replacement of river sand for producing mortar and concrete mixes did not significantly affect the workability of the concrete mixes. Gameiro et al. [20] results showed that the replacement of MWD with river sand at an optimum percentage of 20% enhanced the mechanical and durability properties of the concrete mixes. Ulubeyli et al. [21] also observed an improvement in the durability properties of the concrete mixes such as permeability, water absorption, and corrosion resistance by using MWD.

It was also reported that using MWD as substitution of cement in mortar mixes enhanced the strength and microstructure properties of the mortar mixes [22]. Vardhan et.al [17] research showed that up to 10% of the cement can be replaced by MWD with no compromise on the technical properties of the resulted mix. The results of Shukla et.al [23] also showed that using MWD up to 10% as partial replacement of cement (PRC) can improve the mechanical properties of concrete mixes. Ghorbani et.al also concluded that replacing cement with 10% MWD can enhance the resistance to corrosion of embedded steel reinforcement in concrete as well as the mechanical properties [5]. Rodrigues et al. [24] studied the mechanical properties of concrete mixes with MWD as PRC. The results showed that the compressive strength of the concrete mixes decreased by using higher amounts of MWD. However, this decrease was not significant up to the replacement ratio of 10%. Talah et al.[25] used MWD as PRC up to 15% for producing high-performance concrete. The results showed that the addition of MWD up to 15% improved the chloride and oxygen resistances of the produced concrete. Mashaly et.al [26] investigation showed that replacing cement with MWD up to 20% did not have a significant effect on the physical and mechanical characteristics of the cement pastes compared with the controlled mix.

Aydin and Arel [14] investigated the high volume of marble substitution in cement-paste. The results of their investigation showed that replacing the cement with MWD up to 60 % in the cement paste was effective. It was reported that replacing 10% of MWD with the cement during the concrete production can reduce the emission of CO_2 about 12% [3]. The results of the investigation conducted by Gencel et al. [10] showed that the freeze-thaw and wear resistance of the concrete block pavers were improved by using MWD. The investigation of Kelestemur et al. [27] showed that using higher amounts of MWD enhanced the fire resistance of the cement mortars. Belaidi et al. [28] indicated that replacing cement with MWD and natural pozzolan enhanced the workability characteristics of self-compacting concrete. Gesoglu et al. [29] also reported that using MWD improved the mechanical and durability properties of SCC mixes with the fly ash. Singh et al. [30] studied the characteristics of concrete specimens made with MWD as cement replacement. The results showed that replacing cement with MWD up to 15% improved the hardened properties of the produced concrete. It was also reported that using certain amounts of MWD decreased the drying shrinkage of the concrete specimens [30]. Kabeer and Vyas [31] examined the feasibility of MWD as fine aggregate instead of river sand in mortar mixes. The results demonstrated that the use of MWD up to 20% as replacement of river sand satisfy the minimal expectations. More investigations indicated the substitution of MWD with either cement in paste and mortar or river sand in concrete by the rates of 2.5%, 5%, 7.5%, 10% and 15% resulted in an additional sustainable green construction material as well as a decent one in its properties [32, 33].

Water, as a crucial component of any concrete mixture, plays a vital role in the quality and characteristics of produced concrete. According to some previous works, the mechanical properties of concrete, such as workability, water absorption, flexural strength, compressive strength (CS) and tensile strength (TS) are highly influenced by the chemistry of applied water [34-37]. For the first time, Hendricks Anton Lorenz, a Danish physicist, proposed magnetizing water, a procedure having been proven to provide beneficial effects by changing the chemistry of water [38]. The hydrogen bonds among water molecules cause them to accrete and form clusters. Typically, each cluster contains 100 water molecules at room temperature [38, 39]. On the other hand, when a given water sample undergoes a magnetic field, its composition is influenced in such a way that clusters are broken apart. As a result, numbers and sizes of clusters decrease [40, 41]. Subsequent to such alterations in the structure of water molecule clusters, their activity would be increased [38]. The transformation of water molecule clusters as they pass through a magnetic field, which is kept constant throughout the experiment, is depicted in Fig. 1 [34]. Compared to RTW, MW, in which water molecules are segregated, benefits from a lower level of surface tension [42]. Therefore, the thickness of the magnetized water layer around a cement particle is thinner than that of the tap water, and the magnetized water also contributes to cement particles repelling each other. This can provide a potential explanation for the improvements in the mechanical properties of concrete mixes prepared with magnetized water [35, 38, 39, 42, 43]. As pointed out by Wei. et al.[35], the resistance of concrete against early-stage shrinkage cracking can be improved by employing MW. Based on a research carried out by Gholhaki et al.[44], application of MW ameliorates the workability of self-compacting concrete. Bharath et al. [45] used copper slag as partial replacement of cement and achieved the same result (50% increase). Application of fly ash and granulated blast-furnace slag to their concrete specimens, Su and Wu [39] and Su et al. [43] examined the influence of passing water through a magnet. According to the outcomes of their study, the CS increased by 10-23% and the workability characteristics also improved. Moreover, Ghods [46] found that MW positively affects the mechanical properties, e.g. CS and TS, of SCC containing nano silicate. Similarly, Ahmed [42] reported significantly improved behavior in concrete specimens produced by MW and containing Nano alumina.

As revealed by the literature review, despite the investigations carried out to study the effect of MW on the behaviour of concrete mixes produced with MW, limited research has been conducted for examining such matter in mortar mixes incorporating MWD as PRC. Therefore, to study the effect of MW on the properties of mortar mixes with MWD, various experiments were performed on both fresh and hardened mortar including: standard consistency and setting characteristics, dry density, CS, TS, water absorption and resistance to acid attack.

2- Materials and methods

2.1. Materials

In this research, the following materials were used as constituents of mortar mixes: Portland cement (type II), water, fine aggregate and MWD. It is worth emphasizing that all these materials were obtained from local sources. The Portland cement (specific gravity of 3.20) chosen in this study was consistent with ASTM C150 standard. The chemical composition and particle size distribution of the cement are shown in Table 1 and Fig. 2, respectively. The MWD used in this study as partial cement replacement was collected in a wet state from a local factory near Mashhad city. In order to control the water-to-cement ratio of the mortar mixes the collected MWD was completely oven-dried in an oven at a temperature of 105 °C. The specific gravity of the MWD used in this study was 2.50. In order to analyses the chemical composition of the MWD, the XRF technique was employed and its result is shown in Table 1. The particle size distribution of MWD is also presented in Fig.2. The fine aggregate used in the current mortar mixes was composed of locally available river sand with oven dry density, relative density and water absorption of 1655 (kg/m^3), 2.61 and 3.80 %, respectively. The sieve analysis of the river sand is presented in Table 2. RTW from the laboratory was used for the preparation and curing of the mortar mixes. In order to obtain MW, RTW was passed through a permanent magnet with length of 200mm, internal diameter of 32mm and external diameter of 55mm. The strength of this magnet was 0.65 Tesla. As it can be seen in Fig. 3, the magnet was placed between a water tank and an electric pump. By circulating the water through the magnet, it was magnetized. The water was passed through the permanent magnetic field for 10 rounds with a water flow speed of 0.75 m/s.

