



COMPRESSIVE STRENGTH AND SPLITTING TENSILE STRENGTH OF CONCRETE CUBE USING MAGNETIZED WATER

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Report on cases of collapse of residential buildings and other structures are common in Nigeria which is normally due to structural failure, failure of the materials that were used for the construction and poor design. Buildings Collapse normally results to loss of lives and properties. The study was conducted to determine the effect of Magnetized Water (MW) on the Compressive Strength (CS) and Splitting Tensile Strength (STS) of Concrete Cubes (CC). MW is the water that has passed through magnetic field which could enhance proper hydration of concrete and improve the strength of CC. The CC was produced using sand (4.75 mm diameter), ordinary Portland cement, crushed granite (12 mm diameter) and MW. The mixing ratio of cement, sand and granite for the CC was 1:2:4 and water-cement ratio was 0.5. The treatments were T₁ (concrete produced with Non-Magnetized Water -NMW and cured in MW treated for 1 minute), T₂ (CC with MW treated for 1 minute and cured in NMW), T₃ (CC with MW treated for 1 minute and cured in MW treated for 1 minute), T₄ (CC with MW treated for 2 minutes and cured in NMW), T₅ (CC with MW treated for 2 minutes and cured in MW treated for 2 minutes) and control T₀ (CC produced with NMW and cured in NMW). CS and STS were determined after cured for 7, 14 and 28 days. The mean CSs after cured for 28 days T₁, T₂, T₃, T₄, T₅ and T₀ were 18.13, 22.00, 23.40, 19.07, 17.87 and 18.66 N/mm², respectively. The mean STSs after cured for 28 days T₁, T₂, T₃, T₄, T₅ and T₀ were 1.33, 1.38, 1.59, 1.83, 1.21 and 1.32 N/mm², respectively. MW increased the CS and STS by 25.40% and 37.57% of the concrete cubes, respectively. This shows that magnetized water is economical, simple and environmentally-friendly technology for the production of concrete cubes.

1.0 Introduction

In Nigeria, collapse of buildings and other structures is due to structural failure, and failure of the materials that were used for the construction and poor design. The collapse of buildings normally results in loss of lives and properties. Hamma-adama and Kouider (2017) reported that the use of sub-standard building materials is the major cause of building failure and collapse in Nigeria. Sandcrete blocks that is commonly used in Nigeria for the construction of buildings is sub-standard and they normally fail because they are fragile, they have low compressive and tensile strengths due to low cement content. Concrete and sandcrete cube have high compressive strength but they have low tensile strength and brittle in nature. Tensile strength is an important property of concrete because concrete structures are highly susceptible to tensile cracking due to various kinds of loads and other factors which could lead to failure of a building or structure. Therefore, there is a need for economical ways of improving the strength of the materials which are mainly the concrete and sandcrete blocks.

MW is the water that has been allowed to flow through the magnetic field and the water could enhance proper hydration of the concrete during curing and this could improve the compressive and tensile strengths of the concrete cube (Reddy *et al.*, 2014; Patil and Pathak, 2016). MW is also called magnetic water or magnetically treated water and it has a better property than the ordinary water. Ali *et al.* (2014) pointed out that MW reduced the scale deposition in water pipes. Patil and Pathak (2016) reported that the paste consists of cement and water that binds the aggregate together and hardening of concrete occurs due to chemical reaction between the cement and water during the time of curing thereby making the concrete stronger. Furthermore, MW is environmentally friendly and has low installation cost and no energy requirement for its operation when permanent magnet is used. Magnetic treatment of irrigation water (magnetized water for irrigation) has been used to boost crop yield (Babu, 2010; Yusuf and Ogunlela, 2017). Albahrani (2018) indicated that the compressive strength of concrete produced with MW that was treated in magnetic field for 28 days increased by 26.2%. Kiranmai and Rao (2018) pointed out that the compressive strength of concrete produced with MW that was treated for 24 hours increased by 38.1% after curing for 7 days. Shynier *et al.* (2012) also stated that magnetic water that was used for mixing the concrete improved the compressive strength of the concrete by 10 - 22 N/mm². Reddy *et al.* (2014) stated that MW enhanced proper hydration and improved the compressive strength of concrete by 55%.

