Compressive Strength of Uncured Concrete Cylinders Fully Wrapped with Post-Tensioned Metal Straps

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ABSTRACT

During a national lockdown and curfew, most concrete projects are left without curing; therefore, the building elements need to be strengthened. An effective strengthening method is the use of post-tensioned metal strip (PTMS), which is a relatively new method. In this study, the effectiveness of PTMS in strengthening cylindrical samples without curing was tested. Fifteen cylinders were cast, 12 of which were left without curing for 28 days. Three samples that did not undergo strengthening were used as control samples. The remaining specimens were strengthened using one, two, three, and 5 layers of PTMS. To compare the strengths of the cylinders, three cylinders from the same batch were prepared and cured for 28 days. We found that the compressive strength of the cylinders increased by 39%, 57%, 84%, and 125% when the samples were strengthened using one, two, three, and full layers of PTMS, respectively. Additionally, the failure of the cylinders became ductile as the number of layers increased.

Keywords: Cylinders; Curing; Post-Tension Metal Strap (PTMS); Compressive Test.

1. INTRODUCTION

Various reasons can cause a need for strengthening of existing reinforced concrete beams, such as capacity loss of the elements that might occur owing to material deterioration or sometimes owing to emitting an essential procedure of curing the concrete. This might happen inevitably, as in the case of a national lockdown or curfew, especially due to a pandemic such as the COVID-19 pandemic. Other cases that cause a loss in strength might occur after constructing the element, for instance, in case of increasing the loading, removing an element, or adding a floor to the existing one. In some cases, the loads may be miscalculated during both design and construction (S. Altin, et al., 2005).

For elements resisting compressive stresses, confinement is the key to increasing resistance; otherwise, the elements might fail abruptly. This is true when there is insufficient lateral reinforcement. Alternatively, confinement might have been performed such that the spacing of the confinement is greater than that required by the standards. Leaving concrete without curing also leads to the production of low-quality concrete, which might be inevitable, as in case of a total curfew.

Sudden changes in loading, such as during earthquakes, impose danger on the elements as they act laterally on buildings (Zhou et al., 2019; Al-Maliki et al., 2021; Al-Soudani et al., 2021). For instance, during the 2017 earthquake at the border between Iraq and Iran, 500 people died due to the collapse of buildings (W. Abdullah et al., 2021). The earthquake was regarded as the deadliest of the year, as it had caused damage to 12000 buildings in the affected area (W. Abdullah et al., 2020).

Elements face premature failure when they do not provide confinement or exhibit poor confinement. This can be prevented by reinforcing the elements and confining them, either actively or passively. Therefore, the resistance can be increased by providing confinement reinforcement in the element in the form of ties or stirrups. Confinement can also be performed externally as strengthening of the elements after their construction.

Many methods have been used to strengthen deficient elements. Some of these are expensive, require labor-intensive work, and are not durable. Therefore, Frangou et al., at the University of Sheffield, developed a strengthening method using post-tensioned metal strap (PTMS) (Frangou et al., 1995). This method uses the same heavy-duty metal straps that are typically used in the packaging industry for external confinement of the elements. It uses a pneumatic tensioner for post-tensioning. Numerous experimental studies on the use of PTMS in strengthening elements and specimens have been reported in the literature (C. Chin et al., 2018; C.L Chin 2019a; C.K. Ma et al., 2019; M. Chau-Khun et al., 2015; C.L.Chin et al., 2019b; Y. Helal, 2012; Y. Helal et al., 2016; Y. Yang et al., 2019; M. Setkit and T. Imjai, 2019; H. Moghaddam et al., 2010). Some researchers have attempted to enhance the strength of full-scale elements (Mongabure, P., & Tamaris, 2012). while few studies have investigated the shear strength improvement in concrete beams after exposure to fire (Y. Yang et al., 2019). M. Setkit and T. Imjai (2019) used PTMS to strengthen the beams that failed to bend. However, strengthening cylinders using PTMS for uncured samples has rarely been reported in the literature. Therefore, research on the use of PTMS for strengthening normal concrete is necessary, particularly after the COVID-19 pandemic, when there is a possibility of announcing a curfew without warning.

