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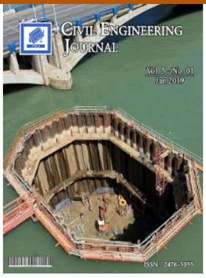

Investigating the Behavior of the Plastic Concrete Made with Different Types of Fibers with an Approach to the Mixing Plans of Plastic Concrete

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Abstract

The complicated nature of the plastic concrete's behavior compared to conventional concrete has led to the study of the behavior of the plastic concrete and the advent of suitable solutions to improve the behavior of the concrete due to the abundance of plastic concrete in the construction of cut-off walls under the dams. For the purpose of a practical study, at first, the mixing plan of the plastic concrete cut-off wall in Nargesi dam was investigated. Then, 22 primitive mixing plans were identified and labeled in the laboratory to identify the optimal mixing plan in accordance with the required technical criteria. After selecting the desired optimal design, to investigate the effect of the fiber on the behavior of this concrete, %0.19 and 0.38% volumes of polypropylene, hooked metal and corrugated metal fibers were used; hence, 168 samples were presented. Compressive strength for the ages of 7, 28, 42 and 90 days with elasticity modulus as well as corresponding stress-strain curves and tensile strength for 90-day age were investigated. The results indicated that the extremely high compressive strength and modulus of elasticity have a very high impact on the amount of bentonite and the ratio of water to bentonite so that with increasing these two values, the compressive strength and modulus of elasticity decrease significantly. The results indicated that using fibers increases deformation which is more evident in samples made with polypropylene fibers. The results also showed that the compressive strength and modulus of elasticity of plastic concrete is increasing linearly with time, and the elastic modulus growth rate is lower than the compressive strength due to the increase in the duration of time, and in other words, the plastic state concrete changes less over time.

Keywords: Plastic Concrete; Polypropylene Fibers; Hooked Metal Fiber; Corrugated Metal Fiber; Compressive and Tensile Strength.

1. Introduction

The major importance of plastic concrete is usually found in dams with reservoir level fluctuations or in areas with high seismicity or crack formation potential. These requirements are strengthened when the dam project is in poor soil lands and it is needed to construct a flexible and soft wall in order to provide the necessary resistance to land changes due to soil compaction and resistance to the structural stress of the dam [1].

Since dams are rarely constructed on impenetrable grounds, some water may flow below the dam [2]. One of the biggest dangers of dams after dewatering is the seepage below the foundation of the dam and the increase of the hydraulic gradient that causes dangers like foundation erosion [3]. In order to control the seepage and drainage under

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the dams, there are methods such as interrupting the drainage current network or reducing it by using a full cut-off wall or reducing the amount of drainage by creating a vertical cut-off semi-penetrating curtain [4].

A cut-off wall concrete can be used as a remedial action to control earth dam leakage in most conditions [5, 6]. The use of conventional concrete with a high elasticity modulus, as compared with other materials, may cause problems such as the fragility of the cut-off wall due to dynamic stress. To solve this problem, adding a certain percentage of clay to plastic concrete materials can, in addition to reducing the hardness and elasticity coefficient, make this concrete more deformable [7].

Therefore, materials must be used in the fabrication of this element that can have deformations proportional to the created deformations. In selecting such materials, it should be noted that the product, in addition to its proper impermeability and strength, should also provide hardness to the construction site. Acceptable compatibility of the wall strain and the surrounding soil causes no additional stress on the wall, and also allows the concrete and the surrounding soil to work together and without detachment [8].

In response to this problem, researchers have suggested plastic concrete [9]. Plastic concrete includes aggregates, cement, water and clay mixtures with high water to cement ratio to produce a deformable material. The factor that produces different properties of conventional concrete in plastic concrete is the presence of bentonite clay in the concrete [10]. Bentonite in plastic concrete makes this concrete more deformable. Also, the presence of bentonite may due to reducing permeability and compressive strength of plastic concrete.

During concreting, bentonite slurry keeps gravel, sand and cement suspended in plastic concrete, which reduces the permeability during the setting time of concrete) and, according to the ICOLD proposal, a bentonite slurry is used to enhance the ductility of concrete [10]. The concrete mixing plan of plastics should have a permeability coefficient within the range of approximately 10^{-7} to 10^{-9} m / s and slump in the range of 15 to 22 cm. In general, bentonite is used in civil engineering sciences for sealing purposes [7, 11-18]. The main use of plastic concrete is the cut-off wall in earth dams and its use in cut-off walls that are drilled in coarse-grained soil has better results than other methods such as injection [19-21]. In fresh concrete, by determining the proper amount, type and size of the fibers, the shrinkage and consequently, the cracks are significantly reduced. Fibers increase tensile strength and significantly reduce permeability by stopping and preventing the growth of small cracks, their coalition, large cracks bridging and forces transference across these cracks [22]. In the reinforcement of concrete fibers during the mixing process, the fibers are spread inside the concrete irregularly and in different directions; hence, the attention to this issue is very important during mixing process [23]. Previous studies have shown that fibers in concrete samples act as a series of tensile fasteners, and as the concrete age rises, they also improve their performance by stabilizing their position in concrete. Fibers can also play the role of the bridge in the concrete structure after the presence of cracks and, by passing the tensile stress out of their width, increase the ultimate tensile strength. However, it should be noted that the amount of fiber should not exceed a certain value, as by increasing the percentage of fibers particularly in longer lengths, the probability of accumulation is increased and the accumulation operation causes tensile weakness. Therefore, an optimal amount determination will be necessary [24].

The most important issues to consider in plastic concrete are the proper percentage of the addition of fibers in concrete types, the correct way of mixing, and the economic and practicality of this method. Also, in this concrete, due to its presence in the earth's environment and its permanent exposure to moisture, it is needed to be careful when selecting the type of fiber. Moreover, the percentage and type of fiber should be selected in such a way that it has a less negative effect on concrete performance and consistency and it is economical. Among the fibers of metal, glass and polypropylene, polypropylene fibers will have the best performance to be added to plastic concrete because in addition to the hydrophobicity and adverse effects of the presence of water, has a very low specific weight and it provides a lot of fiber in a low weight, as well as these fibers are well distributed inside the concrete due to their high deformability and have little adverse effect in the placement of materials alongside each other and density [25, 26].

Saeidi-Jam and Azimi (2015) examined the resistance and permeability parameters of plastic concrete reinforced polypropylene fibers. They concluded that by adding polypropylene fibers, tensile strength increased significantly and for this purpose, the mixing plan was made with 1.17 ratio of water to the cement and 0.12 ratio of bentonite to cement with different percentages of fibers including zero, 0.25 and 0.5 percent. The results showed that the tensile strength increased significantly at the age of 28 days while the strength has been observed at the level of conventional concrete at an early age up to 7 days. Also, with the addition of polypropylene fibers to plastic concrete, the deformability and final strength were considerably improved according to stress-strain diagrams [27].

2. Specifications of the Materials Used In the Mixing Plan

a) Stone Materials

The used rock is a combination of broken and natural materials and is derived from the mines of the Shirin Roud River, which originates from the springs of Arjan plain, Fars province. The specification of these materials is in accordance with Table 1.

Table 1. The distribution of specifications of the stone materials

Sand	Pea gravel	Almond gravel	Sieve number	Sieve size (mm)
100	100	100	1 1/2	38.1
100	100	100	1	25.4
100	100	93.3	3/4	19.05
100	100	22.22	1/2	12.7
99.7	73.6	2	3/8	9.52
99.2	1.8	0.5	4	4.76
80.4	0.1	0	8	2.36
60.1	0	0	16	1.18
34.8	0	0	30	0.59
19.3	0	0	50	0.298
5.1	0	0	100	0.149
1.6	0	0	200	0.074

b) Cement

Cement used in this study is Fars cement type 2, the characteristics of which are listed in Table 2.

Table 2. The distribution of specifications of the cement

Characteristics	Compressive strength (kg/cm^2)			Final curing period (min)	Initial curing period (min)	Specific area (cm^2/g)
	28 days	7 days	3 days			
Results	315	175	100	195	130	2800

c) Bentonite

Bentonite used in the manufacture of concrete is from Darin Kashan company's bentonite, the specifications of which are given in Table 3.

Table 3. The distribution of specifications of the bentonite

Characteristic	Quantity Measured
LL	314.5
PI	283.3
Gs	2.79
Classification	CH
Clay Fraction	72
Silt Fraction	23
Sand Fraction	1
w opt %	23
Dry density	1.56
SSA (m2/gr)	418
CEC (cmol/kg)	68.2

d) Water

Water used in the manufacture of concrete is from drinking water of the workshop which PH is 7.5.

e) Mixing Plan

The mixing plan and specifications of the plastic concrete of the Nargesi dam's cut-off wall are in accordance with Tables 4 and 5, which is in accordance with the wanted technical specifications of the design. The required compressive strength is considered for a 7-day age range of approximately 0.8 to 1.5 MPa and for the age of 28 days is

1.3 to 2.5 MPa and Young's modulus for 28 days is between 200 and 400 MPa.