2.2. Experimental Design

As pointed out formerly, the aim of this study is to study the MW effects on the fresh, hardened and durability characteristics of mortar mixes with MWD as PRC. To achieve this goal, five mortar mixes were produced using MW along with five mortar mixes, in which RTW was used, to form a total of 10 mixes. The mix proportions are depicted in Table 3. The variable parameters in design of current mixtures include:

- The water used for the preparation of the mortar specimens (MW and RTW).
- The MWD replacement content (0%, 10%, 20%, 30% and 40% by weight of cement).

2.3. Mix procedure

For producing the mortar mixes, first RTW provided in the laboratory was passed through a magnet at a constant flow speed of 0.75 m/s for 10 rounds. Then, the cement, MWD and sand were mixed in the drum mixer for about 1 minute. Finally, the water was added to drum mixer and mixed until reaching a homogeneous mix. For preparing the mortar mixes the cement-to-sand ratio was kept constant as 1:3 by weight.

2.4. Testing

2.4.1. Fresh Properties

The Standard consistency, initial and final setting times of the cement pastes with MWD as PRC prepared with either RTW or MW was determined in accordance with ASTMs C187 and C191, respectively.

2.4.2. Compressive and tensile strengths

The CS and TS of the mortar specimens was determined according ASTM C109 and ASTM C190, respectively. To this end, cubic (50 mm) and briquette specimens containing different ratios of MWD (0%, 10%, 20%, 30% and 40%) were produced with MW and RTW. Prior to any test, all samples were removed from the steel moulds 24 hours after casting and kept immersed in saturated lime- water for 28 days. The specimens were tested after 3, 7 and 28 days from the casting date. At each age, three specimens were tested and their mean value was reported as the ultimate CS and TS of the mortar mix.

2.4.3. Water absorption

The 3, 7 and 28 days water absorption of mortar specimens from the casting date was determined using cubic moulds with dimension of 50 mm in accordance with ASTM C1403. The same procedure of the CS and TS tests was used to prepare the water absorption specimens. At each age, three specimens were tested and their mean value was reported as the ultimate water absorption of the mortar mix.

2.4.4 Mass loss

The resistance of the mortar specimens to 5% by weight H_2SO_4 solution was determined by using cubic moulds with dimension of 50 mm. The mortar specimens were first immersed in saturated lime water for 28 days. Then, they were exposed for 28 days to 5% by weight H_2SO_4 solution with pH 1.0. To keep a constant pH value during the curing period, the monitoring and refreshing of H_2SO_4 solution was carried out on a weekly basis. In order to measure the mass loss of the mortar specimens after 3, 7 and 28 days of exposure to H_2SO_4 solution, they were first removed from the solution and then washed with RTW. Then the surface of specimens was dried for an hour at the laboratory environment prior to measuring their mass loss. At each age, three specimens were tested and their mean value was reported as the ultimate mass loss of the mortar mix. The percentage of mass loss was determined according to previous research procedure [7].

3. Results and discussions

3.1. Fresh Properties

3.1.1. Standard consistency and setting characteristics

The results of the standard consistency and initial-final setting times of cement pastes with MWD as PRC prepared with either RTW or MW are tabulated in Fig. 4 and Fig. 5, respectively. As shown in Fig. 4, the standard consistency of cement pastes with MW varies in the range of 31.75% - 32.9%, while these values for the cement pastes with RTW were approximately within the range of 31.8% - 33.5%, respectively. Therefore, the use of MW for preparing the cement pastes leads to slight decrease in the standard consistency of the cement pastes. This means that the amount of needed water for preparing the cement pastes with magnetizing water was slightly lesser than that of the cement pastes with RTW. The results also showed that for all cement pastes prepared with either RTW or MW the standard consistency decreases as higher contents of MWD is used as PRC. This result is in accordance with the previously published results [14, 17, 30]. This lower standard consistency of cement pastes with higher contents of MWD may be justified by the finer particle size distribution of MWD particles which indicates that replacing MWD with cement would require more content of water to become equally workable as the controlled cement paste.

As tabulated in Fig. 5, the initial and final setting times of cement pastes with MW is slightly higher than that of the cement pastes with RTW. This result agrees with the standard consistency results. As can be seen in Fig. 5, the initial setting time of cement pastes prepared with MW and 0%, 10%, 20% ,30 % and 40% MWD as PRC was about 8.70%, 7.85%, 2.85%, 4.25% and 4.40% higher than the cement pastes with RTW at the same replacing ratios, respectively. The final setting time of these cement pastes was approximately 6%, 7.25%, 5.65%, 6.55% and 4.50% higher than the cement pastes with RTW. The results also showed that using higher contents of MWD as PRC leads to longer initial and final setting times regardless of the water type that was used for producing the cement pastes. This result is in accordance with the results of the previous studies [14, 17, 30], which reported an inverse relationship between the initial and final setting times of cement pastes and the amount of MWD used as PRC.

The results also showed that using up to 20% MWD as PRC did not have a significant effect on the time intervals between the initial and final setting times regardless of the water type used to produce the cement pastes. In other words, using up to 20% MWD showed a similar behavior as the controlled mix in the term of setting characteristics. However, using more than 20% MWD as PRC significantly increased the time interval between the initial and final setting times of the cement pastes compared to the controlled mix regardless of the water used to produce it.

It can also be seen in Fig. 5 that the cement pastes with 40% MWD as PRC displayed a longer initial and final setting times of (71.2% and 53.50%) and (78.25% and 55.80%) compared to the cement pastes with 0% MWD, respectively, when using MW and RTW.

3.2. Hardened properties

3.2.1. Dry density

Fig.6 shows the 28 days dry unit mass of all mortar mixes with MWD as PRC with either RTW or MW. As can be seen in Fig.6, the dry unit mass of all mortar mixes with MW was higher than the mortar mixes with RTW. This means that using MW in the production of concrete mixes leads to denser cement matrix as result of pore reduction in the structure of the mortar specimens. This result is in full agreement with the results of previous researches, which concluded that using MW in concrete production improves the density of the concrete mix [35, 36, 38, 42, 43]. The higher dry unit mass of mortar mixes with MW may be justified by more interactions between the cement particles and water molecules as result of passing RTW through the magnetic field. The results showed that the 28 days dry unit mass of magnetized mixes with 0%, 10%, 20%, 30% and 40% MWD as PRC was about 2%, 2%, 3%, 2% and 2.5% higher than that of the mortar specimens with RTW at the same replacement ratios, respectively.

As indicated in Fig.6, for both of the mortar mixes with either RTW or MW the highest 28-day dry unit mass was related to the mortar mixes with 10% MWD as PRC, while the lowest value was related to the mortar mixes with 40% MWD as PRC. The higher and lower dry unit mass of mortar mixes with 10% and 40% MWD as PRC may be justified by the pore filling effect of MWD particles and decrease in the use of cement as the adhesive component of the cement paste, respectively [3, 5, 17, 47].