In this current study, a short period of 1 to 3 minutes were used to produce MW by circulation flow method and determine if the time could be effective for producing MW for concrete cubes instead of 24 hours used by Kiranmai and Rao (2018). Circulation flow method means that water is allowed to flow through magnetic field continuously for a short period of time for about 1 - 2 minutes (Chern, 2012). A static flow method means that there is no flow of water through the magnetic field but a magnet is put by the side of water for a long time like 24 hours or more as reported by Kiranmai and Rao (2018) and 72 hours as reported by Parthiban *et al.* (2016). Podlesny *et al.* (2004) reported that 15 seconds was adequate and effective for producing MW but Aladjajiyani (2007) reported that 1-10 minutes is adequate for effective treatment and production of MW using circulation flow magnetic water treatment method. Circulation flow method is more effective than the single flow magnetic water treatment method and is also better than the static flow magnetic water treatment method for producing MW in which water is allowed to be in the magnetic field for a longer period of time. For the water to be magnetically treated water (magnetized water), the flow of water must cut the magnetic field at right angle based on Fleming's Right-hand rule so that the magnetic force can act on the water (Chern, 2012), otherwise, the water would not be MW. The objectives of this study were to determine the effect of magnetized water produced by circulation flow method within 1 to 3 minutes on the compressive strength and splitting tensile strength of concrete cubes.

2. Materials and Methods

2.1 Location of the study

The study was conducted at the Concrete Laboratory of the Department of Civil Engineering, University of Ilorin, Nigeria. The University of Ilorin is located in Ilorin South Local Government Area of Ilorin city, Kwara State. Ilorin lies on latitude 8°30'N and longitude 4°35'E, with about 340 m above the mean sea level with annual rainfall of 1300 mm (Ejeji and Adeniran, 2009).

2.2 Materials for production of the concrete block

The materials used for the production of the concrete cubes are presented in Table 1. The physical properties of the cement, the sand (fine aggregate) and the crushed granite (coarse aggregate) used in this study are presented in Tables 2, 3 and 4, respectively.

Table 1: Materials used for production of the concrete cube

S/N	Parameters	Source / Type	Properties
1	Ordinary Portland Cement (OPC)	Dangote cement	The properties are within the standard permissible value of IS: 12269-1987.
2	Coarse aggregate	crushed granite	12 mm single size, with specific gravity (relative density) of 2.7 and water absorption of 0.3%;
3	Fine aggregate	sand	Specific gravity of 2.63, fineness modulus of 2.6 and water absorption of 2.5%
4	Pure water	Tap water	Clean water free from impurity
5	PERMAG (Neodymium 406) Magnet	permanent magnet	length, internal and external diameter of 20 mm
6	Weighing balance	ACS-15-ZC73	Max = 30 kg, Min = 1g

Table 2: The properties of the cement used

S/N	Parameters	Permissible value by IS:12269-1987	Experimental value
1	Specific gravity	3.15	3.11
2	Normal consistency	26-33%	28%
3	Initial setting time	Min 45 minutes	80 minutes
4	Final setting time	Max 600 minutes	330 minutes
5	Fineness	Max 10%	1%

Table 3: Physical properties of the sand used (fine aggregate)

S/N	Parameters	Permissible value by IS:12269-1987	Experimental value
1	Specific gravity	2.5 -3.0	2.63
2	Fineness modulus	2.2 -3.2	2.60 (fine sand)
3	Water absorption	Max 2.5%	2.5%
4	Zone of FA	-	3

Table 4: Physical properties crushed granite (coarse aggregate) passing through 12 mm single size

S/N	Parameters	Permissible value as per IS:12269-1987	Experimental value
1	Specific gravity	2.5 to 3	2.70
2	Particle shape	-	Angular
3	Water absorption	1%	0.3%
4	Crushing value	45%	17%
5	Impact value	45%	12.6%