Table 4. The amount of materials used to make 1 cubic meter of plastic concretee

Consumed materials	(kg)
Cement	130
Bentonite	40
Water	382
Sand	705
Pea gravel	520
Almond gravel	259

Table 5. The approved mixing plan of the cut-off wall in Nargesi dam

Cement weight (Kg)	Bentonite weight (Kg)	Water to bentonite proportion (W/B)	Slump (cm)	28 days (kg/cm^2)	
				Compressive strength (kg/cm^2)	Elasticity modulus (kg/cm^2)
130	40	9.55	20.5	13.8	2750

f) Fiber Characteristics

In this research, to measure the effect of fiber on plastic concrete samples, various fiber types have been used including polypropylene, hooked and rippled metal fibers with their specifications provided in Tables 6, 7 and 8.

Table 6. Polypropylene fibers characteristics

Elasticity modulus (N/mm^2)	3500-3900
Gravity (kg/dm^3)	0.91
Length (mm)	12
Nominal diameter (m)	18×10^{-6}
Combustion temperature (c)	360
Alkali attack resistance	High
Elongation percentage	15
Moisture absorption percentage	0
Tensile strength (N/mm^2)	300
Melting point (C)	160-165
Electrical conductivity	Very low

Table 7. Hooked metal fibers characteristics

Fiber figure	Planned or hooked ended
Cross section	Circular
Length	40 mm
Diameter	0.8 mm
Length to diameter proportion (L/D)	50
Bulk density	7850 kg/m^3
Tensile strength	1200 Mpa
Manufacturing factory	BASF Iran

Table 8. Corrugated metal fibers characteristics

Fiber figure	Corrugated or straight ended
Cross section	Circular
Length	30 mm
Diameter	0.8 mm
Length to diameter proportion (L/D)	37.5
Bulk density	7850 kg/m^3
Tensile strength	1180 Mpa
Manufacturing factory	BASF Iran

In Figures 1(a), 1(b) and 1(c), respectively, the shape of corrugated metal fibers, hooked metal fibers and polypropylene fibers, and in Figure 1(d), the concrete made with polypropylene fibers used in this study is shown.

(a) Corrugated metal fibers **(b) Hooked metal fibers** **(c) Polypropylene fibers** **(d) Polypropylene fibrous concrete**

Figure 1. Types of fibers

g) Mixing Plan of Concrete

Test design is a targeted method for determining the effective parameters and interaction between them. With the design of the experiment, more precise information can be obtained with fewer tests and less time. In the traditional way, in order to obtain the effect of each parameter, the rest of the parameters must be constant. Therefore, the number of experiments will increase dramatically. Another disadvantage of this method is that the probability of finding the optimal overall point is low because this method assumes that the parameters are independent and do not interact with each other. While this is not the case and the response of a real system to changing each parameter often appears due to the effect of changing several other parameters.

The test is applied to determine the effective parameters on the output responses and the amount of their interactions and determine the optimal conditions. In this study, we first used Design-Expert software to find an optimal mixing plan. According to the results, this program provided 22 preliminary pilot projects that were tested in the laboratory and the results were presented in the following table. (Factor 3 is the ratio of water to bentonite and factor 4 is the ratio of gravel to sand).

Table 9. Initial mixing plan

	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2
Run	**A:cement Kg**	**B:Bentonit Kg**	**C:w/B**	**D:G/s**	**compressive kg/cm^2**	**Elasticity modulus kg/cm^2**
1	135	42.5	9.25	1.05	12.95	2780
2	125	42.5	9.75	1.05	11.89	2250
3	125	42.5	9.25	1.15	12.05	2390
4	125	37.5	9.25	1.05	13.4	2580
5	120	40	9.5	1.1	11.95	2410
6	125	42.5	9.25	1.05	11.8	2380
7	125	37.5	9.25	1.15	14	3018
8	135	37.5	9.75	1.15	14.15	3080

9	135	37.5	9.25	1.05	14.28	3120
10	130	45	9.5	1.1	11.2	2450
11	125	42.5	9.75	1.15	11.35	2620
12	130	35	9.5	1.1	14.9	3450
13	130	40	9	1.1	14.1	2860
14	135	42.5	9.75	1.05	12.89	2560
15	130	40	9.5	1.1	13.85	2820
16	135	37.5	9.75	1.05	14.15	2910
17	140	40	9.5	1.1	14.4	3020
18	135	37.5	9.25	1.15	14.8	3210
19	125	37.5	9.75	1.15	13.9	2820
20	130	40	9.5	1.2	13.86	2790
21	125	37.5	9.75	1.05	14.1	2905
22	130	40	9.5	1.1	13.75	2620

After examining the mixing plan of Table 9 and the results of the plastic concrete in Nargesi dam in Tables 4 and 5, for the purpose of verifying the results and presenting a practical mixing plan, samples were constructed and examined exactly with the same conditions as the basic mixing plan. The changing process was further evaluated by adding fibers to the original plan. The used fiber was 0.19 and 0.38% vol. for polypropylene, hooked metal and corrugated metal fibers. In Table 10, the results of the compressive strength and modulus of elasticity have been recorded for the ages of 7, 28, 42 and 90-days various concrete samples. (For each plan at any age, three samples have been tested; the average of these three samples is presented in Tables 10 and 11).

Table 10. The results of compressive strength and modulus of elasticity (kg/cm^2) for different ages of plastic concrete plans in this research

Plan type	Compressive strength/ modulus of elasticity (kg/cm^2)	Age of 7 days	Age of 28 days	Age of 42 days	Age of 90 days
Basic plan	Compressive strength	5.31	11.98	14.64	18.92
	Modulus of elasticity	1056.9	2502.1	3260.1	3816.3
Plan with 0.19 vol. polypropylene fiber	Compressive strength	5.94	9.39	13.13	15.18
	Modulus of elasticity	1413.6	2988.1	3713.4	3818
Plan with 0.38 vol. polypropylene fiber	Compressive strength	4.41	8.49	12.42	14.92
	Modulus of elasticity	982	3042.9	3425.8	3512.8
Plan with 0.19 vol. hooked metal fiber	Compressive strength	4.83	12.17	12.78	13.27
	Modulus of elasticity	904.4	2529.2	2582.1	2723.7
Plan with 0.38 vol. hooked metal fiber	Compressive strength	5.3	12.42	13.59	16.32
	Modulus of elasticity	1778.2	3448.8	4083.1	4094.3
Plan with 0.19 vol. corrugated metal fiber	Compressive strength	5.36	12.56	12.78	13.41
	Modulus of elasticity	1071.4	2483.4	2582.1	2743.7
Plan with 0.38 vol. corrugated metal fiber	Compressive strength	5.3	12.64	14.71	17.5
	Modulus of elasticity	1778.2	3170.9	3338.7	3837.9

To better compare the results, bar graphs (Figure 2 and 3) were used. As can be seen, by adding the fibers to the samples, the strength of the samples, especially after the age of 28 days, is reduced. It is certain that in the use of plastic concrete, the main concern is the behavior of this concrete, not the reduction of its strength, and the more deformable concrete is, we will definitely confront with fewer problems during operation.

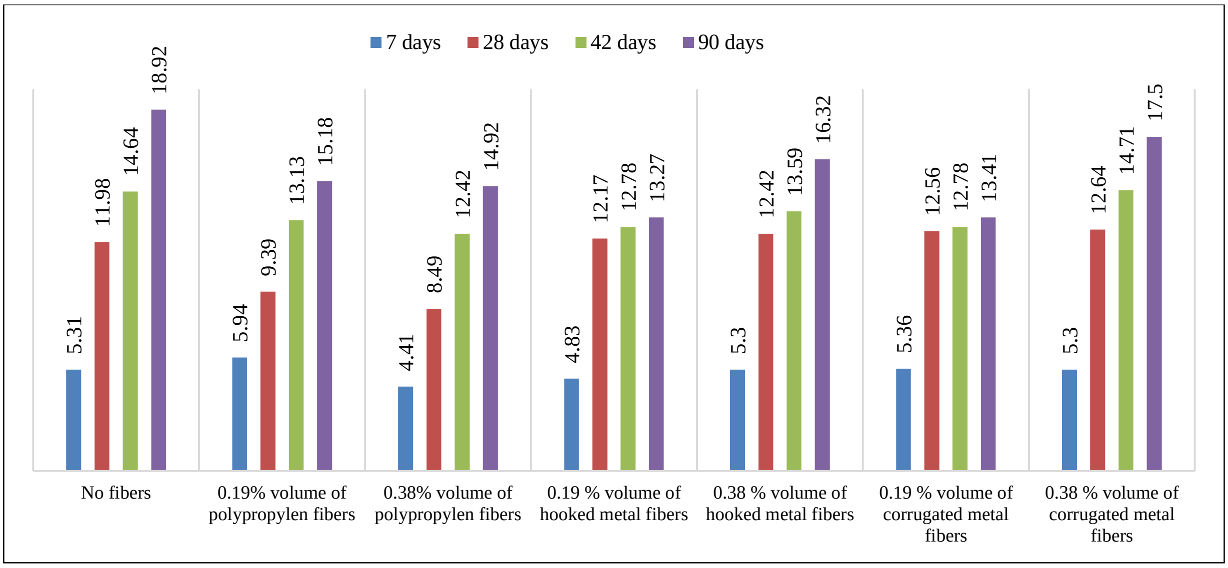


Figure 2. Comparing compressive strength (kg/cm^2) in different ages of concrete samples