3.2.2. Compressive strength

The CS test results of all mortar mixes with MWD as PRC prepared with either RTW or MW after 3, 7 and 28 days is shown in Fig. 7. As indicated in Fig. 7, all the mortar mixes prepared with MW displayed a higher CS than the mortar mixes prepared with RTW at all ages regardless of the MWD replacement ratio. This observation is in accordance with the observations of researches which previously reported an enhancement of the mechanical properties of the concrete mixes namely its CS by using MW. The higher CS of mortars with MW may be justified by the fact that MW demonstrates a higher specific area than the RTW when passing through the magnet.

Previous studies stated that when the water undergoes a magnetic field the water clusters break apart and the number of molecules gathered together significantly declines [34, 38, 41]. As result of this process, the activity of water molecules increases, leading to a more considerable number of interactions between them and the cement particles. In other words, more number of water molecules are available to take part in the hydration process. This is a potential reason behind the increase of CS when MW is used [38, 39, 43]. The same trend explains the tendency of the results of the TS tests.

As can be seen in Fig. 7, the mortar mixes with MW and 0%, 10%, 20%, 30 % and 40 % MWD as PRC indicated an improvement of 32%, 21%, 17%, 26% and 6% in the CS of the mortar mixes after 28 curing days, respectively.

As shown in Fig.7, for both of the mortar mixes with either RTW or MW the highest CS value was related to the mortar mixes with 10% MWD. This result is in accordance with the results of former investigations which stated that the highest CS of the concrete specimens with MWD were achieved by using 10% MWD as PRC [3, 5, 17, 47, 48]. The results showed that the mortar mixes with RTW and MW and 10% MWD displayed an increment of 16% and 7% in the CS value after curing for 28 days, respectively, compared to the control specimens. This higher CS may be justified by the pore filling effect of MWD particles which improves the density of the cement matrix [5]. As it can be indicated in Fig.7, regardless of the water type the mortar mixes with 40% MWD displayed the largest decrease (46% and 53%) in the CS value after 28 curing days relative to the RTW specimens, respectively. This shows that the CS value of the mortars with either RTW or MW decreases significantly with excessive level of MWD because of the decrease in cement content as the adhesive component of the cement paste, as reported by former studies [3, 17, 47, 49, 50]. It can also be said that the addition of MWD after 10%

acts only as filler and does not play a noticeable role in the hydration process of the cement matrix. The same reasons can explain the tendency of the results of the TS test. It can also be seen in Fig.7 that similar to the results of the previous researches the CS value of all mortar mixes with either RTW or MW increases as curing continued, however, the rate of increase varies [5, 43].

3.2.3. Tensile strength

Fig.8 shows the results of the TS test conducted on mortar specimens with MWD as PRC and either RTW or MW after 3, 7 and 28 curing days. As indicated in Fig.8, similar to the CS test results all mortar mixes prepared with MW displayed a higher TS compared to the mortar mixes prepared with RTW at all testing ages regardless of the MWD replacement ratio. This is compatible with past investigations [35, 38, 44]. The TS test results showed that the TS values for the mortar mixes prepared with RTW were about 2.85-3.72 MPa, while these values for the mortar mixes modified with MW were approximately 2.96-3.92 MPa after curing for 28 days. The 28-day TS of mortar specimens with 10%, 20%, 30% and 40 % MWD as partial replacement was improved about 11%, 5.5%, 16%, 3% and 5% by using MW, respectively. As can be seen in Fig.8, similar to the CS test results, regardless of the water type the TS of the mortar mixes decreases significantly by replacing cement with higher contents of MWD. This may be attributed to the decrease in the use of cement as the adhesive component of the cement paste. The results also demonstrate that the mortar mixes with 10% MWD showed the highest TS compared to other specimens regardless of the water type, while the specimens with 40% MWD displayed the least TS compared to other specimens.

3.3. Durability properties

3.3.1. Water absorption

Fig.9 shows the results of the water absorption test conducted on mortar specimens with MWD as PRC prepared with either RTW or MW after 3, 7 and 28 days. As can be indicated in Fig.9, all mortar mixes with MW displayed a lower water absorption than the mortar mixes with RTW at all curing ages. Therefore, it can be stated that the water absorption of mortar mixes decreases by using MW. This can be justified by the less pores in the mortar structure as result of a denser cement matrix. This result is in consistent with past investigations [38, 44]. As indicated in Fig.9, the water absorption values of mortar specimens with MW varies within the rage of 13% -16.1%, while these values for the mortar specimens with RTW were almost within the range of 15.26%-17.8%, respectively. The results showed that using MW reduced the water absorption of the mortar specimens about 15%, 14%, 3%, 9% and 9.5% when using 0%, 10%, 20%, 30% and 40% MWD in comparison with the mortar specimens with RTW, respectively.

As seen in Fig.9, for both of the mortar mixes with MW and RTW, replacing cement with MWD increases the water absorption of the mortar specimens. This result is in accordance with the results of past investigations [3, 5, 14]. This higher water absorption may be attributed to the development of additional calcium silicate hydrate gels which increases the porosity of the cement matrix and consequently the water absorption of the mortars [14-17, 51]. As shown in Fig.9, mortar specimens with 40% MWD either with MW or RTW showed the highest water absorption compared to other mortar specimens, while the lowest water absorption were related to the mortar specimens with 0% MWD regardless of the water type.

3.3.2. Resistance to acid attack

The percentage variation in the mass of the mortar specimens with MWD exposed to a H_2SO_4 solution as PRC after 3, 7 and 28 days of exposure is tabulated in Table 4. As can be seen in Table 4, the mortar mixes with MW displayed a lower mass loss and consequently a higher resistance to acid attack than the mortar mixes with RTW regardless of the MWD replacement ratio at all testing days. It can be concluded that using MW in the production of mortar mixes with MWD as PRC improves the resistance of them to acid attack. The durability characteristics of concrete mixes significantly depends on the porosity of their structure: the lower porosity of a concrete enhances its durability characteristics [14, 52]. It has also been reported that the speed of the acid attack depends on several parameters, such as concrete microstructure, pH value and concentration of the solution [7]. Several studies have been concluded that using MW for producing concrete leads to a denser structure and consequently to a lower number of concrete pores [35, 36, 39, 42]. Therefore, the higher resistance to acid attack of mortar mixes with MW may be due to a lower porosity and improved microstructure of the mortar matrix as result of pores reduction in the structure of the mortar mixes. The results showed that the mortar mixes with MW displayed a lower mass loss of 26%, 36%, 22%, 28% and 28% when using 0%, 10%, 20%, 30% and 40% MWD compared to the mortar mixes with RTW, respectively.

