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EMPLOYMENT OF MAGNETIC WATER TREATMENT IN CONSTRUCTION

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Abstract: Magnetic treatment (MT) is one of the interested techniques that have been widely used in various aspects of life due to its positive effectiveness on the properties of water when utilized. Construction sector received great attention by researchers in order to employ magnetic water (MW) in the production of various building materials especially cement-based materials. This is due to the role of water is involved directly in the hydration process of the cement as well as curing process. The effectiveness of using MW came from the influence of magnetic field (MF) on physical properties of water molecular such as surface tension. Break down in the size of water clusters, therefore, is occurred which increases the activity of water molecular to penetrate the cement particle easily to involve in the hydration process. Various parameters may affect the magnetization process such as time, strength of MF and speed of water through the MF. In the current paper, the impact of using MW in the production of various construction and building materials that based on cement is addressed to clarify the actual need in adopting such an attractive technology to magnetize the water to be used in mixing and curing cement-based materials to construct sustainable concrete structures in construction sites.

Keywords: *Magnetic water, Construction, Building materials, Magnetic water treatment.*

1. Introduction

The technology of magnetized water (MW) has received great attention in the world to employ such technique in different aspects of to life. This is to overcome numerous drawbacks that associated with the usage of tap water since normal water may contain harmful substances and salts [1] which affect negatively on the quality of water. Also, the increment in the waste of water around the world gave good reasons to move towards the adoption of MW in different applications. Magnetic water treatment (MWT) was; therefore, utilized in agriculture [2-5], medical [6-8] and industries such as chemistry industry [9].

The MW is obtained by expose tap water to magnetic field (MF) for a period of time at constant speed. Evidence from literatures showed that the MF causes some changes on the physical properties of water such as PH [10], specific heat, boiling point [10] and surface tension [12,13]. The latter was found to be reduced as the water passes through MF. Thus, small groups of water clusters are resulted from breaking down into large water clusters. The water structure is also affected by the implementing of MF [14] in which the water molecular is re-oriented in one direction under

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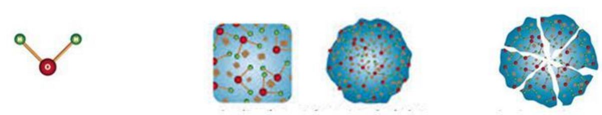
magnetic field. Different parameters influence on the effectiveness of magnetization. Magnetic field strength (MFS) measured by Gauss or Tesla, flow rate or velocity of water and time of exposure of water to the MF. Further details of magnetization are addressed in section two in this paper.

In terms of the industry of cement-based construction, the use of the technology of magnetization the water is still limited on research area rather than in actual construction sites. Many factors need to be explored further on the influence of magnetization of water on properties of cement-based structures with various requirement of design as huge amount of cementitious-based building materials is utilized. Such amount of materials required huge quantities of water. Annually, the production of concrete, for example, in the world consumed around 1 billion tones of water [15]. As the world is concentrated on the production of economical and sustainable cement-based building materials, MW is one of the solutions for saving the water consumption [15,16]. The latter is an important element that used in the production of concrete, for example, in order to construct sustainable concrete structures.

The utilization of MWT in construction have been shown to improve the properties of fresh and hardened cement-based materials [17-20] since water contributes directly to the hydration process of cement which is the most commonly used material in the production of construction and building structures. As mentioned earlier, MF reduces the size of the water clusters which make it easily penetrate the cement particle during the hydration process to produce denser products of hydrations and less porosity which affected lately on the microstructure and strength of cement [21]. Curing process is also involves the usage of water to continue the hydration of cement and to develop the strength of cement-based materials.

2. Concepts of Magnetization

Water is one of the most important elements for life aspects. Generally, water molecular comprises of one negative oxygen atom and two negative hydrogen atoms (Fig.1a). Water molecular is combined with other water molecular to form water clusters. (Fig.1b). The bond between water molecules are loose and source of this bond is referred to the attraction between the oxygen atoms of one molecular with the hydrogen atom of the other molecular [22].