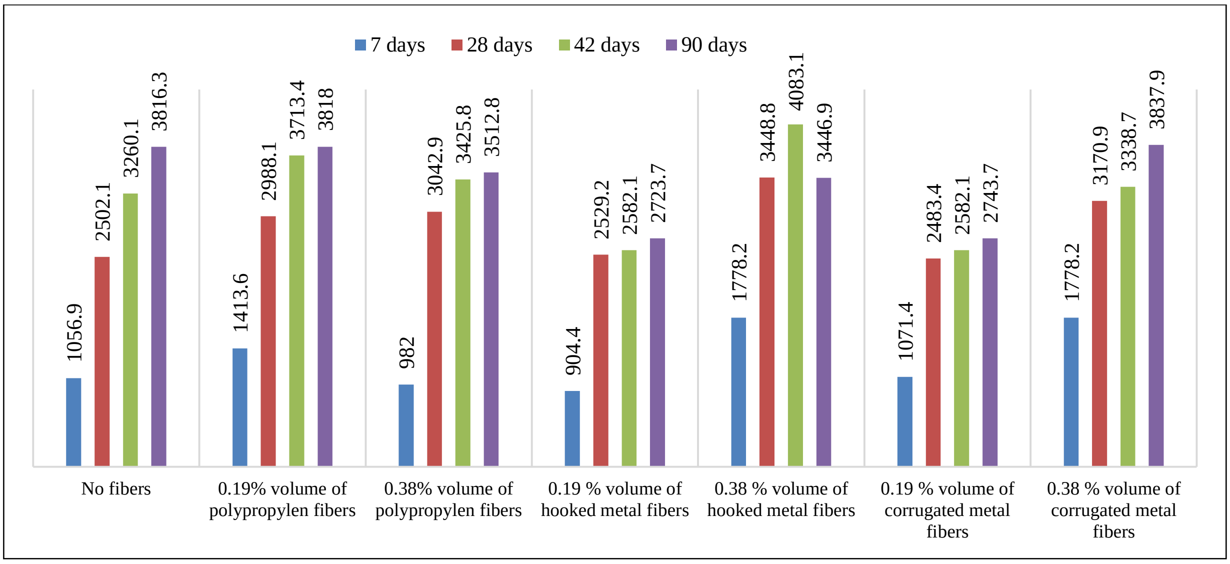


Figure 3. Comparing modulus of elasticity (kg/cm^2) in different ages of concrete samples

3. Results and Discussion

The device used to measure the compressive strength in this study is a single-axis device as shown in Figure 6. Also, this machine can adjust the loading rate to obtain precise results from the failure of the samples. In order to plot the stress-strain curve, it is necessary to record the exact strain rate which was used here from a gauge connected to the fixed part of the device and the strain rate was measured based on the deflection of the lower movable plate, which is due to the minimum strength of the plastic concrete when the plaster is placed on the sample. Due to the gauge skid, accurate results were not produced. The scant method was used to determine the elastic modulus. Accordingly, the following scant modulus is based on the slope of the line between the two points corresponding to the stresses S1 and S2, which is the modulus of elasticity of the concrete or the stress-strain curve modulus of the curve Calculates [11, 28]

$$E = (S2 - S1) / (\mathcal{E}2 - 0.00005)$$

It should be noted that stress is obtained from the ratio of final load to cross-sectional area and strain from the ratio of the amount of deformation to the effective length of the test.

E = the modulus of elasticity

S2 = the stress corresponded to 40% of the final load

S1 = The stress corresponded to the longitudinal strain $\mathcal{E}1 = 0.000050$

Ɛ2 =The strain corresponded to the S2 stress

Figure 5. Two-headed two-way footpads for preparation to be placed under the Concrete breaker

Figure 4. Plastics Concrete Sampling in the Laboratory

Figure 7. Broken sample after testing the compressive strength and how to create a crack in the sample

Figure 6. Concrete breaker jack used in this research

4. Tensile strength

After obtaining the results of compressive strength and studying the effect of each fiber amount on compressive strength, the tensile strength was also studied. The results of the tensile strength of various concrete samples at the age of 28 days are presented in Table 11. As it can be seen, the presence of fibers increases tensile strength significantly and also enhances the weakness of the concrete, which can have a significant impact on the reduction of tensile cracks.

Table 11. The results of the tensile strength of various concrete samples at the age of 28 days

Plan type	Diameter (cm)	Height (cm)	Weight (gr)	Applied load (kg)	Tensile strength (kg/cm^2)	Sample age (day)
Basic plan	10.08	19.93	3356	467	1.48	90
Plan with 0.19 vol. polypropylene fiber	10.1	20.1	3323	738	2.32	90
Plan with 0.38 vol. polypropylene fiber	10.1	20.25	3250	674	2.10	90
Plan with 0.19 vol. hooked metal fiber	10.02	19.92	3315	616	1.97	90
Plan with 0.38 vol. hooked metal fiber	10.06	19.92	3315	708	2.18	90
Plan with 0.19 vol. corrugated metal fiber	10.04	20.08	3382	702	2.22	90
Plan with 0.38 vol. corrugated metal fiber	10.08	19.86	3325	746	2.37	90

To better understand the results of Table 11, Figure 8 is used. As can be seen, according to this chart, samples made with 0.38% corrugated metal fibers and samples with 0.19% vol. of polypropylene fibers had the highest tensile strength. Polypropylene fibers, due to their good dispersion of aggregates and good coherence in comparison to the other samples, showed a better overall performance, which was evident at the time of construction. Also, the device used to measure the tensile strength in this study is shown in Figure 9.

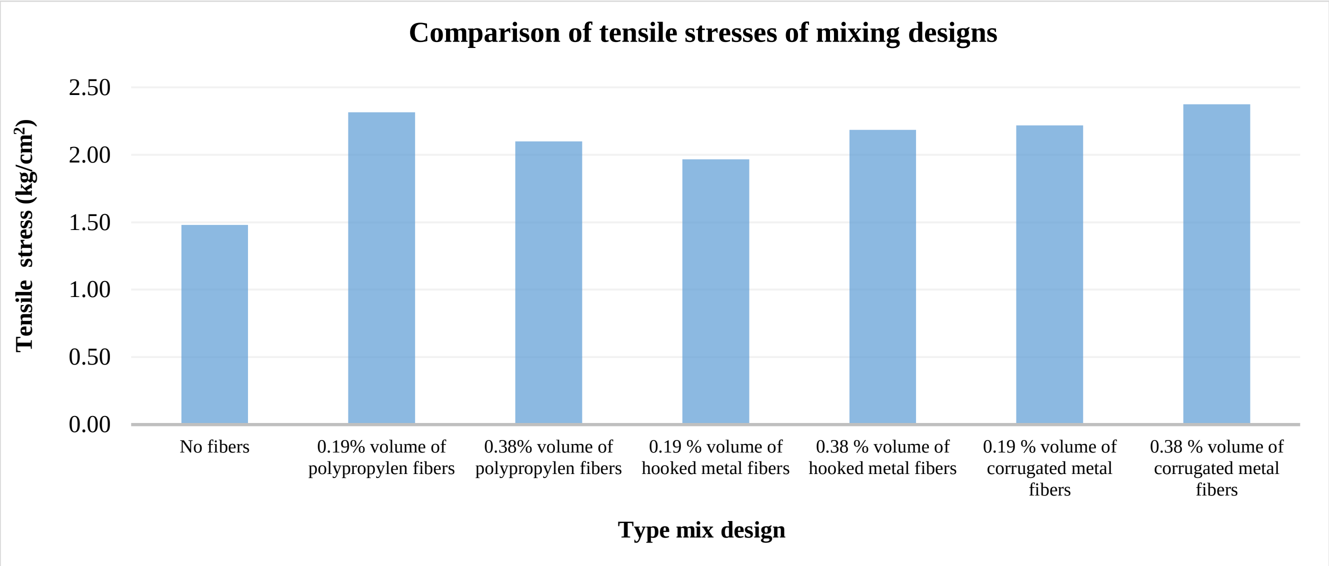
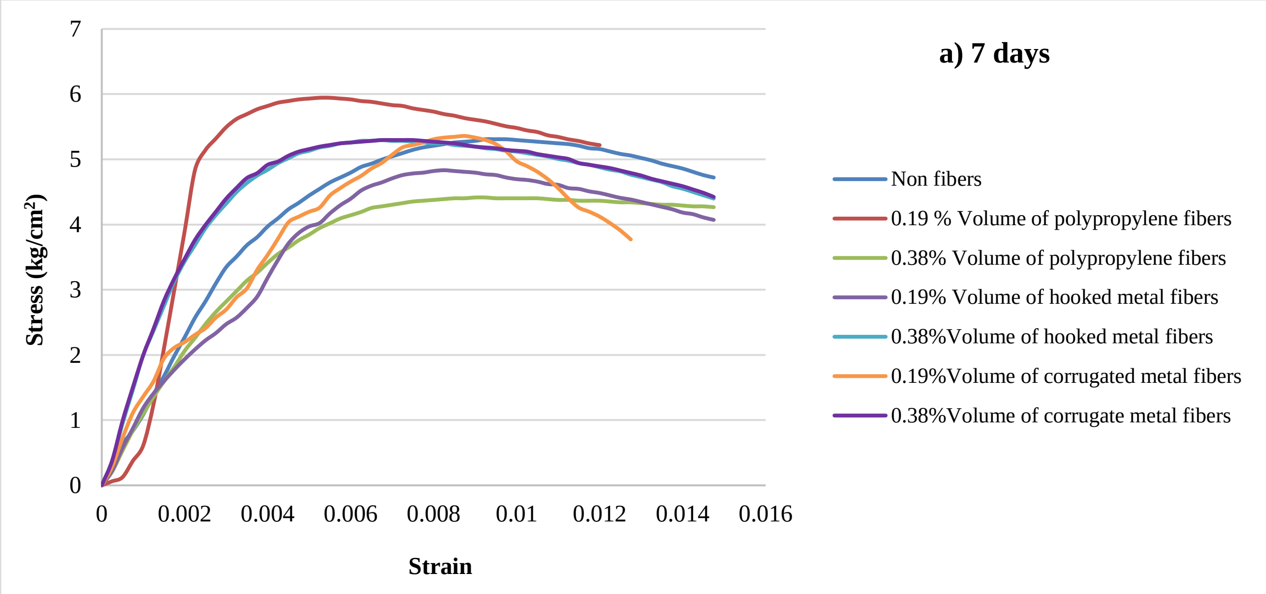