As presented in Table 4 for both of the mortar mixes with either RTW or MW the mass loss of the mortar mixes increases as higher replacement ratios of MWD were used as PRC. This means that replacing higher amounts of cement with MWD leads to a higher mass loss of the mortar mixes. This result is in accordance with the results of the previous study conducted by Aydin and Arel [14] which reported that the mass loss of mortar mixes increases when higher amounts of MWD are used.

Previous researches have been reported that using higher values of MWD in concrete mixes leads to a higher porosity of the concrete structure [14, 16, 17, 51]. Consequently, the higher mass loss of the mortar mixes with higher content of MWD may be attributed to higher porosity of their structure as result of using higher content of MWD. As indicated in Table 4, the maximum loss of all mortar mixes with either RTW or MW exposed to H_2SO_4 solution, was seen after 28 days of exposure. The results also showed that the highest mass loss among all of the mortar mixes with either RTW or MW results after 28 days of exposure to the H_2SO_4 solution was related to the mortar mixes with 40% MWD as PRC. It can also be seen from the figure that using 10% MWD in mortar mixes did slightly increase the mass loss of the mortar specimens compared to the controlled specimens at all testing days.

4. Conclusions

In the present research, the effect of MW on the fresh, hardened and durability properties of mortar mixes modified with different ratios of MWD as PRC (up to 40%) was investigated. For this purpose, standard consistency, setting times, dry density, CS, TS, water absorption, resistance to sulphuric acid attack were determined. The following conclusions were drawn:

1. The standard consistency results indicated that using MW leads to slight decrease in the standard consistency of the mortar mixes. The results also showed that replacing cement with higher contents of MWD decreases the standard consistency of the mortar mixes regardless of the water type.
2. The initial and final setting times of all mortar mixes with MW was slightly higher than that of the mortar mixes with RTW. It was also found that there is an inverse relationship between the initial and final setting times of the mortar mixes and amount of MWD used as PRC.
3. Using MW enhanced the hardened properties of the mortar specimens compared to the specimens with RTW regardless of the MWD content.
4. The compressive strength results of the mortar specimens also showed that using 10% MWD as cement replacement displayed an increment of 16% and 7% after curing for

28 days for RTW and MW, respectively. However, using higher amounts of MWD leads to porous microstructure and consequently to a lower strength.

5. The results of tensile strength also demonstrate that the mortar mixes with 10% MWD showed an increment of 8% and 4% after 28 days of curing which are the highest value compared to other specimens for RPW and MW, respectively.
6. The water absorption and mass loss tests results showed that the mortar specimens with MW displayed a lower water absorption and a higher resistance to sulphuric acid attack than the specimens with RTW regardless of the MWD content, respectively.
7. Replacing cement with higher contents of MWD leads to a higher porosity of the mortar structure and consequently to a higher water absorption and mass loss of the mortar specimens.

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Material	Chemical composition (%)									
	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	CL	LOI
Cement (Type II)	21.4	63.6	4.5	3.5	2.1	2.5	0.5	0.5	0.07	1.9
MWD	1.3	85.3	0.6	0.4	0.6	0.3	0.1	0.1	0.02	2.4

Table 1. Chemical composition of the cement and MWD [5].

Table 2. Sieve analysis of river sand used for producing mortar mixes.

Sieve size (mm)	Passing material (%)
4.750	100.00
2.360	95
1.180	85.25
0.600	50.75
0.300	20.10
0.150	4.50
0.075	0.50

Table 3. Composition of the mortar mixes.

Mix NO.	Water type	MWD (%)	Cement (%)
1	Regular Tap	0	100
2		10	90
3		20	80
4		30	70
5		40	60
6	Magnetized	0	100
7		10	90
8		20	80
9		30	70
10		40	60

Table 4. Percentage change in the mass of the mortar mixes with MWD as PRC after 3, 7 and 28 days of exposure to a 5% by weight H_2SO_4 solution.

Mix NO.	Water type	Cement (%)	MWD (%)	Mass loss (%)		
				3 days	7 days	28 days
1	Regular	100	0	0.2	1.9	15
2		90	10	0.85	2.1	15.6
3		80	20	1.4	2.4	16.1
4		70	30	1.75	3.15	18
5		60	40	2	3.4	18.8
6	Magnetized	100	0	0.1	1.3	11
7		90	10	0.4	1.4	11.5
8		80	20	1.1	1.8	12.5
9		70	30	1.25	2.2	13
10		60	40	1.35	2.25	13.3

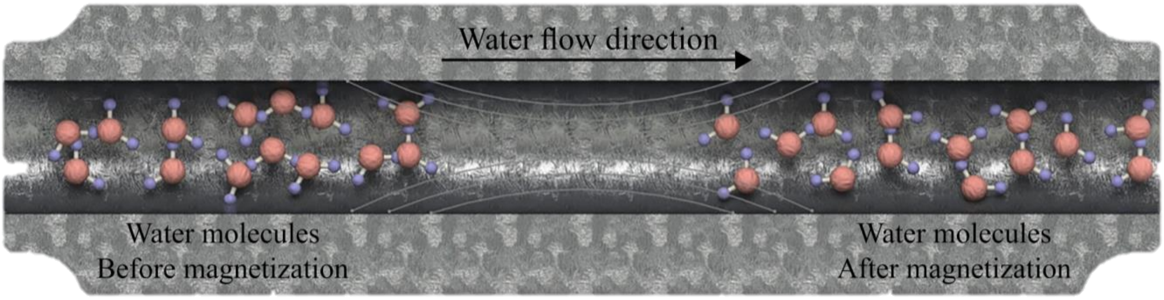


Fig. 1. Effect of magnetic field on water molecule clusters [34].

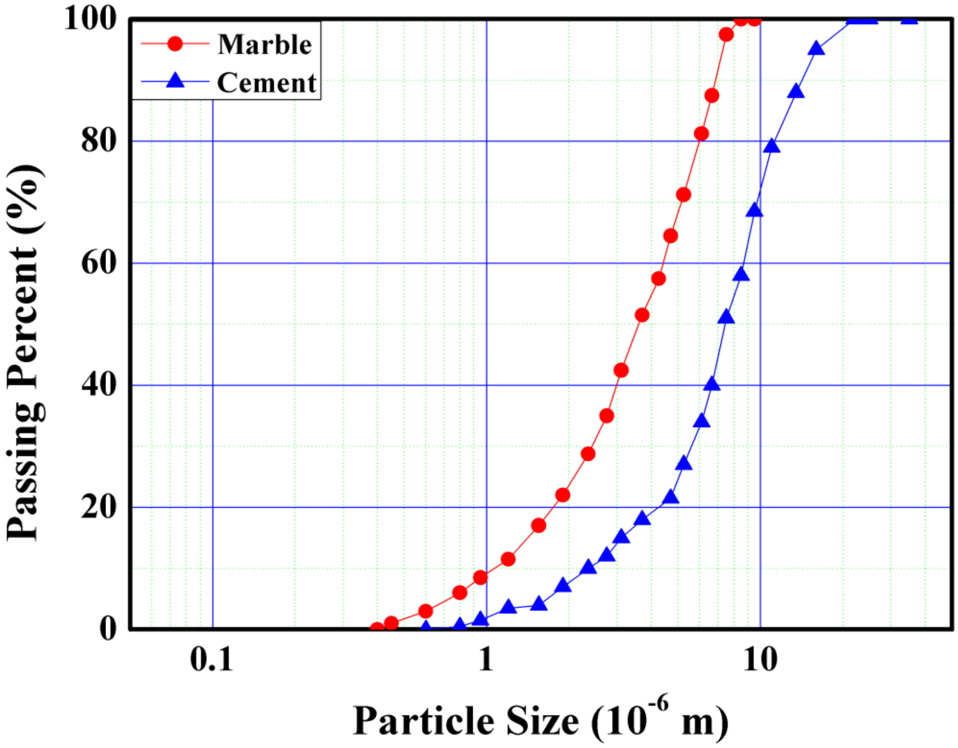


Fig 2. Particle size distribution of cement and MWD [5].

