Investigating the Effectiveness of Liquid Membrane - Forming Concrete Curing Compounds Produced in Ethiopia

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Abstract. Liquid membrane-forming compound curing is a type of water retaining curing concrete technique by forming a membrane on the surface of the concrete. This study aimed to investigate the effectiveness of liquid membrane – forming concrete curing compounds produced in Ethiopia. The methodology include compressive strength and water absorption (on C-25 and C-40 grades of concrete) for samples examined under laboratory conditions and by exposing samples to external weather conditions which were cured through curing compounds, water sprinkling and plastic sheet covering. Additionally drying time and deleterious reaction tests were carried out. Liquid membrane – forming concrete curing compounds produced in Ethiopia are effective in compressive strength but not in water absorption, which water absorption was used to measure concrete quality in this study. Water sprinkling and plastic sheet covering methods were effective in compressive strength and water absorption than curing compounds. Regarding cost comparisons, water sprinkling method of curing is less costly than curing compounds and burlap coverings, and curing compound is more costly than the two.

Keywords: Curing compounds · Drying time · Deleterious reaction · Compressive strength · Water absorption

1 Introduction

Curing assures the maintenance of satisfactory moisture content and temperature in concrete for a period of time immediately following placing and finishing. Curing can be performed either by preventing evaporation of water from freshly placed concrete or by adding additional water to the concrete [1]. Liquid membrane-forming compounds

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enable concrete curing through retaining the water to the inside of concrete by forming a membrane on the surface of the concrete to prevent evaporation of water. In Ethiopia production of liquid membrane-forming compounds and application was started and still it is limited to few manufacturers and construction projects. Membrane-forming curing compounds typically consist of a wax or resin that is emulsified in water or dissolved in a solvent. The compound is applied to the concrete surface and then the water or solvent constituent evaporates leaving the wax or resin to form a membrane over the surface of the concrete [2]. ASTM C - 309 -07, classifies liquid membrane-forming curing compounds by the color of the compound and the solid constituent present for forming the membrane [3].

The Constructor- Civil Engineering Home [4] listed the following uses of curing compounds [4]:

- If wet curing is not possible, then the curing compound can be used to cure the concrete surface.
- For larger areas of concrete surfaces that are opened to sunlight, wind, etc. curing is a big task. But with the presence of the curing compound, it is easier.
- Curing of concrete pavements, runways, bridge decks, etc. can be cured to reach their maximum strength.
- A maximum durability of structure will be developed.
- Curing compound can be used for curing of canal linings, dams.
- Columns, beams, slabs can also be cured with curing compound.
- The membrane cane removed easily after complete curing.

Application of membrane-forming curing compounds is easy, short in time and not labor intensive [5]. Curing compounds should be applied as soon as finishing is completed, and bleeding has ceased [3]. At this stage, the bleed water has just left the surface and the texturing has increased the surface area resulting in increased evaporation. As the delay in the application of the curing compound under adverse conditions, plastic shrinkage cracking can result [6]. ASTMC 309 -07 specifies 200 ft^2/gal (5m^2/L) for testing purpose and noted that the application rate used for testing may, or may not, be the same as the rate to be used for field application. In a study conducted by researchers in Iowa department of transportation [5], results show that the specimens that were sprayed at 400 ft^2/gal (10 m^2/L) lost almost as much moisture as those that were sprayed at 100 ft^2/gal (2.5 m^2/L) [5].

For normal concrete with a water-cementitious materials ratio greater than about 0.45, because there is a water in excess of that needed for hydration and pozzolanic reactions membrane-forming curing compounds can be effective [7]. However, Copeland and Bragg [6], stated that membrane-forming curing compounds may not retain enough water in the concrete for concrete mixtures with high cement contents and low water-cement ratios (less than 0.40). In this case, concrete may require special curing needs [8]. Dinesh W. et al. [9], in their study of "Effectiveness of curing compound on concrete" conclude that the strength of membrane curing is not efficient as compared to conventional curing [9].