(a) (b) (c)

Figure 1. Water molecular and water cluster [22]

MW could be obtained by passing tap water through permanent magnetic MF with constant speed for period of time. Physical properties of water then changed such as surface tension of water [13] which leads to reduce the number of water molecular in the clusters (Fig.1c) and the size of the clusters is affected by the MF. Water clusters are therefore breaking down into small clusters (Fig.2). This is due to the effect of MF in weakening the intraclusters hydrogen attraction. Also, expose water to MF leads to re-structure (re-organize) water molecules in the cluster (Fig.3) into one direction depending on different parameters which will be cover later elsewhere in this paper.

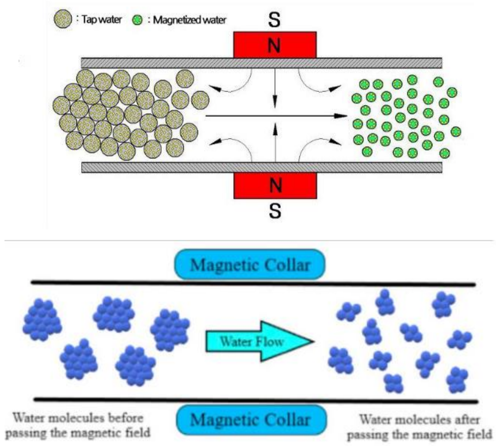


Figure 2. Influence of magnetization on the size of water clusters [23, 24]

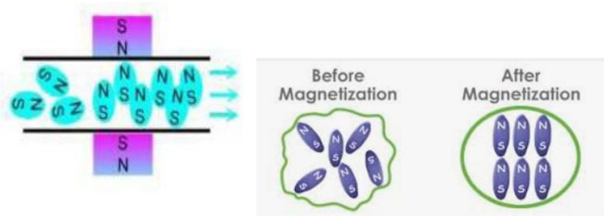


Figure.3. Re-structure of water molecular under magnetic field [25, 26]

The effectiveness of magnetization on water properties depends on different variables such as the strength of the MF, velocity of water that passing through the MF and the period of time in which water is exposed to MF [27]. Many suppliers within these days provide different types of magnetic devices (MDs) that ensure the application of permanent MFs with different strengths and for various applications in life. For research purposes, some researchers used such MDs in their experiment program (as shown in the following sections) to study the effect of magnetizations on properties of water as well as the properties of materials where MW is utilized. Other group of researchers design their own magnetic devices using permanent magnets that provided by different suppliers to achieve the objectives of their research under specific conditions of magnetization.

3. Magnetic water in cement-based construction materials

Excessive research work was reported in literatures to clarify the influence of using MW in mixing or curing different building materials such as concrete [28-33].The magnetization was conducted using different types of magnets such as permanent, temporary and electromagnets. The following sections explore different experimental programs that adopted by researchers to identify the most effective method for magnetization the water using various MDs which were purchased from different suppliers or designed by the researchers.

4. Magnetized cement paste and mortar

An experimental investigation was carried out to explore the effect of magnetic treated water on physical and mechanical properties of cement mortar [34]. The MW was obtained via using magnetic device which was manufactured locally. The tap water (TW) was allowed to pass through the device. The latter comprises of four circles. The strength of each circle was 500 Gauss and of 2000 L/hr discharge. Both TW and MW was used to mix cement mortar of (1:3) mixing ratio. The cement was Sulphate resistance Portland cement Type (V). The fine aggregate was supplied from Wilayt Ali source, Iraq with grading of zone 2. Different water-to-cement (w/c) ratios were used (0.4, 0.45, 0.5, 0.55 and 0.6). Tests were conducted on cement paste. These tests were standard consistency, initial and final setting times. Other set of tests were performed on cement mortar (with and without MW) by means of compression test at different curing ages (1 and 7 days).