2. EXPERIMENTAL PROGRAM

A total of 15 cylinders were cast and tested for their compressive strengths. The cylinder had a diameter of 150 mm and height of 300 mm. A standard steel mold was used. The testing was performed under standard conditions at a loading rate of 0.2 MPa/s. The samples were left in their molds for 30 days without curing and then tested using a universal testing machine. To compare the results, three samples from similar batches were prepared and tested after 28 days of immersion in water.

2.1 General material properties

Apart from metal straps and strapping machines, all other materials are locally available in Sulaymaniyah Governorate in the Kurdistan region of Iraq.

2.1.1 Cement

The cement used was ordinary Portland cement (IQS 5-CEM I 42.5 R). Fresh cement from the company's storage was used to avoid other weak points in the tests.

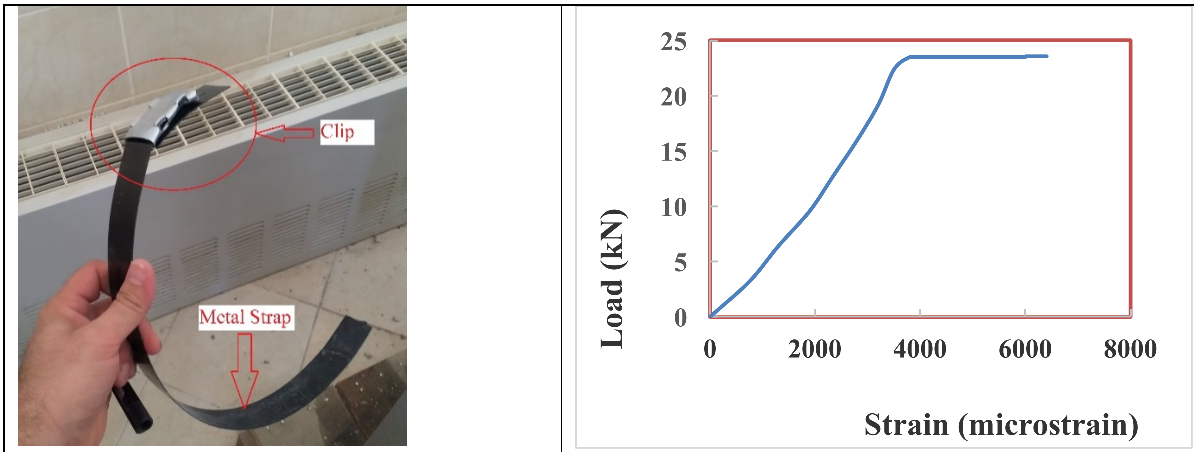
2.1.2 Coarse and fine aggregate tests

The coarse aggregate was a mixture of natural and crushed stones. The maximum size of the coarse aggregate was selected as 10 mm, and the mixed design was used based on that size. The sieve analyses of both the fine and coarse aggregates were compared with the ranges set by ASTM C33-92.

Fine aggregates are naturally available in rivers. The maximum size of the fine aggregate was 4.75 mm. The fineness modulus of the sand was 3.31.

2.1.3 Metal straps

For the purpose of strengthening, metal straps were used, which are similar to belts but are made from metal. These materials were bought from China in rolls. Metal straps are used in the packaging industry and categorized as heavy-duty metal straps. The width of the used sample was 31.75 mm, and the thickness was 0.8 mm, giving a cross-sectional area of 25.4 mm^2. An example of the metal strap with a clip is shown in Figure 1 (a). Aluminum clips were purchased to secure the joints at the two ends of the straps. The metal straps had a yield strength of 928 MPa. The modulus of elasticity of the straps was 237 GPa. The load–strain curves of the tested samples are shown in Figure 1 (b). The behavior of the material was elastic perfectly plastic because the strain increases with increasing stress until it reaches the yield strength, remains there for an elongation of 9%, and then breaks. Figure 1 (b) shows that the behavior is similar to that of steel rebars, as the machine used for testing was built to test only rebars.



(a) Metal strap and the clip

(b) Load–strain curve of the metal strap

Figure 1: Metal strap with its clip and four notches, with load–strain curve.