Even so the liquid membrane – forming curing compounds manufactured in Ethiopia, the competence of products on curing concrete was not investigated by researchers.

Accordingly, this study focus mainly on the effectiveness of products of liquid membrane – forming curing compounds produced in Ethiopia. The study investigates the compressive strength and water absorption of C-25 and C-40 grades of concrete cured by liquid – forming curing compounds and additionally, tried to answer the question does liquid membrane – forming curing compounds produced in Ethiopia effective than conventional curing methods. The purpose of selecting those two grades of concrete is to investigate the effectiveness of curing compounds with different concrete grades. This is because of curing compounds is more effective in the low grade of concrete only. To achieve the major objective of the research, the specific objectives are organized as follows:

- To examine the drying time of curing compounds and deleterious reaction of curing compounds with concrete.
- To examine the effectiveness of curing compounds through compressive strength and water absorption tests on C- 25 and C-40 concrete grades.
- Assessing sample conditioning effects by exposing specimens to various field water moisture retentions and water adding, and also to chemical curing compounds from the test results of compressive strength and water absorption capacity.
- To evaluate and compare the economical aspect of conventional curing practices with that of the chemical curing compound.

2 Materials and Methods

2.1 Materials

The concrete making materials used in this research were cement, fine aggregate, coarse aggregate and water. Four liquid membrane – forming concrete curing compound products which are produced in Ethiopia by three companies (one company produce two types of curing compounds) were used, product (1) a resin-based clear curing compound, product (2) a clear translucent, product (3) Clear Liquid –Emulsified paraffin wax, product (4) clear translucent which has sodium silicate and creates a film of adhering microcrystalline. The companies import raw materials for producing the curing compounds from Dubai and China. The type of cement used in this study was 42.5R Ordinary Portland Cement (OPC) equivalent to ASTMtype I (CEM I 42.5 R) cement from Derba Cement Factory and Lalibela sand. While, the coarse aggregate extracted from Meshenti aggregate crushing plant site with the maximum size of 25 mm was used. Material Property tests of the aggregates were carried out according to ASTMstandards and the water utilized in the concrete mix was drinkable water.

2.2 Experimental Procedures

Testing Properties of Membrane Forming Curing Compounds. Drying time and deleterious reaction tests were conducted in this study as evaluation of suitability of curing compounds to use these products of curing compounds as one of curing techniques in concrete. The tests were carried out as per ASTM C-309 [3].

Casting and Curing of Concrete Specimens. The required volumes of mix ingredients were measured and mixing was done thoroughly to ensure that a homogenous mix is obtained. The specimens were subjected to different curing techniques. For in laboratory samples the samples subjected to curing through soaking or immersion in a curing tank and curing compounds curing without exposing these samples. For field weather exposed samples curing was carried out through water sprinkling, plastic sheet covering and curing compounds curing techniques.

Liquid Membrane - Forming Concrete Curing Compound Preparation and Application. Application of curing compounds performed as per the specifications given by the manufacturers. For product (1), (3) and (4) curing compounds single layer application was done since there is no recommended double layer application. However, for the product (2) double coat application was recommended by the manufacturer and this also done. Even double coat is recommended, for economical effectiveness single layer applications were performed in this study. For all products, the curing compound was applied through spraying in a uniform manner as soon as the surface water disappears.

Tests and Procedures for Compressive Strength and Water Absorption. Concrete samples were casted for determination of compressive strength and water absorption and comparison is done with the control specimens. Laboratory experimental tests and tests for samples exposed to field weather conditions or samples outside the laboratory on C-25 and C-40 concrete grade were conducted. The purpose of selecting those two grades of concrete is to investigate the effectiveness of curing compounds with different concrete grades. This is because of curing compounds is more effective in the low grade of concrete. Copeland and Bragg [6], states that membrane-forming curing compounds may not retain enough water in the concrete for concrete mixtures with high cement contents and low water-cement ratios (less than 0.40) [6]. Field tests might be important to investigate the effectiveness of curing compounds when exposed to actual weather conditions. The time that concrete was casted, placed and cured was, Ethiopian spring time season which is on September. The room temperature were between 20 °C and 26 °C and temperature outside room was between 25 °C–28 °C of T max. and T min. was between 13.8°C–16 °C, relative humidity ranges from 62%–84% and wind run was recorded in between 0.28 m/s–0.72 m/s at the time.