2.3 Production of the magnetized water

The MW was produced by allowing the water to flow through the magnetic treatment unit that is surrounded by 12 pieces of neodymium magnet (Figure 1). A neodymium magnet is a strong permanent magnet that can work effectively at room temperature and high temperatures up to 80 °C without demagnetization. It is a strong magnet with magnetic flux density ranging from 1.0-1.5 Tesla (10,000 – 15,000 Gauss). Each of the neodymium magnets is 10 × 25 × 50 mm and is produced from Neodymium (Nd), Iron (Fe) and Boron (B) together to form an NdFeB magnet. The water was allowed to pass through the treatment unit in 1 minute for treatment T₁ and T₂ when the water was passed through the magnetic treatment unit 2 times for 2 minutes. The magnetic treatment unit is a rectangular pipe made from the

perspex glass (15 by 60 mm and 600 mm long), folded (bend) to form 3 layers to effectively use the available 12 pieces of neodymium magnets in order to have maximum magnetic field and to make it compact. The neodymium magnets cover a total length of 450 mm ($50 \text{ mm} \times 3 \times 3\text{-layers} = 450 \text{ mm}$) on the magnetic treatment unit as shown in Figure 1.

Magnetized water is produced when the control tap is opened and the raw water flow from the tank through the pipe to the magnetic treatment unit where the magnetic field radiates or passes across the water and the water becomes magnetically treated water or simply as magnetized water (Figure 2). The flow of water in the magnetic treatment unit is perpendicular to the magnetic field to obey the Fleming's right-hand rule so that the water become magnetically treated water. The magnetized water was collected from the outlet with a bucket and then used for mixing the concrete and/or for curing the concrete cubes.



Figure 1: Magnetic water treatment unit with three pieces of magnets on both sides of the pipe



Figure 2: Pictorial view of the water tank connected to the magnetic water treatment unit

2.4 Production of the concrete cubes

A $100 \times 100 \times 100 \text{ mm}$ cube mould was used to produce the concrete needed for the compressive test. The materials used for the concrete were sand sieved through 4.75 mm (fine aggregate), crushed granite with the size of 12 mm single size (coarse aggregate), Portland cement and magnetized water. The ratio of cement, sand and crushed granite was 1:2:4 by weight which was by EN BS 812-5 1990. The concrete for splitting tensile strength was produced using a cylindrical pipe of 101.6 mm diameter and 200 mm high as the mould. The water-cement ratio by weight was 0.5. The materials were thoroughly mixed and lubricant was added to the formwork before concrete was poured into the mould to ease the removal of the concrete and compacted following ENV 13670-1. A hand trowel was used to finish the top surface of the concrete. Pictorial views of the concrete blocks for compressive strength and splitting tensile strength are shown in Figures 3 and 4. The treatments (T_0 , T_1 , T_2 , T_3 , T_4 and T_5) used to produce the concrete blocks are described in Table 5.



Figure 3: Pictorial view of the concrete for compressive strength test



Figure 4: Pictorial view of the concrete for splitting tensile strength test

Table 5: The description of the treatments used to produce the concrete blocks

T ₀	T ₁	T ₂	T ₃	T ₄	T ₅
Concrete cube produced with non-magnetized water and cured in non-magnetized water (T ₀ = Control)	Concrete cube was produced with non-magnetized water and cured in magnetized water that was treated for 1 minute in the magnetic field. The water only passed through the magnetic treatment unit once for 1 minute	Concrete cube was produced with non-magnetized water and cured in magnetized water treated for 1 minute in the magnetic field. The water only passed through the magnetic treatment unit once to achieve 1 minute.	Concrete cube produced with magnetized water treated for 1 minute and cured in magnetized water treated for 1 minute in the magnetic field. The water only passed through the magnetic treatment unit once for 1 minute in each case.	Concrete cube produced with magnetized water treated for 2 minutes in which the water was passed through the magnetic treatment unit 2 times and cured in non-magnetized water	Concrete cube produced with magnetized water treated for 2 minutes and cured in magnetized water treated for 2 minutes. The water only passed through the magnetic treatment unit twice to achieve 2 minutes in each case

2.5 Determination of Compressive Strength of the Concrete Cube

The compressive strength of the concrete was determined using a Hand compression machine EL31 – 072 model with 1560 kN capacity (Figure 5) in the Department of Civil Engineering Laboratory, Faculty of Engineering and Technology, University of Ilorin, Nigeria following BS EN 1991-5 1998. The concrete cube cracked when the concrete cube could no longer withstand the load (compressive force) exerted by the compression machine. The compressive strength was determined from Equation (1) (Zhang *et al.*, 2008).

$$f_c = \frac{F}{A_c} \quad (1)$$

where: f_c is the compressive strength (N/mm²), F is the failure load (N) and A_c is the area of the concrete block (mm²).