Results indicated that the initial and final setting times were found to be reduced with the usage of MW in cement mortar samples when compared with control samples and for all w/c ratios. The reduction was (60%, 50%, 27.78% and 21.88%) and (19.2%, 16.15%, 16.63% and 19.60%) for initial and final setting times respectively and for w/c of (0.4, 0.45, 0.5, 0.55 and 0.6) respectively. It is observed that the influence of MW was higher on initial setting time than final setting time. Contrary to setting time, an increment in compressive strength was obtained for MW samples in comparison with control specimens and for all w/c ratios. The percentage of enhancement in compressive strength of 1 day curing was (9.10%, 14.29%, 15.38%, 7.69% and 8.33%) for w/c of (0.4, 0.45, 0.5, 0.55 and 0.6) respectively. Higher enhancement in compressive strength was reported for magnetic water samples that tested after 7 days of curing. This improvement was (22.73%, 18.52%, 20%, 18.37% and 20%) for w/c of (0.4, 0.45, 0.5, 0.55 and 0.6) respectively.

Another study was conducted to investigate the impact of using MW on properties of cement-based materials [35]. It was reported that the fluidity of cement paste was improved with the usage of MW. The increment in the flowability was increased with the increment in the magnetic field strength regardless of the flow rate. The significant increment was found for cement paste that prepared with MW that obtained with 810 mT and for 0.73 m/s of flow rate. The fluidity was reduced as flow rate was increased more than 0.73 m/s since the water will be exposed to short time to the magnetic field as the water flow velocity was high (up to 1.01 m/s) thus little effect or no significant effect is expected of the magnetization process on water clusters at higher flow rate. The setting time of cement paste was found as well to be not affected by the change of the flow rates (0.39, 0.59, 0.73 and 1.01 m/s), but the effect of MFS on setting time was significant. Reduction of setting time (initial and final setting times) was increased with the increment in the magnetic field strength from 250 mT to 810 mT. The higher the magnetic strength, the smaller the clusters water which penetrate easily cement grains and accelerate the hydration process of cement thus set in short time.

The compressive strength of cement mortar samples was higher when magnetic water was used and the highest was observed for samples that tested at early ages. The highest compressive strength was reported for flow rate of 0.73 m/s. An increment of 44% was recorded for magnetic samples using 810 mT at 3 days of curing; however, less increment in the compressive strength (20%) was noted for magnetic samples that tested at 28 days. In terms of flexural strength, no significant influence of magnetic water was observed on flexural strength of cement water when compared with control samples. Most of the obtained flexural strength was remained the same for specific flow rate and specific magnetic field strength.

5. Magnetized cement-based adhesives

Limited work was reported in the literatures in terms of using magnetic treated water in developing bonding agent used in Fibre Reinforced Polymer (FRP) strengthening system. Only one study was recorded in which group of researchers [36] investigated the influence of water that magnetized via permanent magnets on compression and splitting tensile strengths of cement-based adhesive (CBA) that utilized as bonding agent between concrete substrates and near-surface mounted (NSM) strengthening technique. In their work, tap water was magnetically treated using two different magnetic devices (MDs) (Fig.4) which were designed in laboratory by other group of researchers [37]. The strength of MF for both devices was 9000 and 6000 Gauss which was measured via Gauss meter. One of the MDs (Fig.4 left) consists of ten permanent Neodymium block magnets while the other magnetic device (Fig.4 right) contains twelve cylindrical permanent Neodymium magnets. Each device was connected to a pump on of its end and a water tank in the other end of the device (Fig.5). The water was allowed to circulate through the device for different periods of time (15, 30 and 60 mins) with various velocities of water (0.2 and 0.4 m^3/hr). The MW was used to mix the ingredients of cement-based adhesives (CBA-A and CBA-B). These two types of CBA comprise of superplasticizer (Viscocrete®5-500), water and powder–state materials. These materials are: Ordinary Portland cement, microcement, silica filler, silica fume. However, a thermoset primer was used as well in CBA-A only.