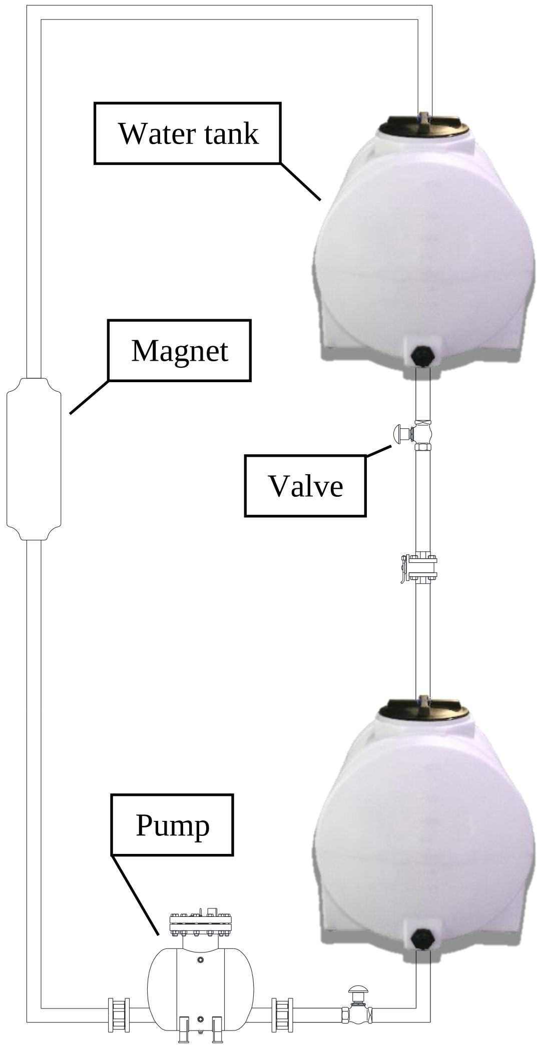


Fig. 3. Magnetic water generating machine [34].

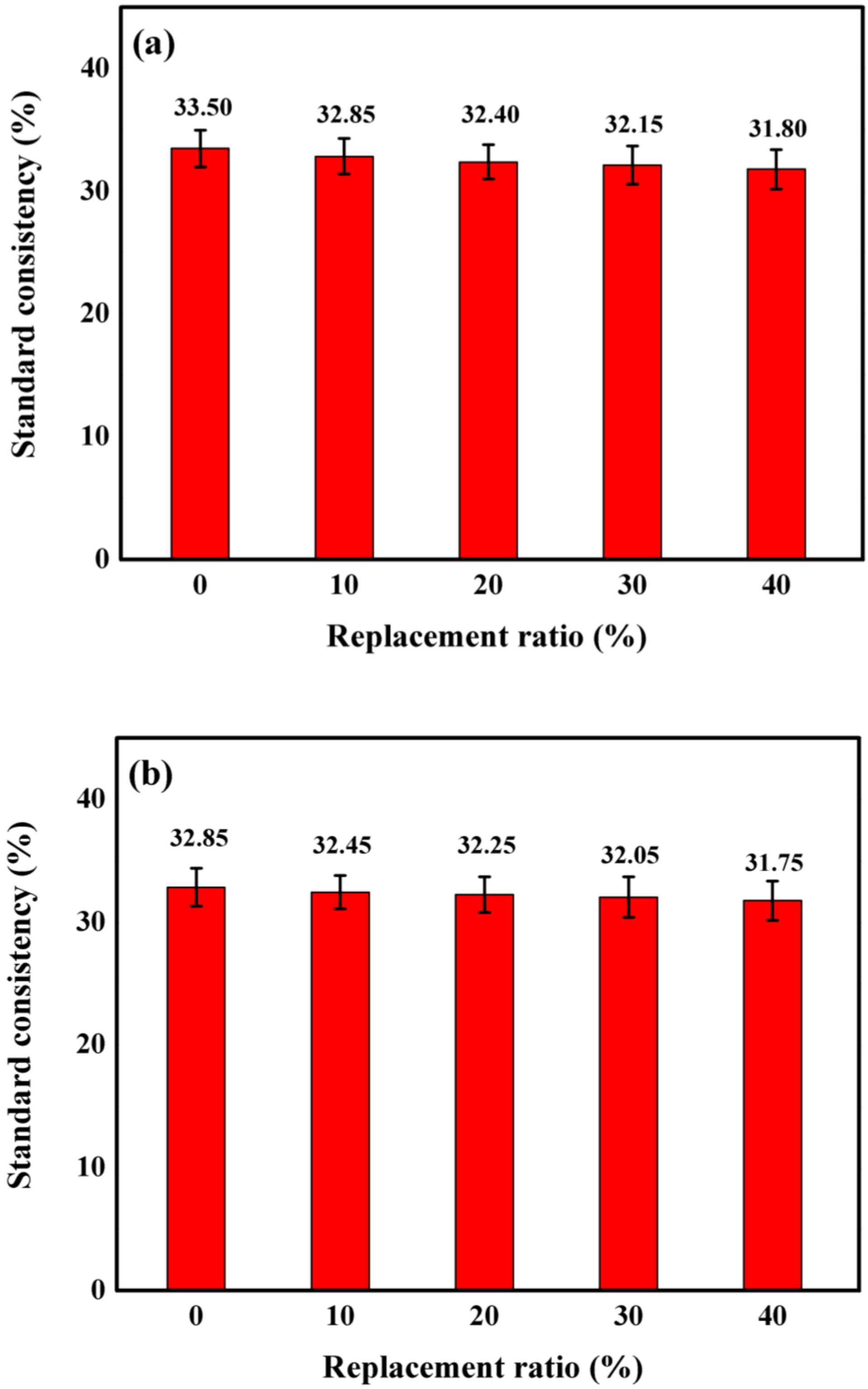


Fig 4. Standard consistency of mortar mixes with MWD as PRC prepared with (a) RTW and (b) MW.