2.6 Determination of splitting tensile strength of the cylindrical concrete block

The tensile strength was done using split-cylinder test and was determined using Equation (2) reported by Zhang *et al.* (2008).

$$f_t = \frac{2F}{\pi Ld} \quad (2)$$

where: f_t is the tensile strength of the concrete block (N/mm²), F is the failure load (N), L is the length or height of the concrete block (mm), d is the diameter of the concrete block (mm) and π is equal to 3.142.

2.7 Paired t-test statistical analysis

Paired t-test was used to determine if the effect of MW was significant on the compressive strength and splitting tensile strength. The mean difference between the results of MW and that of control (NMW) was determined. The mean, standard deviation, the standard error and the t-test values were determined using Equations (3), (4a) or (4b), (5) and (6), respectively as given by Montgomery (1998) and Ogunlela and Yusuf (2016).

$$\bar{d} = \frac{\sum d}{n} \quad (3)$$

$$\delta = \sqrt{\frac{\sum d^2 - n(\bar{d})^2}{n-1}} \quad (4a)$$

$$\delta = \sqrt{\frac{\sum (d - \bar{d})^2}{n-1}} \quad (4b)$$

$$\delta_{Er} = \frac{\delta}{\sqrt{n}} \quad (5)$$

$$t_{cal} = \frac{\bar{d}}{\delta_{Er}} \quad (6)$$

where \bar{d} is the mean of the difference from x_1 and x_2 , $\sum d$ is the summation of d , n is the number of the observations, δ is the standard deviation, δ_{Er} is the standard error and t_{cal} is the calculated value of t - test. The data used for the computation of the paired t-test for illustration was the result of compressive strength extracted from Table 7 is presented in Table 6.

Table 6: Data of compressive strength of the concrete cubes for computing the paired t-test

T_3	T_0	$d = T_3 - T_0$	d^2
16.27	12.93	3.34	11.1556
20.77	16.53	4.24	17.9776
23.40	18.66	4.74	22.4676
$n = 3$		$\sum d = 12.32$	$\sum d^2 = 51.6008$

T_0, T_3 were as defined in the Abstract and Table 5

$$\bar{d} = \frac{12.32}{3} = 4.107 \quad (3)$$

$$\delta = \sqrt{\frac{51.6008 - 3(4.107)^2}{3-1}} = 0.707 \quad (4a)$$

$$\delta_{Er} = \frac{0.707}{\sqrt{3}} = 0.408 \quad (5)$$

$$t_{cal} = \frac{4.107}{0.408} = 10.066 \quad (6)$$

Similarly, this procedure was used for computing the t-test for T_1 versus T_0 , T_2 versus T_0 , T_4 versus T_0 , and T_5 versus T_0 for the compressive strength and splitting tensile strength,

3. Results and Discussion

3.1 Compressive strengths of the concrete cubes

The results of mean compressive strength of concrete cubes produced using MW and NMW, cured in MW or NMW for 7, 14 and 28 days are presented in Table 7 and the results of the statistical analysis of t-test for the compressive strength is presented in Table 8. The mean compressive strength of concrete cube produced with MW treated for 1 minute and cured in MW treated for 1 minute which was denoted as treatment T_3 had the highest compressive strength. The mean compressive strengths after cured for 28 days for T_1 , T_2 , T_3 , T_4 , T_5 and T_0 (control) were 18.13 ± 1.15 , 22.00 ± 2.08 , 23.40 ± 0.20 , 19.07 ± 1.67 , 17.87 ± 2.20 and 18.66 ± 0.58 N/mm², respectively as presented in Table 7. The trends of the impact of magnetized water on the compressive strength of the concrete cubes at 7, 14 and 28 curing days is shown in Figure 5.

From Table 7, the compressive strength of the concrete cube increased from 7 days to 28 days during curing both for the concrete cubes produced with magnetized water and non-magnetized water. The concrete cubes produced with the magnetized water treated for 1 minute that was allowed to pass through the magnetic treatment unit 1 time and also cured (soaked in water for hydration) in magnetized water treated for 1 minute which was denoted by T_3 had the highest compressive strength than the other cubes produced with MW. T_2 in which MW was treated for 1 minute and cured in NMW had higher compressive strength next to T_3 . The cubes produced using NMW and cured NMW (control denoted as T_0) had lower compressive strength than T_2 and T_3 . The concrete cubes produced with MW treated for 2 minutes and cured in NMW (T_4) had higher compressive strength than the concrete cubes from the control. The result of this study was in agreement with the studies of (Ahmed, 2009; Reddy et al., 2014; Ghorbani et al., 2018; Kiranmai and Rao. 2018; and Yusuf et al., 2021) which reported that MW increased the compressive strength of concrete.