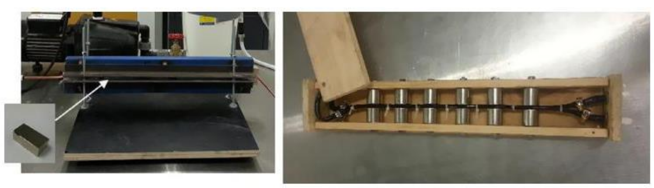


Figure 4. Designed magnetic devices with various magnetic field strengths [36]

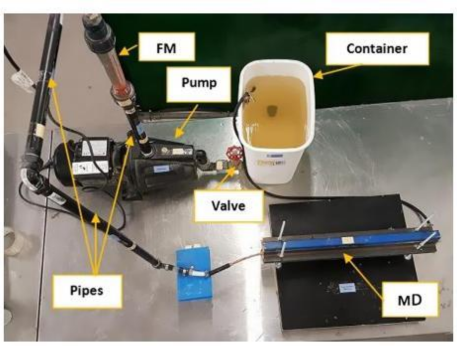


Figure 5. Arrangements for magnetization the water [36]

Compression and indirect tension tests were performed in accordance to AS 1012.11 and AS 1012.12 respectively using cylindrical samples with 100mm diameter and 200mm height for both control and MW samples. The measured compressive and splitting tensile strengths were obtained at various curing periods (3, 7, 14, 21 and 28days). Results indicated that MW enhanced the mechanical properties when compared with control samples. Highest increment in the strengths was reported for CBA samples using water that magnetized with device of 9000 Gauss and for all velocities of water and for the same time of water circulation in the device. Within the magnetized samples, CBA-A showed higher improvement in the strengths than those of CBA-B using magnetic device of 9000 Gauss of magnetic strength.

Furthermore, in order to explore the influence of circulation time of water on strength, CBA samples were tested in compression and indirect tension using magnetic device of 9000 Gauss magnetic field strength at specific flow rate (0.1 m^3/hr) and for three different periods of time for water circulation (15 mins, half hour and 1 hr). It was reported that the effect of circulation time was found to be higher on splitting tensile strength that compressive strength. A reported enhancement of 23.55% in the indirect tensile strength at age of 7 days was recorded for CBA-A when MW was used and when circulation time of water was increased from 15mins to half an hour. When circulation time was increased from half an hour to an hour, a 29.91% increment in the splitting tensile strength was achieved. Regarding the effect of flow rate on compression and splitting tension strengths, it was recorded that highest increment (22.46%) in the compressive strength at 28 days was obtained for CBA-A samples with flow rate of 0.1 m^3/hr in comparison with other samples with other flow rates (0.2 and 0.4 m^3/hr). Highest improvement (56.25%) in splitting tensile strength at 3 days was reported for 0.1 m^3/hr and for samples of CBA-A.

6. Magnetized concrete

6.1 Normal concrete

Excessive experimental work was conducted by groups of researchers [37], to explore the effect of incorporating magnetic water in normal strength concrete. MW was explored in their study as mixing water to prepare three different mixes of concrete (mix A, mix B and mix C). These mixes were varies in mix proportion (cement: sand: gravel) as well as with water-to-cement ratio (w/c). The mixing ratios were ((1: 1: 1.87: 3.37), (1: 1.5: 3) and (1: 1.7: 2.54)) for mixes A, B and C respectively. Each one of the three mixes (A, B and C) was obtained using various w/c ratios. Mix A was prepared using two w/c ratios (0.55 and 0.53) by weight. Another two different w/c ratios (0.43 and 0.42) was utilized to obtain mix B. In terms of mix C, it was prepared using three different w/c ratios (0.47, 0.48 and 0.5). The water was magnetized using two magnetic devices with two different magnetic field strengths (6000 and 9000 Gauss). The water was allowed to pass through permanent magnetic with velocity of 1000 mm/sec and the water was allowed as well to circulate through the device for 5 minutes.

The workability of fresh concrete was conducted in accordance to ASTM C-143-90a using slump test for control mixes as well as for magnetized concrete mixes. Mechanical properties were conducted for both magnetized and non-magnetized concrete samples. These specimens were fabricated using cylindrical moulds with (100×200 mm) in dimensions and cured for various periods 7, 14 and 28 days) using tap water for curing at ambient conditions. Compression and indirect tension tests were performed in accordance to ASTM C39 and ASTM C496-06 respectively using loading rate of 2.36kN/s and 0.63kN/s respectively.