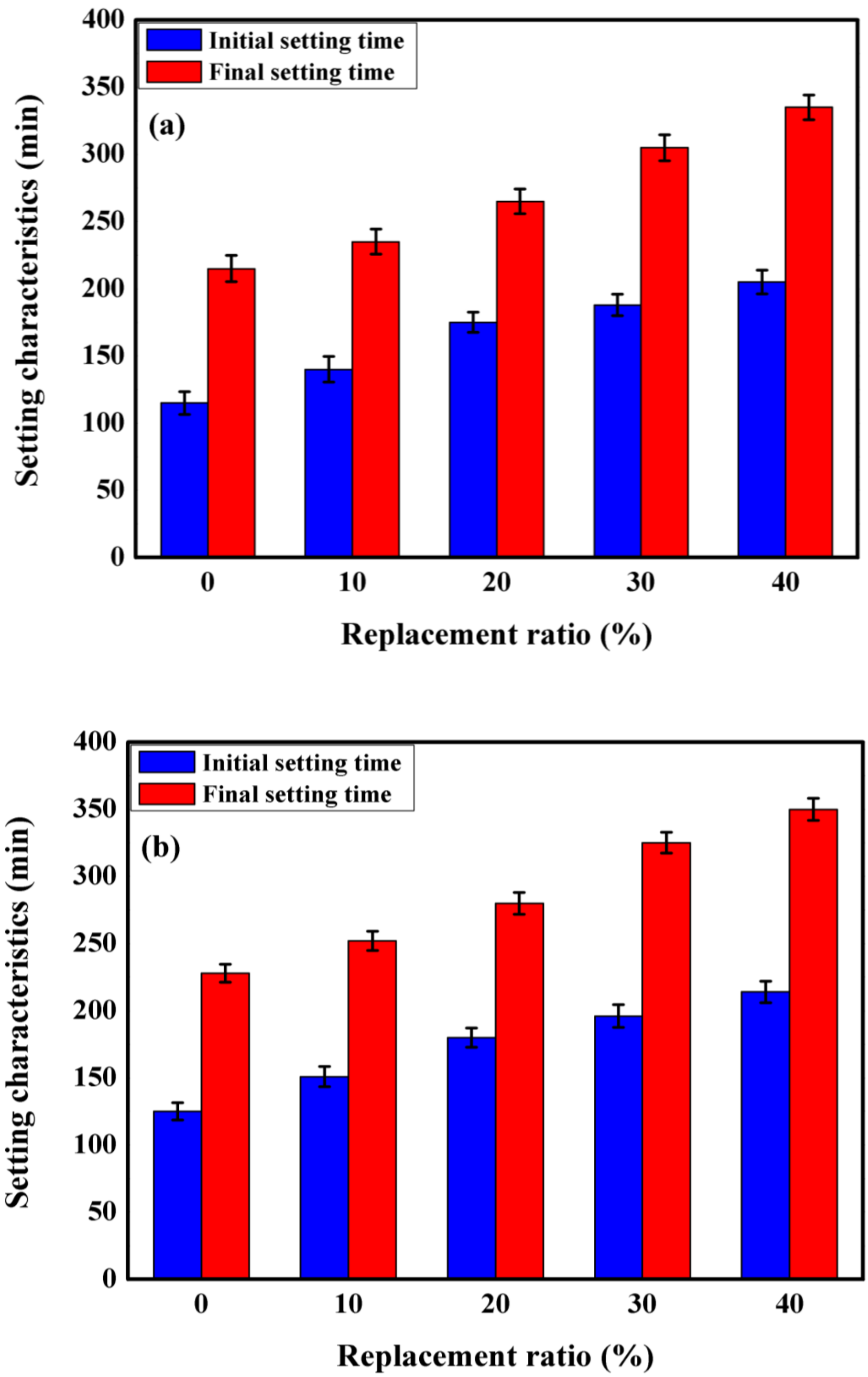
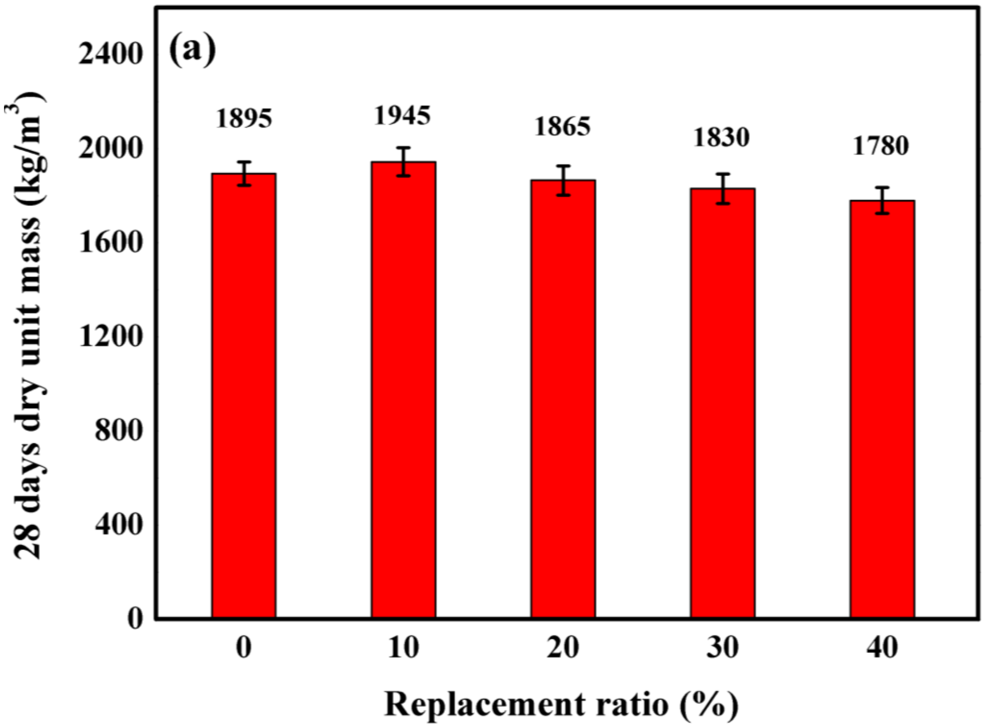


Fig 5. Setting characteristics of mortar mixes with MWD as PRC prepared with (a) RTW and (b) MW.