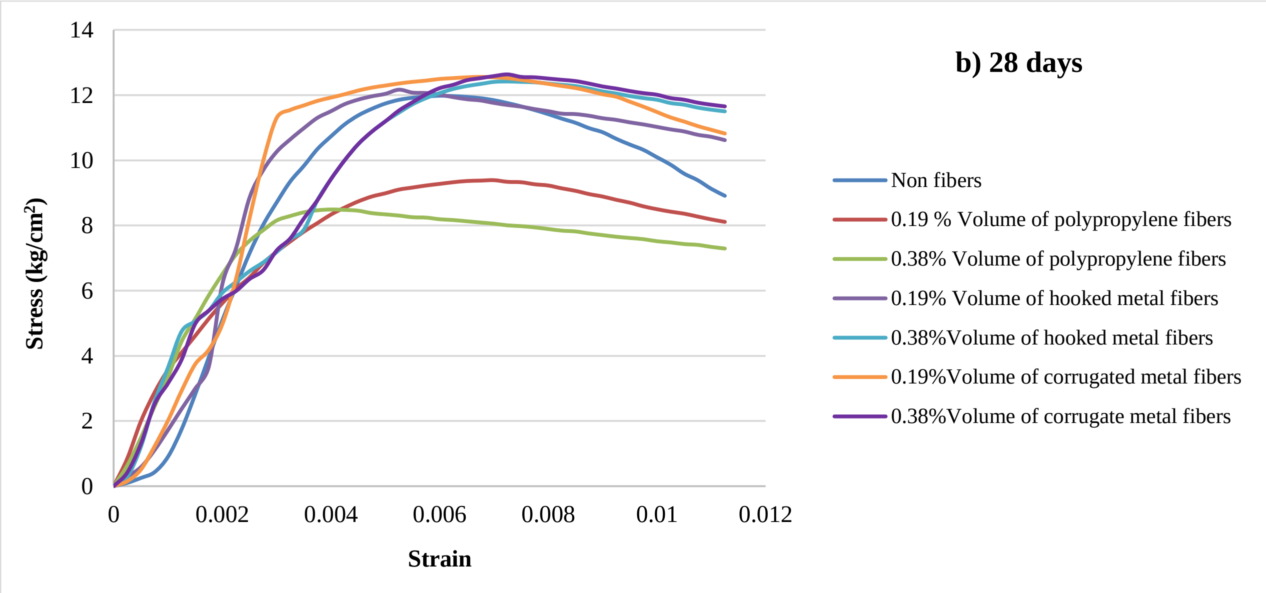
Figure 8. Comparing tensile strength (kg/cm^2) in the 28 age of concrete samples Draw stress (kg/cm^2)

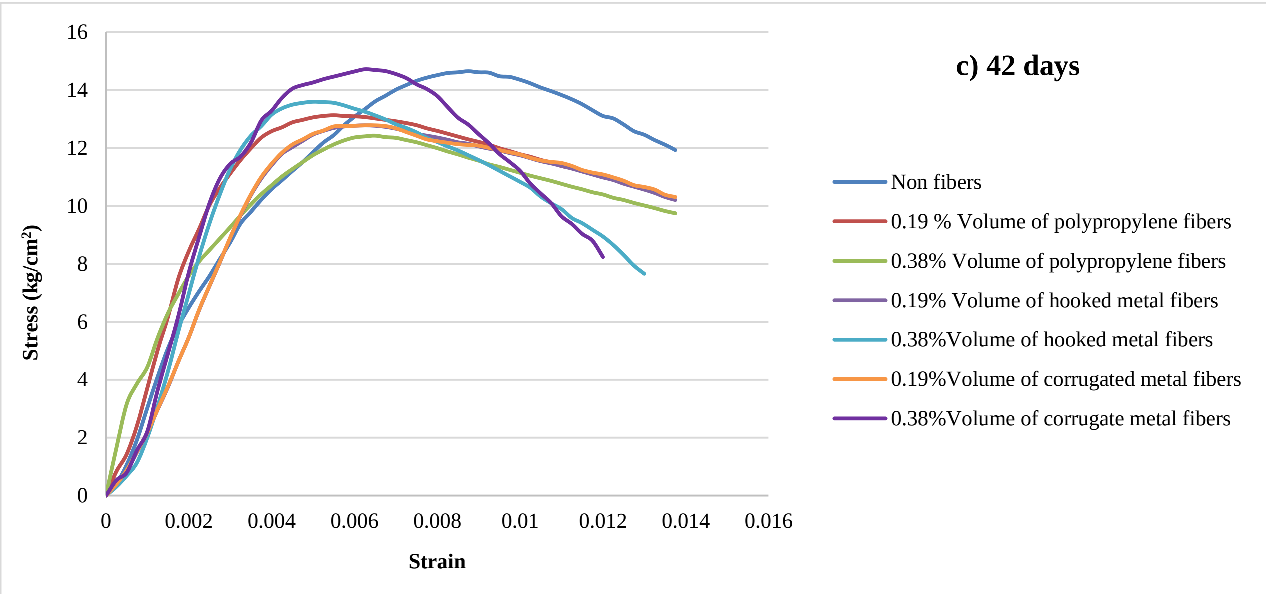
Figure 9. The tensile strength test device

5. Investigating the Behavior of Concrete Samples of Different Ages

In plastic concrete, it has been tried to let samples tolerate many deformations until failure. In fact, in this type of concrete, it is not important to only have the strength for the application and if the hardness of the concrete cut-off wall is too high in relation to the surrounding environment, concrete is not able to harmonize itself with the soil when loaded, which causes a brittle fracture in concrete. In these walls, it is necessary to reduce the hardness of the wall as much as possible so that better treatment can be seen when the deformation occurs in the soil. One of the objectives of this study was to examine the behavior of plastic concrete designs of different ages, as clearly indicated in Figure10. In these graphs, the stress-strain curves for the ages of 7, 28, 42 and 90 days are plotted for different plans. First, it is clear that as the ages of the samples increase, the surfaces under the stress-strain curves decrease, which means less ductility of the older samples and, secondly, it is clear that the surfaces below the strain-strain graphs of the samples made with polypropylene fibers are higher, which means that the offered plans by the polypropylene fibers are more deformable.


a) 7 days
Stress (kg/cm²)
Strain
Non fibers
0.19 % Volume of polypropylene fibers
0.38% Volume of polypropylene fibers
0.19% Volume of hooked metal fibers
0.38%Volume of hooked metal fibers
0.19%Volume of corrugated metal fibers
0.38%Volume of corrugate metal fibers


b) 28 days
Stress (kg/cm²)
Strain
Non fibers
0.19 % Volume of polypropylene fibers
0.38% Volume of polypropylene fibers
0.19% Volume of hooked metal fibers
0.38%Volume of hooked metal fibers
0.19%Volume of corrugated metal fibers
0.38%Volume of corrugate metal fibers


c) 42 days
Stress (kg/cm²)
Strain
Non fibers
0.19 % Volume of polypropylene fibers
0.38% Volume of polypropylene fibers
0.19% Volume of hooked metal fibers
0.38%Volume of hooked metal fibers
0.19%Volume of corrugated metal fibers
0.38%Volume of corrugate metal fibers