An increment in slump was reported for all magnetized concrete mixes (A, B and C) when compared with control samples. It was reported that the slump increases with the increment in the magnetic device strength. Highest increment (90.5%) in the slump was for magnetic samples of mix C with w/c =0.48 when compared with control samples for the same mix (mix C). When w/c was increased to 0.52 for mix C, the slump was found to be increased as well and the reported increment was 133.33%.

In terms of mix A, highest increment (80%) in the slump was obtained for mix A with w/c=0.55 for MD with highest magnetic field strength (9000 Gauss) when compared with control samples. Less increment (55%) were obtained for magnetic concrete samples of mix B with w/c =0.43 and for magnetic device with the highest magnetic strength (9000 Gauss) in comparison with control sample for the mix (mix B).

Regarding splitting tensile strength at 28 days, samples with MW showed higher strength than control samples for all mixes. Both mixes (A and B) showed same increment (around 16%) and for the highest magnetic field strength (9000 Gauss). However, less increment in the splitting tensile strength (around 9%) was reported for magnetic samples for mix C. In terms of compressive strength, all magnetic water samples for various mixes (A2, B2 and C2) showed higher compressive strength at all ages of curing (7,14 and 28days) when compared with control samples that prepared with tap water (A, B and C). Highest improvement in the strength was reported for mix B2 and for all ages of curing when compared with other mixes (A2 and C2). The increment in the compressive strength of C2 was 9.96%, 16.19% and 21.55% for age of curing of 7 days, 14 days and 28 days respectively.

Another group of researchers [38] conducted an investigation on M20 grade concrete. Mixing ratio was (1: 2.27: 3.45) with w/c of 0.54. MW was used for mixing some mixes and curing of others. The magnetization of water involves the usage of rounded magnets with strength of 985 Gauss. Tap water was used to fill glass beaker (Fig.6) which was then placed on the permanent magnet for various exposure periods (1, 2, 3, 4, 5, 6, 12, 18, 24, 36, 48, 60, 72 hrs). Within this type magnetization, water was exposed to North Pole and South Pole. Thus the used MW was (North Pole (NP) for some samples and other specimens used South Pole (SP) while another group of samples was prepared using mixture of poles (50% NP +50% SP). Salt water was also used for magnetization and was used to prepare some mixes. Compressive strength was conducted for control and magnetic concrete samples using the optimum exposure time of water using the one of the magnetized type of water (type of poles mixed or single) with the highest results. Cubic samples with size of 150×150×150mm were used to perform compression test at 28 days of curing.

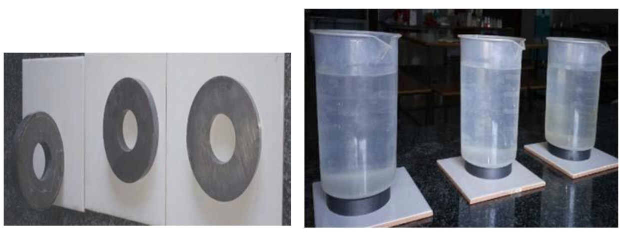


Figure 6. Type of magnets used in the magnetization [38]

In terms of the effect of exposure time on concrete strength, reduction in the strength was reported for samples where water was magnetized for short periods of time (up to 5 hrs). The strength was noted to increase for concrete samples with water that magnetically treated after 5hrs and up to 24hrs of the exposure to the MF. The rate of increment in the strength after 24 hrs was found to be the same. Within the magnetic samples, concrete that mixed with MW mixed poles (50% NP+ 50% SP) showed the highest compressive strength (43.5 MPa) in comparison with samples that prepared with single poles. Also, higher strength (40.5 MPa) was found for samples with NP only and less strength was (37.3 MPa) for specimens that prepared with water of SP only. The negative effect of magnetization of water up to 5 hrs of exposing to MF was attributed to the clusters of water tried to move in various direction under the effect of magnetic field to change their new positions. Water clusters thus become closer to each other at initial time of exposure. Within the increment in the time of magnetization (up to 24 hrs), these clusters tried to orient themselves in the direction of the magnetic field within the increment in the exposure time and up to 24hrs.As magnetization time was increased after 24hrs, breaking the bonds between water clusters as well as re-orientation reached their ultimate limit thus no significant change in the strength was found when water was magnetized for more than 24 hrs.