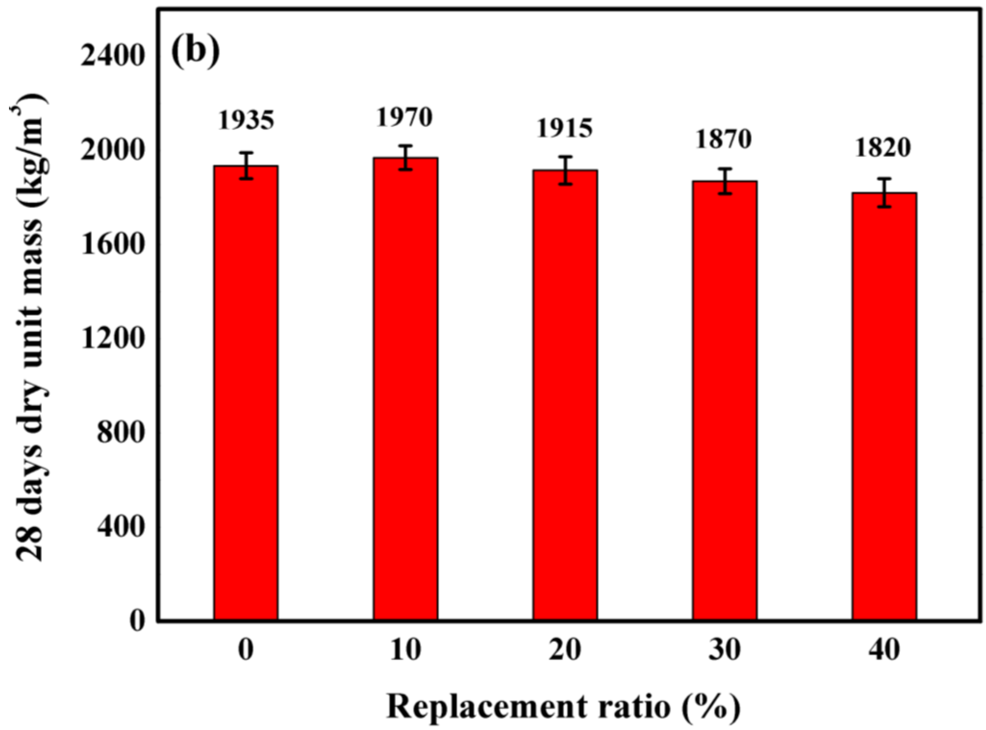


Fig 6. 28-day dry unit mass of mortar mixes with MWD as PRC prepared with (a) RTW and (b) MW.

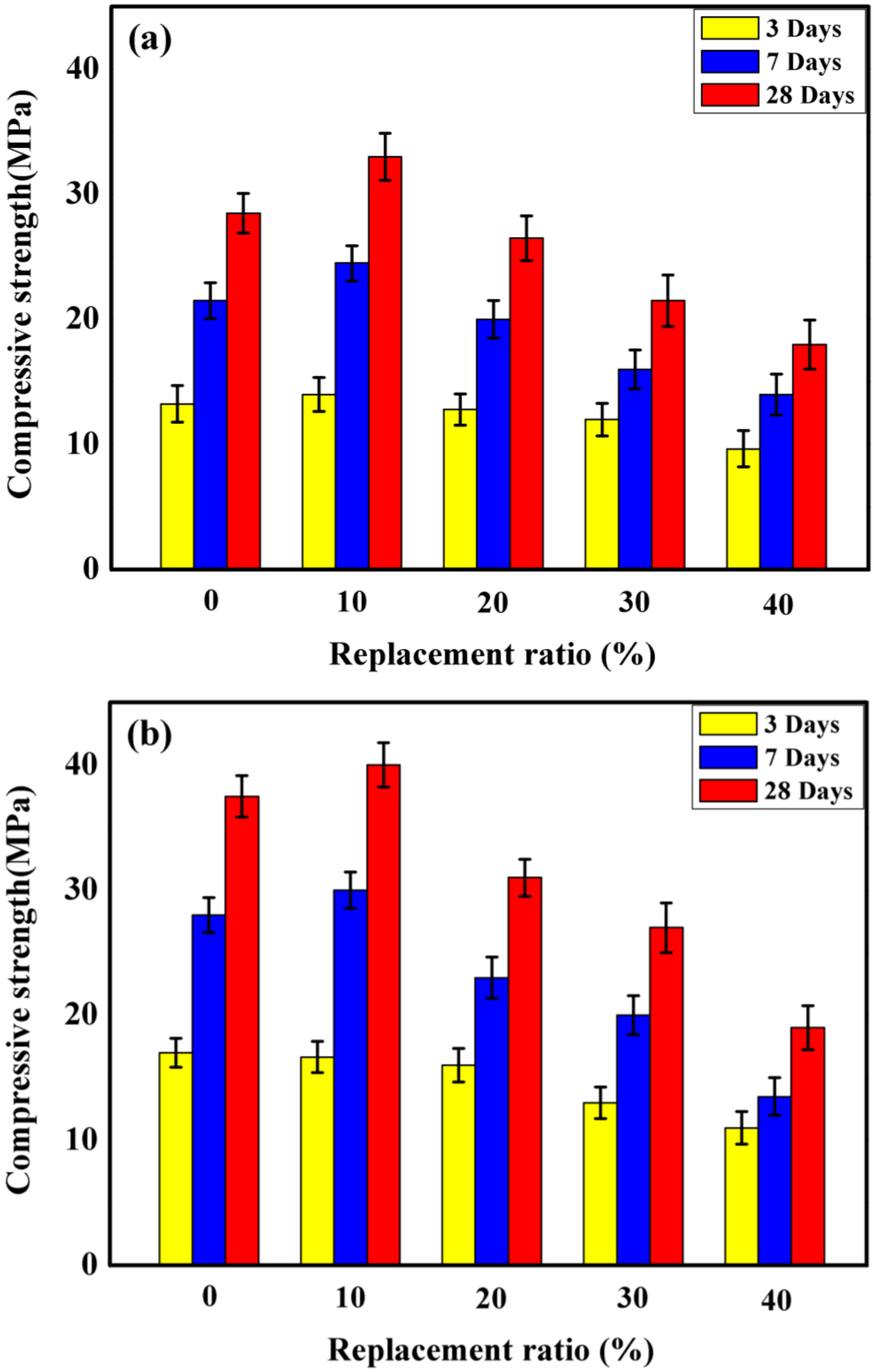


Fig 7. Compressives strentgh of mortar mixes with MWD as PRC prepared with (a) RTW and (b) MW.