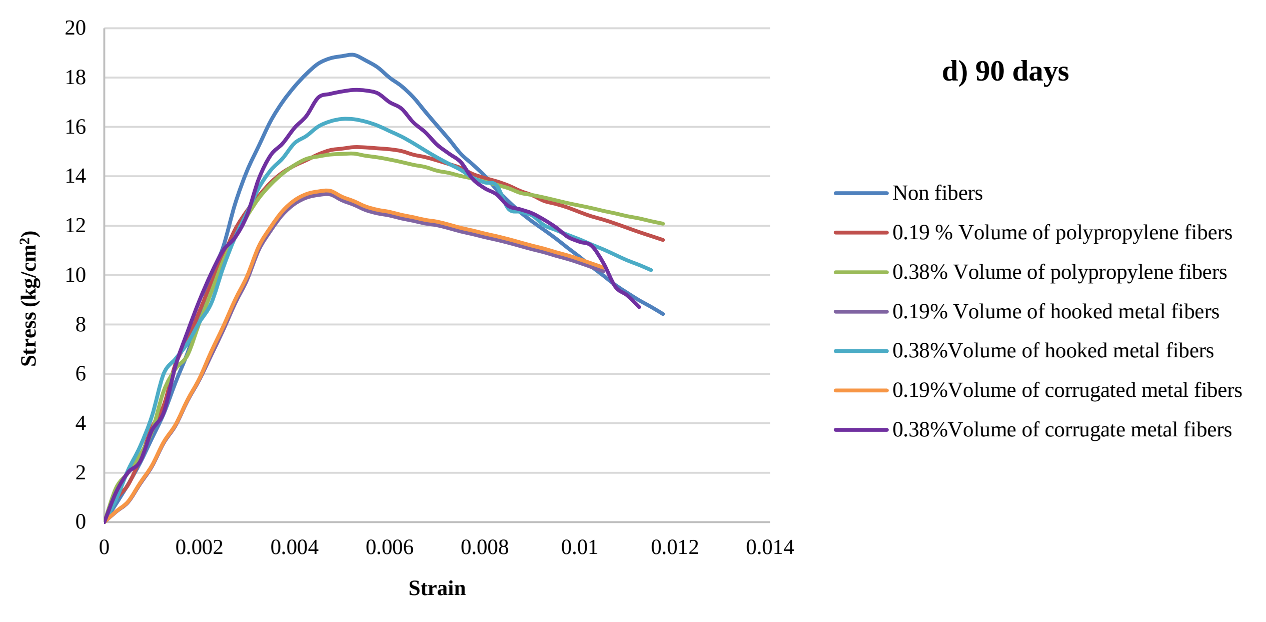
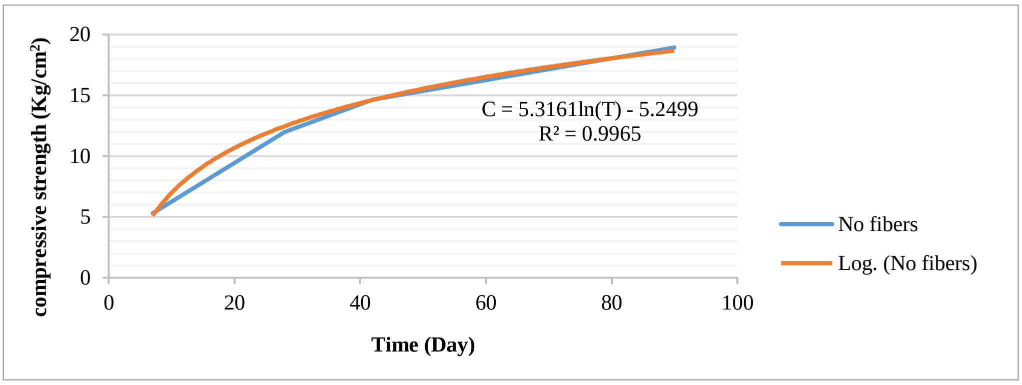
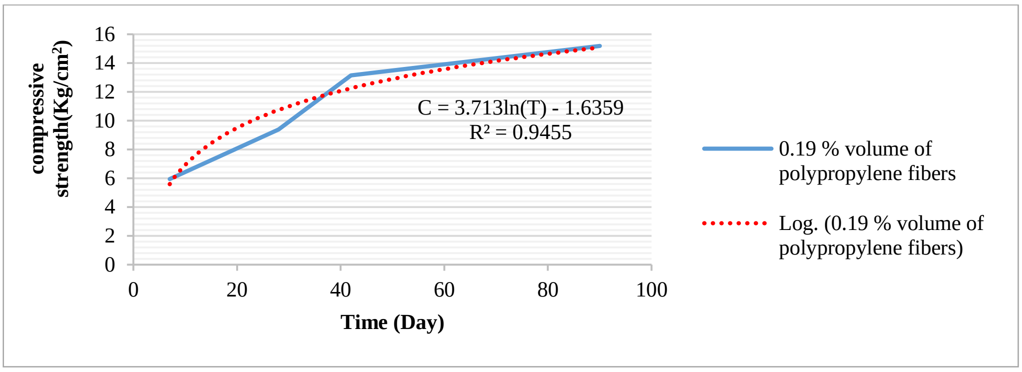


Figure 10. The stress-strain curves for different ages

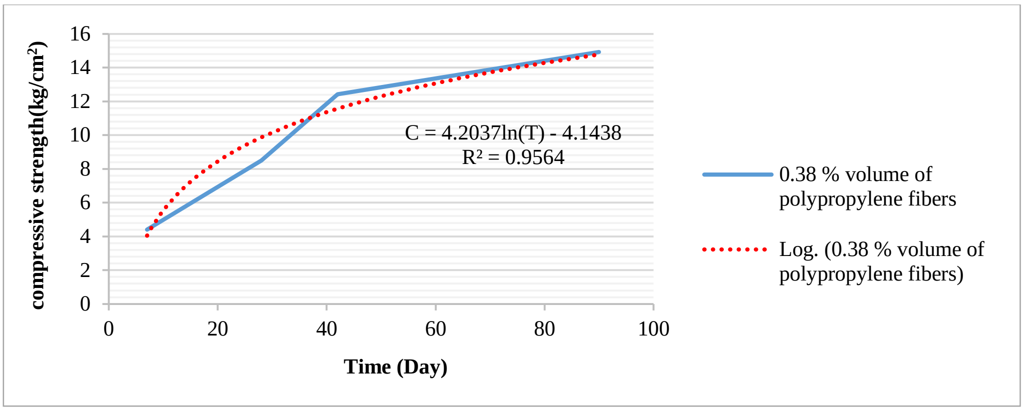
One of the most important issues that has been rarely addressed in research is the impact of time on plastic concrete parameters. As shown in Figure 18 of ICOLD, bulletin B51, the strength of the plastic concrete is linearly increasing, even after 1,000 days of sample ages. This issue is very important in damming projects because it is usually a long way between the time of construction of the cut-off wall and the time of dewatering, and certainly the characteristics of the plastic concrete during the dewatering period that is affected by the loading is important, i.e. the determination of the relationship between time and other parameters plastic concrete can be effective. The behavior of plastic concrete is quite different from that of conventional concrete, but what designers consider in their calculations is the strength and modulus of elasticity of this concrete at the age of 28 days, that is, they consider the behavior of this concrete is similar to that of ordinary concrete and it can cause a lot of problems in its position due to the time of dewatering. Therefore, the study of the relationship between compressive strength and elastic modulus can be very important. For this purpose, these issues have been addressed in Figures 11 and 12.



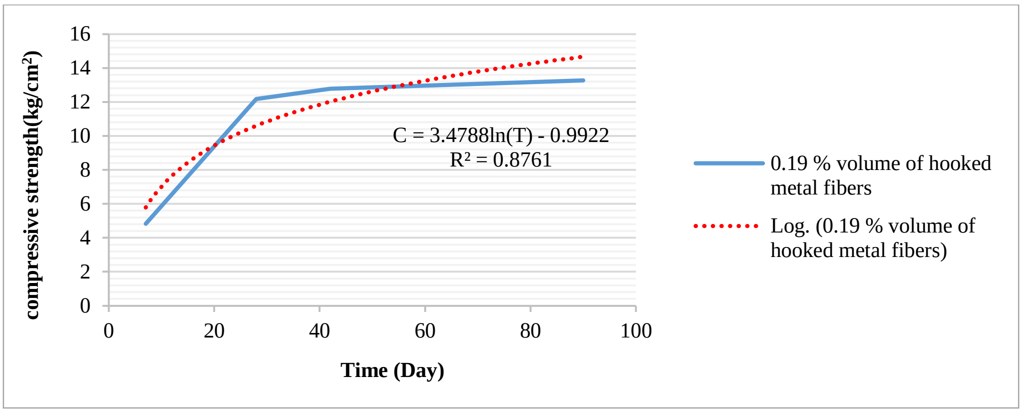
a) No fibers



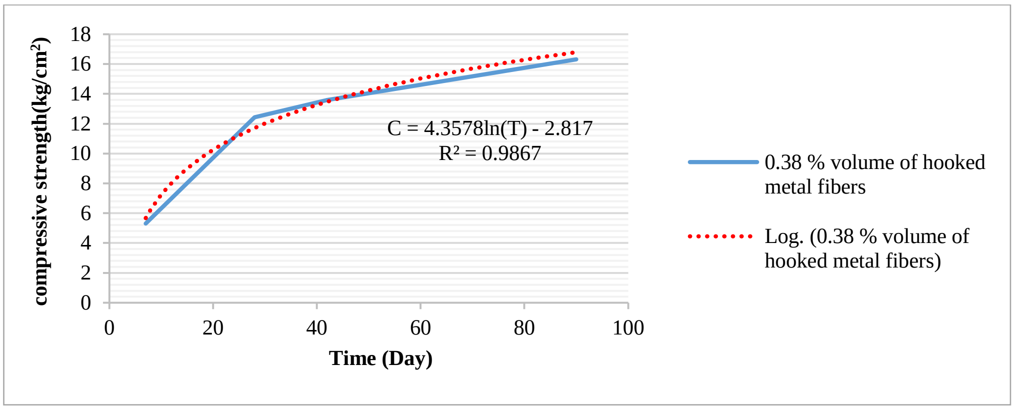
b) 0.19 % volume of polypropylene fibers