Regarding the usage of MW for mixing, an increment in the compressive strength (55.7%) was recorded for concrete samples that prepared with N+S (MW) of 24hrs magnetization period and cured with tap water when compared with control samples. The obtained compressive strength was of 28 days of curing in tap water. In terms of the effect of magnetic water on curing control samples, higher strength was recorded for samples that cured with magnetic water in comparison with samples that cured with tap water regardless of the water that used in mixing. The increment in strength (7.4%) was for control samples that mixed with MW in comparison with control specimens. Within the magnetic water samples, the increment was 5% for concrete that mixed and cured with MW when compared with MW specimens that cured with tap water. As magnetized salt water was used for mixing, higher compressive strength (33.62 MPa) was for salt magnetized water concrete when compared with samples that prepared with salt water concrete (without magnetization). It was also observed that magnetization salt water reduces the strength when compared with samples where tap water for magnetization.

Another investigation was carried out to address the effect of incorporating MW on workability and compressive strength of concrete that including silica fume [39]. MW was used for mixing and it was obtained by passing TW through magnetic field. This was obtained with the usage of copper piper that wrapped 3250 rounds with solenoid coil of 68mm length and 1mm in diameter (Fig.7). A direct electric current was then connected to the coil to generate the magnetic field with magnetic strength of 0.09 Tesla and 0.12 Tesla. The tap water was passing through the pipe with flow velocity of 18 liter/hr. Six concrete mixes were prepared and then tested in flesh and hardened states. These mixes were (C1- C6). Three of these mixes (C1, C3 and C5) contain silica fume as partial replacement of cement (10%) with different w/b ratios (0.25, 0.35 and 0.45) respectively. Other three mixes (C2, C4 and C6) contain no silica fume in their compositions and the w/c ratio for these mixes was 0.25, 0.35 and 0.45 respectively.

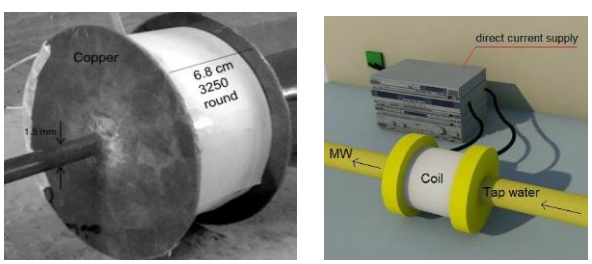


Figure 7. Details of magnetic device [39]

Results of slump test indicated that magnetic specimens showed higher slump than control samples and for all w/c and w/b ratios. Also, it was observed that the higher the magnetic field strength, the higher the obtained slump. Highest slump (230mm) was recorded for magnetic samples for w/b of 0.35 and with 10% of silica fume using MW with magnetic intensity of 0.12 Tesla. As the w/c and w/b ratio increases the 0.35, the slump was reduced for all control and magnetic mixes.

In terms of compressive strength, it was concluded that an increment (15%) was obtained for magnetic samples containing superplasticizer. It was also observed that the higher MF intensity, the higher the enhancements in the strength at age of curing up to 28 days. Less effect of magnetic water was recorded on late age of curing (90 days). The replacement of cement with silica fume was found to decrease the effect of MW on compressive strength of concrete.

6.2 Special concrete

One of the special types is self-compacting concrete (SCC). An experimental investigation was carried out to explore the effect magnetic treated water on water demand, compressive strength and dosage of superplasticizer of SCC [40]. The water was magnetized using magnetic device (Gamma Special 1) which was provided by Italian company (Euro Gamma 2000) with magnetic field strength of 1.4 T. The magnetic device was attached to the edge of a hose of 1500mm internal diameter. Tap water (TW) was allowed to pass under the magnetic device at speeding rate of 25 mL/s. The magnetized water (MW) was then collected and used within 5 mins. The MW was used in mixing SCC mix. The latter comprises of using ordinary Portland cement (Type I), sand and gravel with specific gravity of 2.69 and 2.67 respectively, filler (limestone powder) with specific gravity of 2.8, superplasticizer (commercially available as Glenium 110) provided by BASF, Ohio, Viscosity modifying admixture (VMA) (commercially available as Rheomac VMA 362) and water.