2.2 Materials and specimen fabrication

The objective of the mixed design was to achieve a compressive concrete strength of 25 MPa. For that purpose, the concrete mix was designed based on ACI 211.1-91, using a mixing ratio of 1:2.02:2.384 for cement, coarse aggregate, and fine aggregate. In addition, the water-to-cement ratio was set at 0.61. Table 1 lists the mix proportions of the concrete. All samples were cast on the same day. During casting, a slump cone test was performed to measure the slump of the concrete, which was found to be 110 mm. After casting the concrete, the samples were left in their molds for 28 days without curing, apart from the three samples that were used for comparison. A set of three samples without curing was tested as a control sample. The configuration of the metal strap was used as a variable.

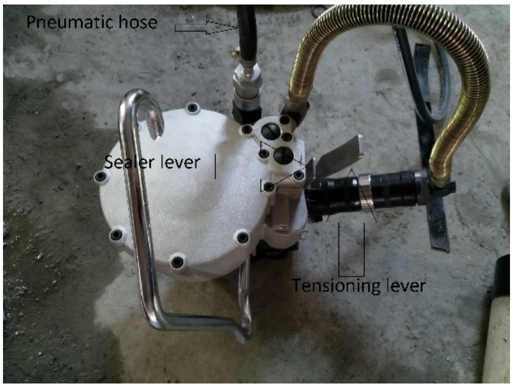
Table 1: Mass of the ingredients of the concrete

Water (kg)	Cement (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	Total (kg)
255	380	769	907	2311

2.3 Strengthening

Metal straps were used for strengthening. The way it is used is like buckling up a belt. First, the desired strap length was cut from the roll using an angle grinder. Then, an aluminum clip was placed at one end of the straps to a length of 110 mm. Then, the clip was manually bent to lock it in place. Subsequently, the free end of the straps was wrapped around the cylindrical concrete until they returned to the clip. The free end was then placed back in the clip for a second time, making a knot, as shown in Figure 2 (a). Next, the pneumatic tensioner was used, as shown in Figure 2 (b).

(a) Procedure of strapping



(b) Metal tensioner

Figure 2: Strengthening procedure using PTMS.

The tensioner comprises two parts required for post-tensioning, which are the tensioner and sealer. Tensioners are typically used for tensioning the straps. After tensioning the straps to the desired tension, the sealer part can be operated by pressing the lever marked in Figure 2 (b). The machine is commercially known as the KZ-32 strap packing tool. The locking force of the machine is approximately 18.4 kN. Both the pneumatic tensioner and sealer were operated on an air compressor.

When the sealer is used, the jaws of the machine bite the clip and create four notches, which make it sufficiently strong to relax. Moghaddam et al. proved that no relaxation occurred in a sample tensioned for 2 months and that the amount of tension on the samples was adequate to actively strengthen them, which was estimated to be 30% of the total yield strength of the material. In terms of stretching without rupture, the material could be elongated to 9% in 30 mm of its length, which complies with ASTM D3953. Notably, the width of the strap was 31.75 mm, and its thickness was 0.8 mm; thus, the jaws of the machine were made to house this type of strap; otherwise, a different type of machine should be used based on the width of the strap. In addition, the clips were created such that they can house the width of the strap, so they must be ordered correctly; otherwise, they might not be able to deliver the task. Apart from the control samples, all other samples were strengthened using four layers of PTMS on the top and bottom edges of the concrete cylinder to avoid weak points in the cylinders, and the strengthening was provided in layers of one, two, three, and fully wrapped, as shown in Figure 3.

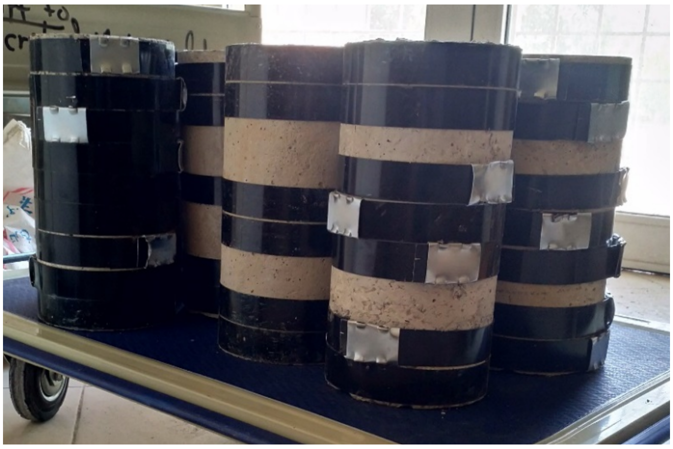


Figure 3: Samples after strapping

2.4 Equipment setup and testing procedure

A machine manufactured by a Control Company was used to test the samples for compression. The load rating of 0.2 MPa per second was used for the tests. Before testing the samples, the capping process was performed using gypsum plaster at a gypsum-to-water ratio of 2:1.