The result of this study revealed that T_3 increased compressive strength of concrete cubes by 4.74 N/mm² (25.40%) when the MW was treated for 1 minute by circulation flow method and cured in MW treated for 1 minute. This was in agreement with the study of Parthiban et al. (2016) that MW increased the compressive strength of the concrete by 39.48% when the water was treated for 72 hours with a static flow method. Kiranmai and Rao. (2018) pointed out that MW increased the compressive strength of concrete increased by 38.1% after curing for 7 days. The result of this study also agreed with the study of Reddy et al. (2014) that MW increased the compressive strength of concrete by 55% because MW enhances better hydration of the concrete thereby making the concrete stronger. Nan et al. (2003) reported that magnetic fields breakdown the clusters of large molecules of water into smaller clusters molecules. This could allow penetration of MW into cement particles and enhances proper hydration thereby improving the strength of the concrete cube. In this current study, T_3 increased the compressive strength of concrete cubes by 4.74 N/mm² (25.40%) when the water was passed through the magnetic field for 1 minute. The effect of MW treated for 1 minute and cured in MW treated for 1 minute (T_3) was significant on the compressive strength of the concrete cube

compared with concrete cube from the control with the calculated Paired t-test was 10.066 which is greater than the table value of t-test of 9.925 at $\alpha \leq 0.010$. The effects T_1 , T_2 , T_4 and T_5 were not significant on the compressive strength of the concrete cube when compared to T_0 (Table 8).

Table 7: Mean compressive strength of the concrete cube

Curing day	Mean compressive strength of the concrete block (N/mm ²)					
	T_0	T_1	T_2	T_3	T_4	T_5
7	12.93±0.83	12.40±0.72	13.70±0.17	16.27±1.01	12.07±0.31	10.77±1.43
14	16.53±0.25	16.07±0.25	19.43±0.43	20.77±0.35	16.93±0.31	13.60±0.25
28	18.66±0.58	18.13±1.15	22.00±2.08	23.40±0.20	19.07±1.67	17.87±2.20

$T_0, T_1, T_2, T_3, T_4, T_5$ were as defined in the Abstract and Table 5

Table 8: Result of Paired t-test for the compressive strength of the concrete cube

Treatment	DF	Calculated value of t	Table value of t at $\alpha \leq 0.025$	Table value of t at $\alpha \leq 0.010$
T_1 versus T_0	2	-25.350*	6,205	9.925
T_2 versus T_0	2	2.966 ^{NS}	6,205	9.925
T_3 versus T_0	2	10.066**	6,205	9.925
T_4 versus T_0	2	-0.763*	6,205	9.925
T_5 versus T_0	2	-3.161*	6,205	9.925

DF = Degree of freedom, $T_0, T_1, T_2, T_3, T_4, T_5$ were as defined in the Abstract and Table 5

*= significant (by reducing the compressive strength of the block due to the effect of the treatment) at $\alpha \leq 0.010$,

**= significant at $\alpha \leq 0.010$, NS = Not significant

The negative value of the t-test indicates reduction in the strength of the cube due to the effect of the treatment.