Four samples were prepared as control samples with various water-to-cement ratios (w/c) (0.35, 0.40, 0.45, and 0.50). For each w/c, an adjustment in the dosage of the superlasticizer was conducted to achieve the desired spread diameter of 600±10 mm. A fixed value of the filler (1wt% of cement) was used for all mixes to meet the requirements of ACI 237R. Another four samples were prepared in similar proportions as control samples, but MW was used instead of TW in mixing the ingredients of concrete.

Various tests were performed on SCC samples (control and magnetized). These tests involve slump flow test, T50, L-Box, V-Funnel, and visual stability index (VSI). These tests were conducted in accordance to ASTM C1611 and EFNARC. Additionally, compression test was conducted on hardened samples at various curing periods (7 and 28 days). As indicated from results of flowability, reduction in water demand was recorded for magnetic concrete samples in comparison with control specimens and for all w/c ratios. This reduction was found to be increased with the increment in the w/c. Thus, the highest obtained reduction (11.9%) was for samples with w/c of 0.5 and lowest reduction (8.5%) was recorded for samples with w/c of 0.35. Such behavior was attributed to the influence of water clusters by the magnetic field since the latter breakdown these clusters into smaller clusters which made them easily interact with cement grains.

The dosage of superplasticizer was also affect by the usage of MW in concrete. Such dosage was found to be reduced with the usage of MW and for all w/c ratios and the highest reduction (43.4%) was reported for the lowest w/c ratio (0.35). This was related to the increment of the flowability of concrete due to the MW; therefore, less superplasticizer was needed. It was also reported that there was no effect of MW on viscosity of concrete and only the flowability was affected. Such observations were drawn based on the test results of VSI and for all tested samples.

In terms of compressive strength, magnetic concrete samples with various w/c ratios showed higher compressive strength than control samples for all curing periods (7 and 28 days). An increment of (10.97%, 9.02%, 12.42% and 14.34%) in compressive strength at 7 days was reported for concrete samples with MW for different w/c ratios (0.35, 0.4, 0.45 and .5) respectively when compared with control specimens. The increment in compressive strength was higher for 28 days. Such increment was (12.03%, 11.65%, 11.43% and 16.25%) for magnetic water samples when compared with control samples for various w/c ratios (0.35, 0.4, 0.45 and 0.5) respectively. Similar behavior was reported as well for magnetic samples with superplasticizer for different w/c ratios. The increment in compressive strength for these samples was (3.06%, 3.18%, 6.62% and 8.82%) for 7 days curing period and (6.84%, 8.01%, 10% and 9.38%) for 28 days curing and for w/c ratios of (0.35, 0.4, 0.45 and 0.5) respectively. The enhancement in the strength was attributed to effect of MW effect on the microstructure of concrete by reducing the voids which result in a denser structure as confirmed by the characterization of concrete samples by SEM. The latter was performed on samples (control and magnetic concrete) with w/c of 0.35.

7. Conclusions

Magnetic water treatment (MWT) is one of the most modern technologies that employed in reality in various industries in life but this is not the same case in construct concrete structural members. The key-advantages of MWT is to use less water than using tap water due to the change in the physical properties of water by magnetization in addition to improve the properties of water. Some factors affected the effectiveness of magnetization and these are strength of magnetic device, flow rate of water as expose to the magnetic field as well as the period of time. Evidences from literatures showed an incredible improvements in fresh and hardened properties of cement-based materials when MW was utilized in mixing or curing. As the nowadays is to reduce the waste in water in the construction industry with the improvement in the properties of cement-based materials using magnetic treated water, the need to adopt the MWT technology became an urgent and important demand to construct sustainable building structures.

Conflict of interest

The author declare that there are no conflicts of interest regarding the publication of this manuscript.

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