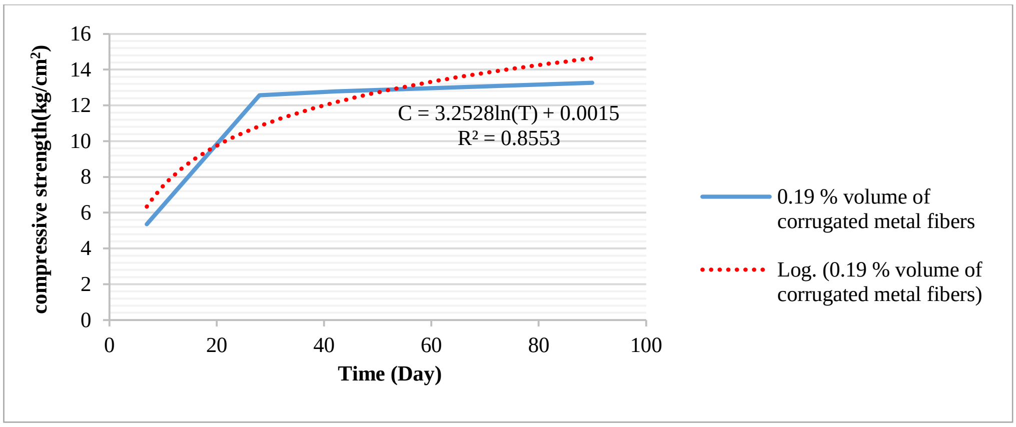
c) 0.38 % volume of polypropylene fibers



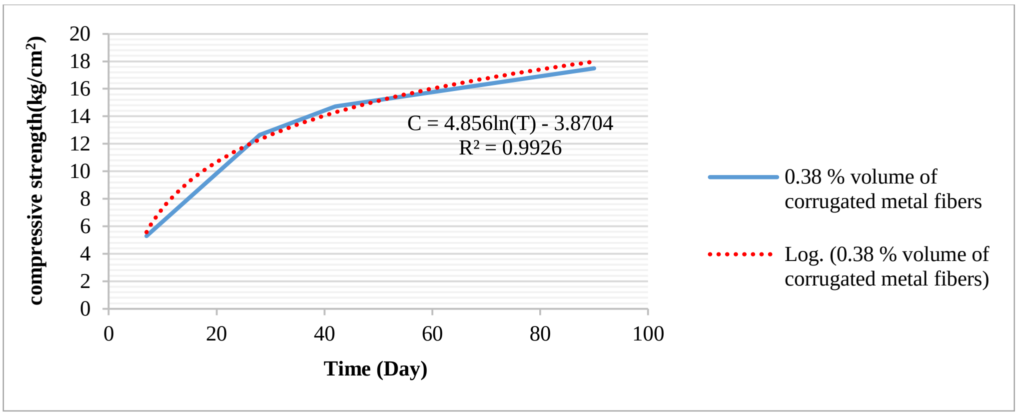
d) 0.19 % volume of hooked metal fibers



e) 0.38 % volume of hooked metal fibers



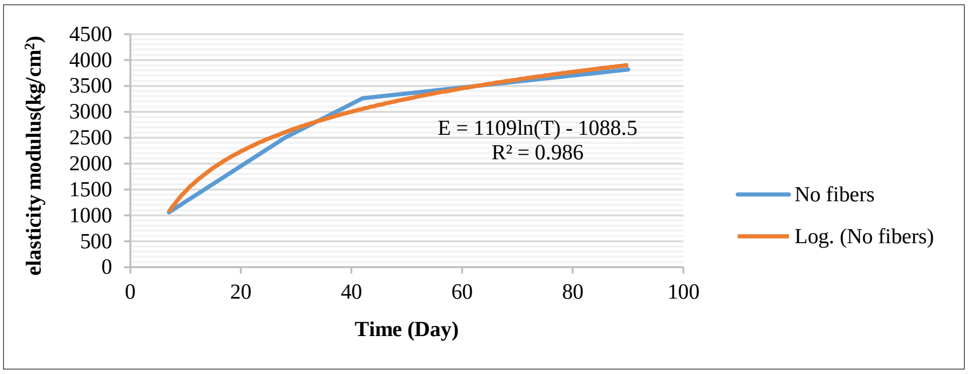
f) 0.19 % volume of corrugated metal fibers



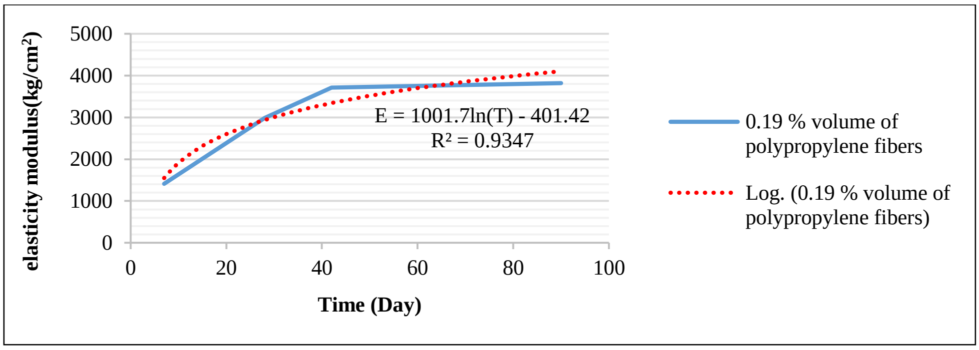
g) 0.38 % volume of corrugated metal fibers

Figure 11. Regression line and time envelope diagram - compressive strength of various concrete samples

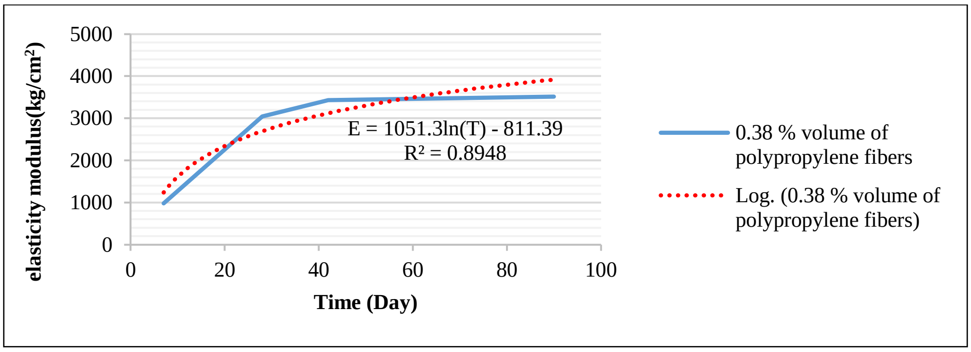
In this step, we decided in addition to the effect of the time parameter on the compressive strength, the effect of this parameter on the modulus of elasticity is also determined. Figure 12 shows the relationship between the modulus of elasticity and the time parameter, which can be important in its own position as mentioned above.