2.5 Cylinder samples

All the sample labels and their description are shown in Table 2.

Table 2: Sample numbers and descriptions

Sample description	Curing status	Sample label
Control sample	Not cured	3
Sample strengthened using one layer of PTMS	Not cured	3
Sample strengthened using two layers of PTMS	Not cured	3
Sample strengthened using three layers of PTMS	Not cured	3
Sample strengthened using full layers of PTMS	Not cured	3
Not strengthened	Cured	3

3. RESULTS AND DISCUSSION

3.1 Effects of PTMS

Table 3 shows all compressive strengths and the percentage of increase in the compressive strength based on the type of strengthening. The average compressive strength of the control sample was 20.37 MPa. When one layer of PTMS was used, the compressive strength of the concrete increased by 39% compared to the control sample. However, this load increasing rate increased further by 18% when the number of layers was increased from one to two. Furthermore, when the number of layers was increased to three, the rate of increase in the compressive strength of the concrete was 27%. Thus, with an increase in the number of layers, the compressive strength increased. This rate reached its peak once the samples were fully wrapped with PTMS, as the rate of increase was 41%. Compared with the control samples, the compressive strength of the fully wrapped samples increased by 125%, which is more than double the compressive strength of the control samples.

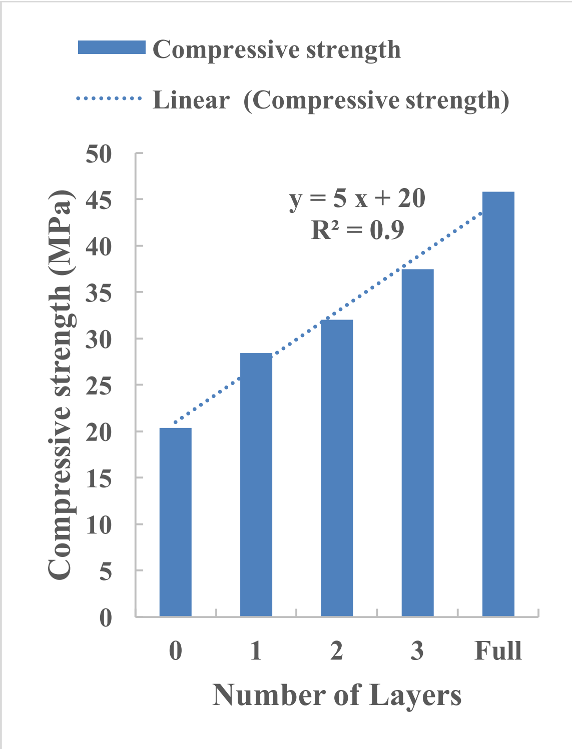
Table 3: Crushing loads of the samples.

Sample	Compressive strength (MPa)				Strength Percent increase
	1	2	3	Average	
Control sample	18.11	20.94	22.07	20.37	
One layer	25.41	30.91	28.9	28.41	39%
Two layers	34.17	30.25	31.7	32.04	57%
Three layers	38.65	36.31	37.5	37.49	84%
Full wrap	45.00	46.6	45.8	45.8	125%
Cured concrete	26.65	28.93	26.55	27.38	34%