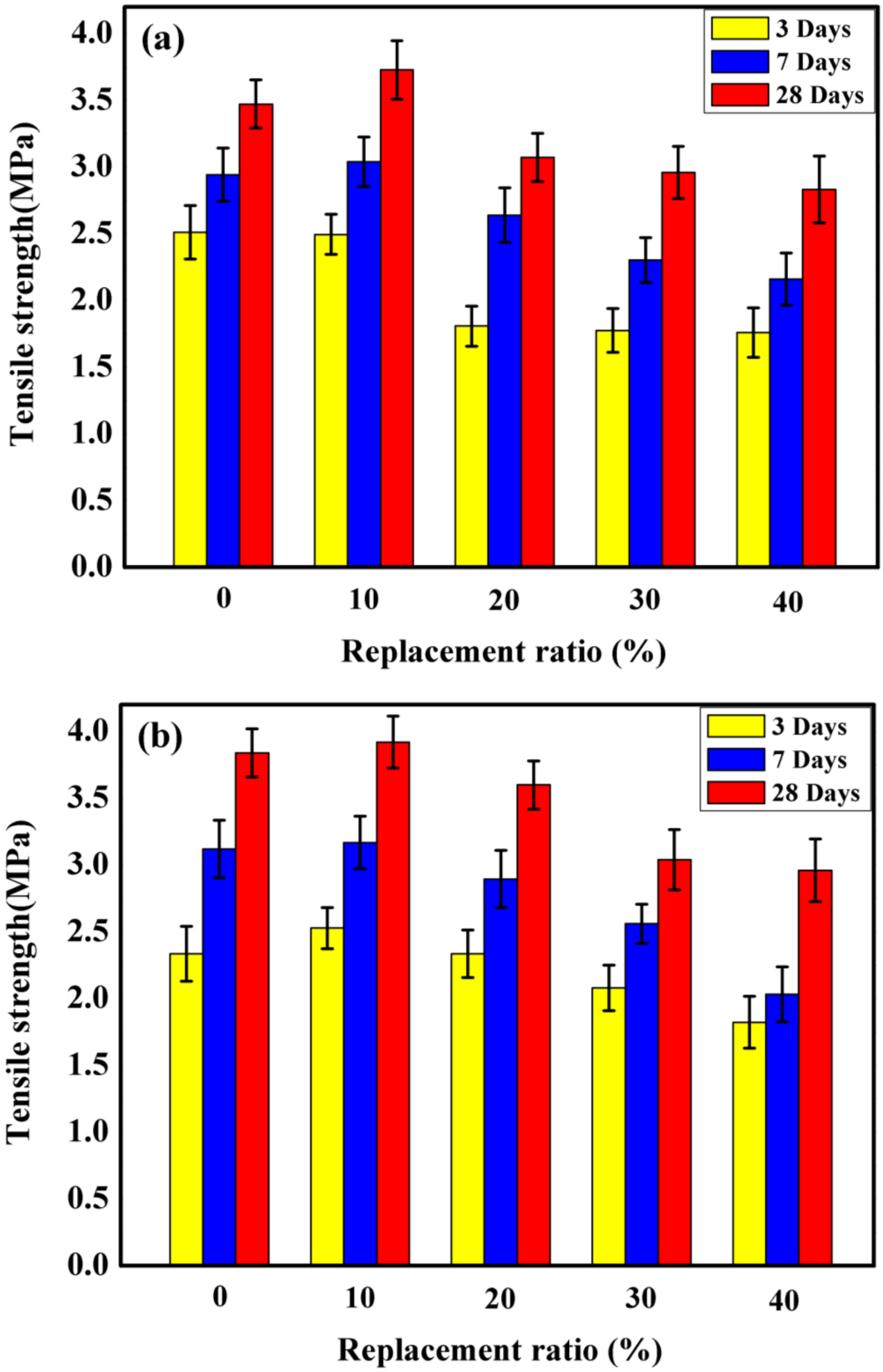


Fig 8. Tensile strentgh of mortar mixes with MWD as PRC prepared with (a) RTW and (b) MW.

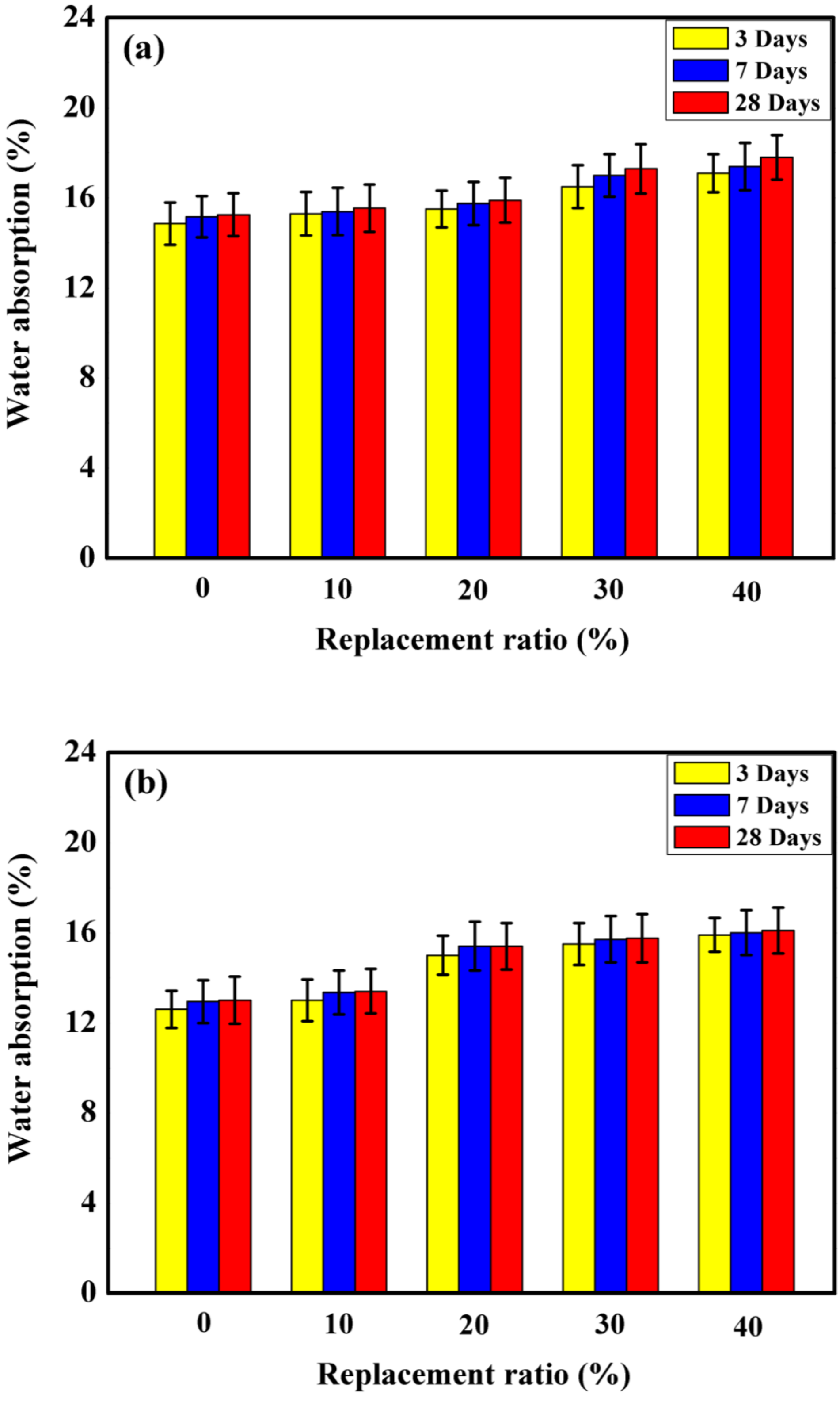


Fig 9. Water absorption of mortar mixes with MWD as PRC prepared with (a) RTW and (b) MW.