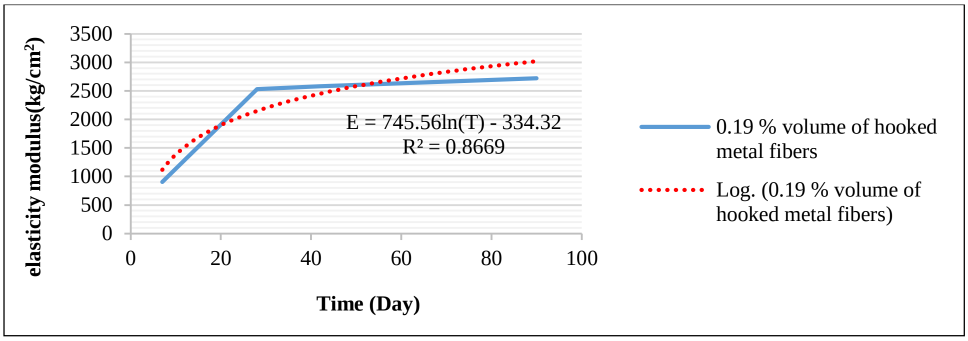
a) No fibers



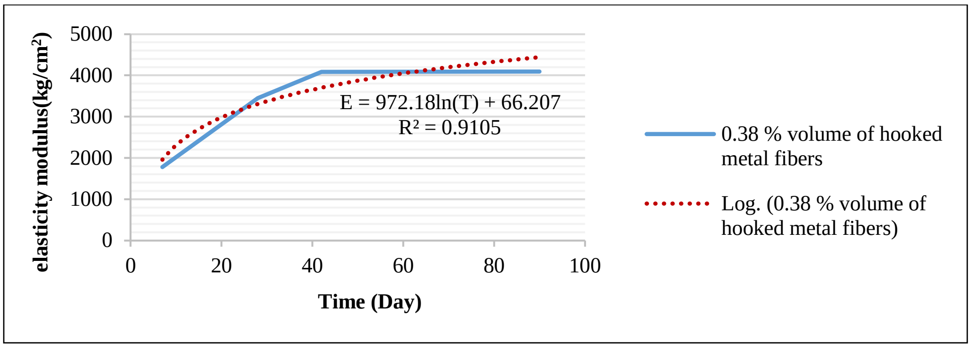
b) 0.19 % volume of polypropylene fibers



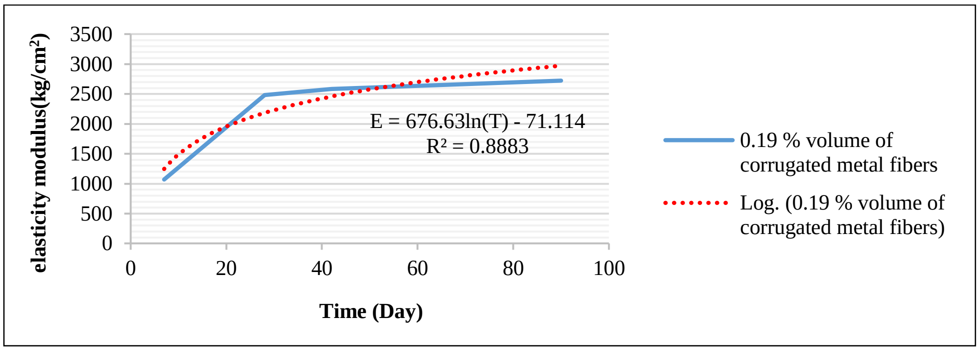
c) 0.38 % volume of polypropylene fibers



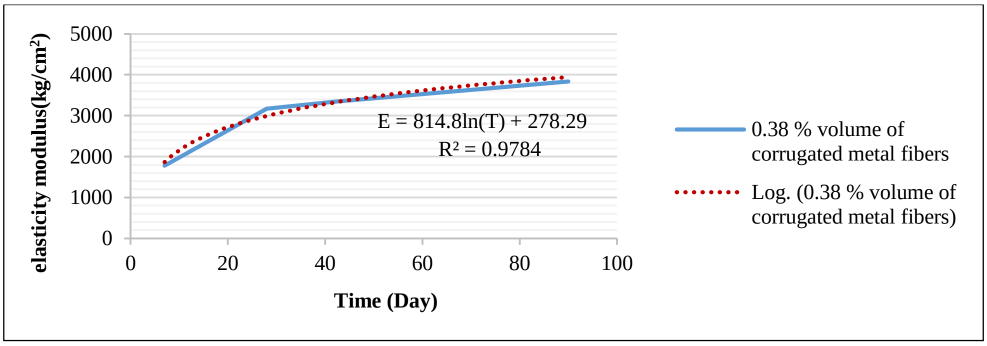
d) 0.19 % volume of hooked metal fibers



e) 0.38 % volume of hooked metal fibers



f) 0.19 % volume of corrugated metal fibers



g) 0.38 % volume of corrugated metal fibers

Figure 12. Regression line and time envelope diagram –elasticity modulus of various concrete samples

Bazkiagurai and Mousavinezhad (2017) investigated the effects of adding polypropylene fibers on plastics concrete specimens at the age of 28 days. It was concluded that the addition of fibers reduced the compressive strength and modulus of elasticity in the tested samples. The value of this reduction for compressive strength was at most 52.27% and for the modulus of elasticity was 16.98% [29].

In the present study, the reduction in compressive strength at the age of 28 days for 0.19% vol. of polypropylene fibers and for 0.38% vol. of these fibers was 21.6% and 29.1%, respectively. Regarding the modulus of elasticity, the modulus of elasticity has been increased, thus the increased modulus of elasticity was obtained by adding Polypropylene fibers at age of 28 days for samples made with 0.19% and 0.38% vol. of polypropylene fibers 19.4% and 21.6%, respectively.

Lotf-Ahmadi and Ghasemzadeh-Mousavinejad (2014) studied mechanical properties of kaolinite plastics concrete and the use of methaclene and polypropylene fibers. They showed that by adding polypropylene fibers to plastic concrete, tensile strength improved but compressive strength reduced. In the present study, as already mentioned, polypropylene fibers have been shown to increase tensile strength and reduce compressive strength, which confirms the results of this study [30].

In another study, it was stated that increasing the water-to-cement ratio increases the compressive strength at a time interval of 7 to 42 days, and it decreases the compressive strength in the range of 7 to 42 days by increasing the amount of bentonite. It should be noted that if the bentonite slurry curing time is not sufficient for curing bentonite, the increment rate of strength from 42 days to 90 days is sharply reduced to about 21%, which is true in this study[31].

Another study stated that increasing the strength of plastic concrete over time was a function of the ratio of bentonite to cement and the amount of cement had less effect. Plastic concrete with higher bentonite to cement ratio have less speed to obtain strength, but in general, the increment process of strengthening for various plastic concretes after 28 days is almost identical [32]. The results of this study also confirm this issue and it is clear that the increment process of strengthening for plastic concretes up to 28 days is much slower than ordinary concrete.

Due to the relationships shown in Figures. 11 and 12, the increase in the strength and modulus elasticity of plastic concrete after the 90-day age of concrete has continued significantly and is consistent with Figure 18 presented in the B51 bulletin of ICOLD letter. Due to the fact that there is usually a great deal of time between running the cut-off wall and the dewatering time, this particular characteristic of the plastic concrete is of particular importance[33].

Thus, using Figures 11 and 12, the relationship between compressive strength and time, as well as the relationship between elasticity modulus and time, is presented in Table 12. In all of these relationships, the regression coefficient (R^2) which is close to or greater than 90%, indicates the accuracy of the presented relationships.

Table 12. Relationships between compressive strength and modulus of elasticity over time in different designs of this research

Relationships	Basic plan	Plan with 0.19 vol. polypropylene fiber	Plan with 0.38 vol. polypropylene fiber	Plan with 0.19 vol. hooked metal fiber	Plan with 0.38 vol. hooked metal fiber	Plan with 0.19 vol. corrugated metal fiber	Plan with 0.38 vol. corrugated metal fiber
Time-compressive strength relationship	C=5.32 Ln(T)-5.25	C=3.71 Ln(T)-1.64	C=4.2 Ln(T)-4.14	C=3.48 Ln(T)-0.99	C=4.36 Ln(T)-2.82	C=3.25 Ln(T)-.002	C=4.86 Ln(T)-3.87
Regression curve	R^2=0.99	R^2=0.94	R^2=0.96	R^2=0.88	R^2=0.99	R^2=0.86	R^2=0.99
Time-elasticity of modulus relationship	E=1109 Ln(T)-1088.5	E=1001.7 Ln(T)-401.4	E=1051.3Ln(T)-811.4	E=745.6 Ln(T)-334.3	E=972.2 Ln(T)+66.2	E=676.6 Ln(T)-71.1	E=814.8 Ln(T)+278.3
Regression curve	R^2=0.99	R^2=0.94	R^2=0.89	R^2=0.87	R^2=0.91	R^2=0.89	R^2=0.91

Abbaslu et al., (2016) studied the compatibility of Saponite materials and bentonite in the cut-off wall of four different mixing plans with concrete and botanical materials to achieve the most suitable pan. The results showed that by increasing the amount of bentonite, there was a significant decrease in compressive strength and tensile strength [28].

Zhang et al. (2013) conducted a study on the mechanical properties of plastic concrete. The results of this study show that the ratio of water to bentonite and the amount of bentonite are very influential in the mechanical properties of plastic concrete. By increasing these two parameters, the compressive strength, tensile, shear and also modulus of elasticity decreased while the friction angle of shear samples increased [18].

Kazimyan et al. (2016) carried out research on concrete bentonite plastics by changing their physical properties. The results of this study showed that the amount of water on the properties of concrete has a great effect and, with the constant stagnation of water and with increasing the amount of cement compressive strength and modulus elasticity increases rapidly [34].