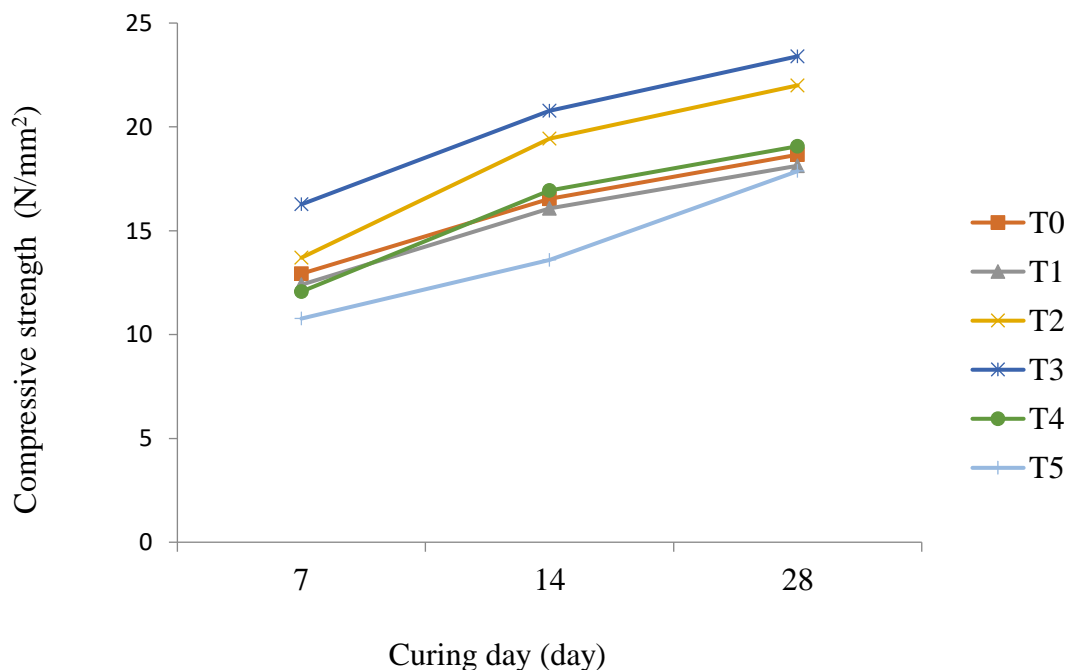


Figure 5: The trend of impact of magnetized water on the compressive strength of concrete cube $T_0, T_1, T_2, T_3, T_4, T_5$ were as defined in the Abstract and Table 5

3.2 Tensile strengths of concrete brick

The mean result of tensile strength is presented in Table 9 and the statistical analysis of t-test for the splitting tensile strength was presented in Table 10. The mean tensile strength after cured for 28 days for T₁, T₂, T₃, T₄, T₅ and T₀ (control) were 1.38±0.03, 1.59±0.24, 1.83±0.22, 1.21±0.06, 1.32±0.32 and 1.33±0.20 N/mm², respectively (Table 9). The trends of impact of magnetized water on the splitting tensile strength of the concrete brick at 7, 14 and 28 curing day is presented in Figure 6. T₂ and T₃ also increased the tensile strength of the concrete brick and T₃ gave higher tensile strength than T₂ but T₂ had higher tensile strength than T₀, T₁, T₄ and T₅ (Table 9). The concrete brick produced with MW treated for 1 and cured in MW treated for 1 minute (T₃) increased the splitting tensile strength by 0.5 N/mm² (37.57%) while the concrete brick produced with MW treated for 1 but cured in NMW increased the splitting tensile strength by 0.26 N/mm² (19.55%).

The effect of MW treated for 1 minute and cured in MW treated for 1 minute which was allowed to flow 1 time through the magnetic treatment unit was significant on the tensile strength when compared to the concrete brick from the control with the calculated value of t-test of 23.110 that is greater than the table value of t-test of 9.925 at $\alpha \leq 0.010$ (Table 10). This means that MW had a positive effect on the splitting tensile strength of the concrete. The finding agrees with the studies of Parthiban et al. (2016) and Kiranmai and Rao (2018) that MW water increased the strength of concrete cubes. The increment in the compressive and tensile strengths of the concrete was enhanced by proper hydration by the MW treated in which water was allow to flow through the magnetic field for 1 minute. In addition, putting the water (MW) into the magnetic treatment unit for the second time and third time after it has been treated, the magnetic properties could be reduced and this could reduce the strength of the concrete cube.