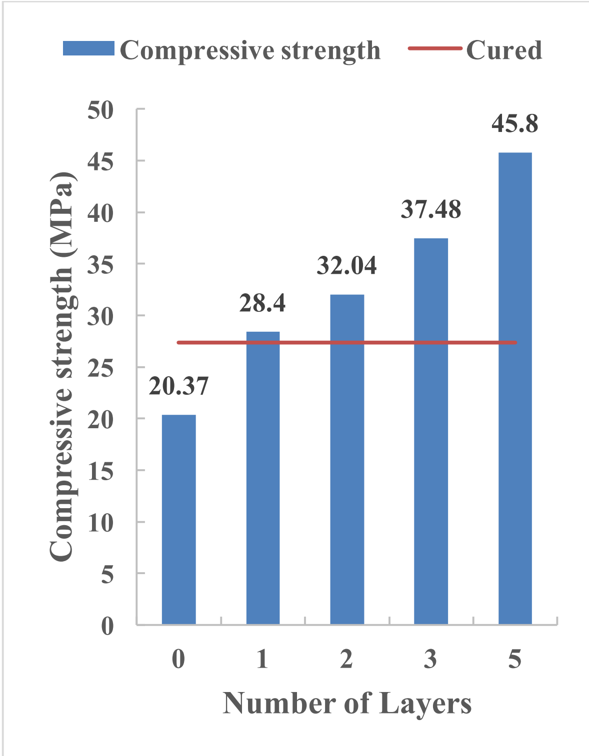
Figure 4(a) and (b) show the compressive strengths of the samples. The compressive strength of the samples increased linearly with an increase in the number of layers; thus, an equation was derived to predict the compressive strength using the number of layers used for strengthening, as follows:

$$y = 5x + 20$$

where *y* is the compressive strength in MPa, and *x* is the number of layers used to strengthen the concrete. The base of this equation is 20 MPa, which underestimates the compressive strength of the control sample concrete. This equation underestimates the results for all the layers. In the fully wrapped case, five layers were sufficient to achieve full wrapping. Therefore, if number 5 is included in the equation, the result comes out to be 45 MPa, which is very close to the value obtained during the tests.



(a) Compressive strength of the samples



(b) Comparison between the samples

Figure 4: Compressive strengths of the samples wrapped with different layers of PTMS.

3.2 Effects of curing

When comparing between the cured samples and those without curing, it can be observed that curing increased the compressive strength of the samples by 34% on average. In addition, the difference between the trials for concrete without curing was substantial, as there was a 4 MPa difference between the two groups of samples. This proves that the concrete without curing was inconsistent.

3.3 Effects of PTMS on the cured sample

As shown in Figure 4 (b), when only one layer of PTMS was used, the strength of the concrete was 4% greater than that of the cured samples. This rate of enhancement was increased to 17% when the number of layers was increased to two and further by 37% when the number of layers was increased to three. Finally, the strength increased by 67% when the samples were strengthened with PTMS fully wrapped around the cylinder compared with the cured samples.

3.4 Crack pattern

The failure mode of the concrete indicated that it was squeezed by PTMS and fully confined actively. In Figure 5 (a), the concrete portions are seen popping out between the straps, resembling a curtain, which indicates failure in the unconfined parts. The failure of PTMS occurred immediately at the edge of the clip, as shown in Figure 5(b), creating a sound similar to that of rupturing steel bars during the tensile strength test.

(a) Crack pattern

(b) Strap failure point

(c) Ductility of strengthened sample

Figure 5: (a) Crack pattern, (b) strap failure, and (c) ductility of the sample with PTMS.

3.5 Ductility of the samples

During the tests, the concrete failed in a ductile manner without any internal reinforcement, which proves that this method of strengthening can achieve ductile behavior for samples even without providing any reinforcement. The results appeared on the testing machine screen of the sample strengthened with three layers, as shown in Figure 5 (c).

5. Conclusions

In this study, concrete samples without curing were strengthened using PTMS. The following conclusions can be drawn:

1. During curfew and a total lockdown, concrete elements cannot be cured, which may cause a loss in their strength; therefore, strengthening is required.

2. There was a strength scatter between the compressive strengths of the concrete samples that were not cured, which reached 4 MPa owing to the inconsistent drying surface of the concrete.

3. The compressive strength of concrete can be significantly increased by using PTMS for strengthening the samples. The rate of increase was 39%, 57%, 84%, and 125% for samples strengthened with one, two, three, and five (or wrapped fully with) layers of PTMS, respectively.

4. The compressive strength of the uncured samples strengthened with PTMS was greater than that of the cured samples by 4%, 17%, 37%, and 67% when the samples were strengthened with one, two, three, and five (or wrapped fully with) layers of PTMS, respectively.

5. The failure of the samples showed evidence of PTMS actively confining the concrete, as parts of the concrete popped out between the layers of PTMS as the concrete underneath the straps was squeezed and confined.

6. The failure was more ductile, and toughness of the concrete samples increased with an increase in the number of layers of PTMS.

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