Some of the results of this study have been presented in the following diagrams, which are derived from the 22 initial mixing plans and all confirm the above. Figures 7 and 8 respectively show that the compressive strength and modulus of elasticity are reduced by increasing the amount of bentonite and increased with increasing the amount of cement.

Figures 9 and 10 show the effect of aggregate ratio and cement rate on compressive strength and elasticity modulus, respectively. As it is known, the increase in the proportion of aggregate (the ratio of sand to sand) or in other words, the increase in the magnitude of the compressive strength and modulus of elasticity increases. This also applies to the increase of cement.

Figures 11 and 12 show the effect of cement and water-to-bentonite ratio. As can be seen, the compressive strength and modulus of elasticity decrease with increasing water to bentonite ratio.

Innovation in this research can be used to use a variety of fibers and their impact and performance on the compressive strength and tensile strength of plastic concrete, as it is usually considered less in this research than in various studies, and it is clear from the results obtained. The use of fibers improves the behavior of plastic concrete or in other words, increases the surface under the stress curve-strain, which can greatly contribute to the performance of this concrete. Among the hooked metal fibers, corrugated metal, polypropylene fibers, as well as polypropylene fibers showed better performance than other fibers.

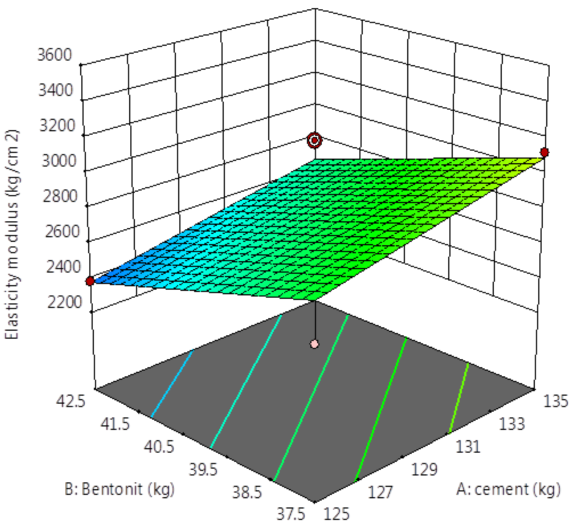


Figure 14. The effect of cement and bentonite amount on the modulus of elasticity

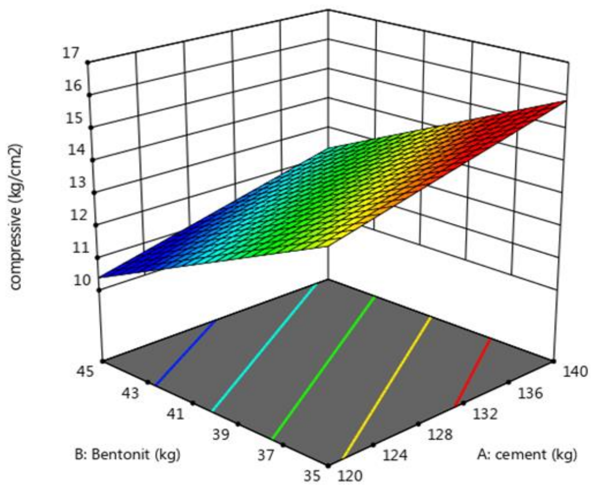


Figure 13. The effect of cement and bentonite amount on compressive strength

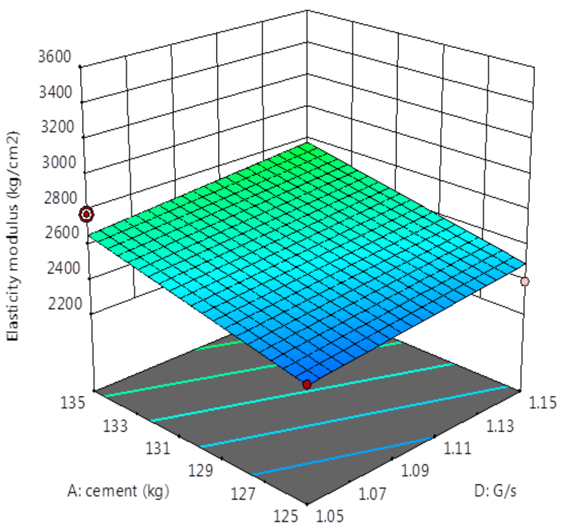


Figure 16.The effect of cement and aggregate amount on the modulus of elasticity

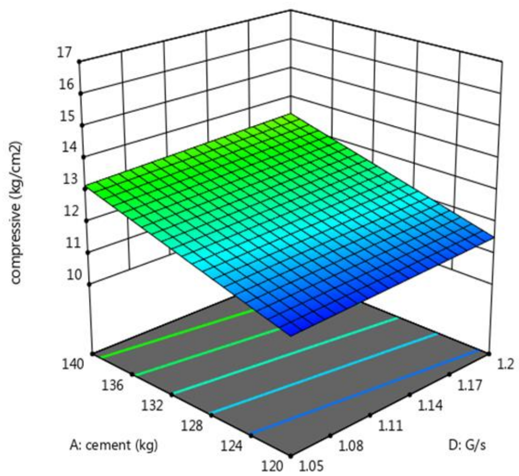


Figure 15. The effect of cement and aggregate amount on the compressive strength

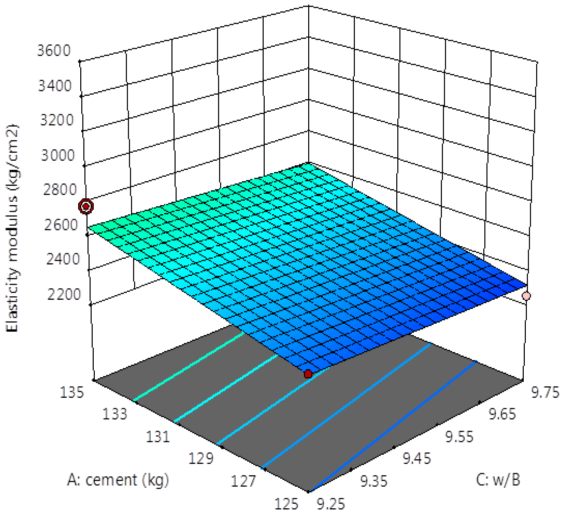


Figure 18. The effect of cement and the proportion of water to bentonite on the modulus of elasticity

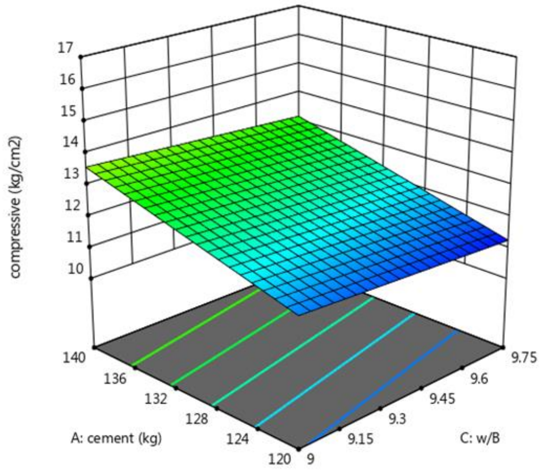


Figure 17. The effect of cement and the proportion of water to bentonite on the compressive strength

6. Conclusions

- The growth rate of elasticity modulus due to the increase in time is lower than the compressive strength increment ratio, and in other words, the concrete's plasticity changes less over time.
- 2. According to Figure 2, the addition of all fibers in this study almost reduced the compressive strength of concrete at different ages and this decrease in compressive strength was observed with increasing fiber content in samples made with polypropylene fibers.
- 3. The purpose of adding fibers to concrete samples in this study was not to increase the compressive strength but to improve the concrete behavior and increase the surface area below the stress-strain graph of concrete. According to Figure 10, it is clear that all fibers improve the plastic concrete behavior and the best fiber in terms of performance and improving the behavior of this concrete is polypropylene fiber. About 0.2% vol. of this fiber can be considered as optimum.
- 4- According to Figure 8, the addition of the fiber increased the tensile strength of all concrete samples, which, on average, the tensile strengths of samples made of fibers had a strength growth more than 50% higher than the concrete samples without fibers. The results of the experiments indicate that, by adding fiber, the stress-strain behavior of the samples has improved with increasing the surface under the stress-strain curve and strain softening, which means increased ductility, final strength and more energy absorption by samples.
- 5. The compressive strength of the plastic concrete increases over time and in this regard, it is similar to conventional concrete. However, there is a difference in the way of gaining strength. While in conventional concretes, 7-day strength is about 65-70% of 28-day strength, it is 50% or lower in plastic concretes, which is indicative of a slower process of obtaining the strength of plastic concrete compared to conventional concrete. Figures 8 and 9 show, over time, the compressive strength and the elasticity modulus of the plastic concrete are increasing linearly, which corresponds to Figure 18 presented in the B51 bulletin in ICOLD letter.

Due to this feature, plastic concrete is advised; it can be considered as a reason for this increase. Hence, designers, instead of the 28-day strength, consider a 90-day compressive strength as a criterion for planning.

7. Conflicts of Interest

The authors declare no conflict of interest.

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