Table 9: Mean tensile strength of the concrete brick

Curing day	Mean tensile strength of the concrete cube (N/mm ²)					
	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅
7	1.08±0.07	0.95±0.07	1.17±0.10	1.53±0.07	0.74±0.08	0.76±0.11
14	1.12±0.22	1.00±0.03	1.25±0.06	1.62±0.03	0.98±0.26	0.97±0.14
28	1.33±0.20	1.38±0.03	1.59±0.24	1.83±0.22	1.21±0.06	1.32±0.32

T₀, T₁, T₂, T₃, T₄ and T₅ were as defined in the Abstract

Table 10: Paired t-test for the tensile strength of the concrete

Treatment	DF	Calculated value of t	Table value of t at $\alpha \leq 0.025$	Table value of t at $\alpha \leq 0.010$
T ₁ versus T ₀	2	-1.451 ^{NS}	6,205	9.925
T ₂ versus T ₀	2	3.119 ^{NS}	6,205	9.925
T ₃ versus T ₀	2	23.110 ^{**}	6,205	9.925
T ₄ versus T ₀	2	-3.085 ^{NS}	6,205	9.925
T ₅ versus T ₀	2	-2.329 ^{NS}	6,205	9.925

DF = Degree of freedom, T₀, T₁, T₂, T₃, T₄, T₅ were as defined in the Abstract

**= significant at $\alpha \leq 0.010$, NS = Not significant,

The negative value of the t-test indicates reduction in the strength of the concrete cube due to the effect of the treatment.

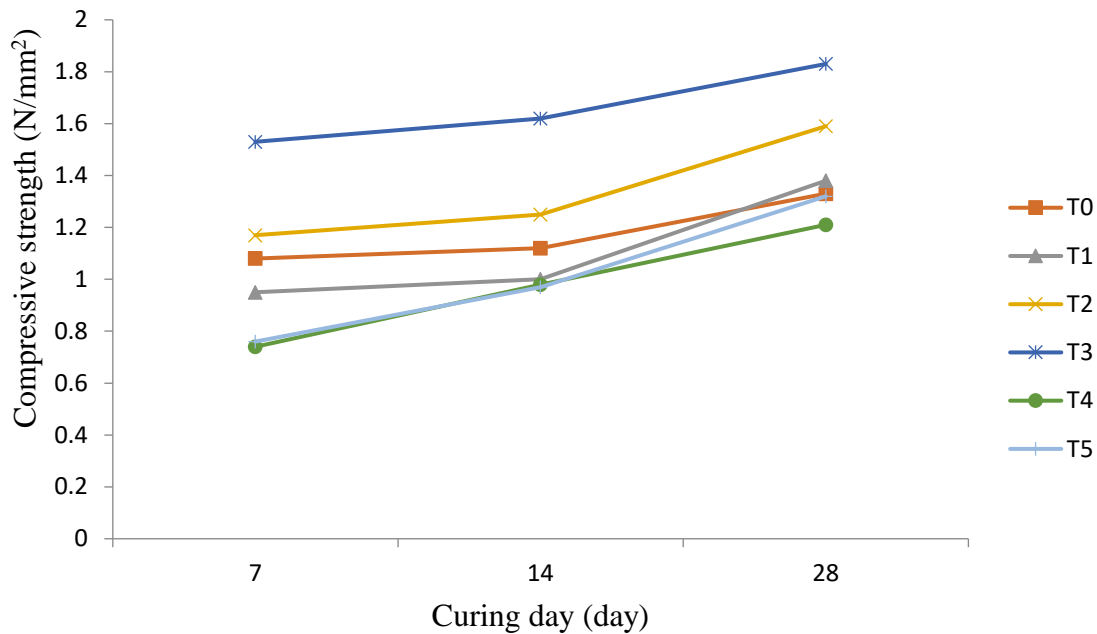


Figure 6: The trend of impact of magnetized water on the tensile strength of concrete brick T_0 , T_1 , T_2 , T_3 , T_4 , T_5 were as defined in the Abstract

4. Conclusion

MW was produced using 12 pieces of $10 \times 25 \times 50$ mm neodymium permanent magnet arranged on the two sides of a plastic rectangular pipe. MW that was used to produce concrete cubes increased the compressive and tensile strengths of the cube. MW treated for 1 minute when the water was allowed to flow through the magnetic treatment unit by 1 time and cured in MW treated for 1 minute increased the compressive strength and splitting tensile strength by 4.74 N/mm^2 (25.40%) and 0.5 N/mm^2 (37.57%), respectively. MW that was treated for 1 minute by passing through magnetic one time and cured in MW was found to produce better results than the MW that was allowed to pass through the magnetic treatment unit two times or by multiple flows which probably reduce the magnetic treatment effect and reduced the strengths of the concrete cubes. MW is recommended for producing concrete cubes.

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