Compressive Strength Test. The compressive strength tests for 3, 7 and 28 days were conducted for C-25 and C-40 concrete grades for samples in lab and field. Curing is essential to achieve expected compressive strength thus 3, 7 and 28 days compressive strength tests were conducted as per specification. This is used to examine early strength of samples of concrete and due to 99% of compressive strength achieved at 28 days. For tests exposed to field weather conditions two curing methods (water sprinkling and plastic sheet covering) were used for comparison with curing compounds. In lab samples also cured through immersion curing and curing compounds.

Water Absorption Test. The test conducted at 28 day as per ASTM C 642 [10]. Water absorption test method for hardened concrete used to see potential water absorption by concrete through full immersion of cube samples in the water. This test carried out for both samples exposed to field weather conditions and in lab.

Curing Cost Comparison Between Two Locally Practiced Methods and Curing Compounds. The curing methods used in this study for comparisons are water sprinkling, burlap covering and curing compounds. The cost of curing is compiled by considering the cost of materials and cost of labor for those curing methods. Material and labor costs for water and burlap curing depend on the current Bahir Dar city market price.

3 Results and Discussions

The results obtained from the; chemical properties of liquid membrane curing compounds, compressive strength and water absorption are discussed in this section.

3.1 Test results on membrane forming curing compounds

Drying Time Test Results. The drying time test is the test that the drying time of curing compounds after application. ASTM recommends that the curing compound shall be dry for touching in not more than 4 h.

The curing compounds of all the products drying time are less than 4h, indicating that all curing compounds fulfill standards of ASTM 309–07 [3]. Table 1 below shows that the drying time of each curing compounds.

Table 1. Drying time results of curing compounds

Id	Drying time (Hr.)
Product (1)	2
Product (2)	1
Product (3)	1.5
Product (4)	1

Deleterious Reactions Test Results. In case of all curing compounds, there was no deleterious reaction with the concrete. Hence, the result shows that no softening of concrete surface for the test done through scratching, after the surface of the concrete is dried properly. Any softening of the liquid membrane-forming compound-treated surface evaluated by such comparison shall be considered sufficient cause for rejection of the compound.

3.2 Compressive Strength Test Results

C-25 Compressive Strength Test Results for Samples in the Laboratory. The results of C-25 compressive strength for samples cured by curing compounds and immersion at 3, 7 and 28 days in the lab are also shown in the Fig. 1. As shown in figure the results of compressive strength of each curing methods are achieved the desired strength at 3, 7 and 28 days.

The three days compressive strength test results show that the immersion curing or control group has highest compressive strength than curing compounds. From those of curing compounds, at three-days, product (2) (with double coat), and results the highest strength from the remaining curing compounds. P (3), p (4) and p (1) compressive strength could be understood as in their decreasing order.

Similar to the three-day compressive strength test results, the seven day compressive strength of immersion curing (control group) also exceeds the results of the curing compounds. Product (2) curing compound has the highest compressive strength from the remaining. And product (2), product (4) and product (1) compressive strength could be understood as following those in their decreasing order.

The 28 - day's compressive strength of the C-25 grade of concrete shows that samples of immersion cured have highest compressive strength than curing compounds. At 28 - day's product (2) (with double coat) has highest compressive strength than the remaining curing compounds. And product (4), (1), (2*) and (3) compressive strength could be understood as in their decreasing order. Product (2)* is product (2) with single application and the compressive strength of this product resulted the desired strength. Double coat application for product (2) curing compound shows higher compressive strength, thus application of double coat influence the compressive strength without considering other factors. However, even double coat application of product (2) strength is higher, single coat application is achieved the desired strength. Due to this, except C-25 in lab compressive strength all tests considered single layer application of product (2).

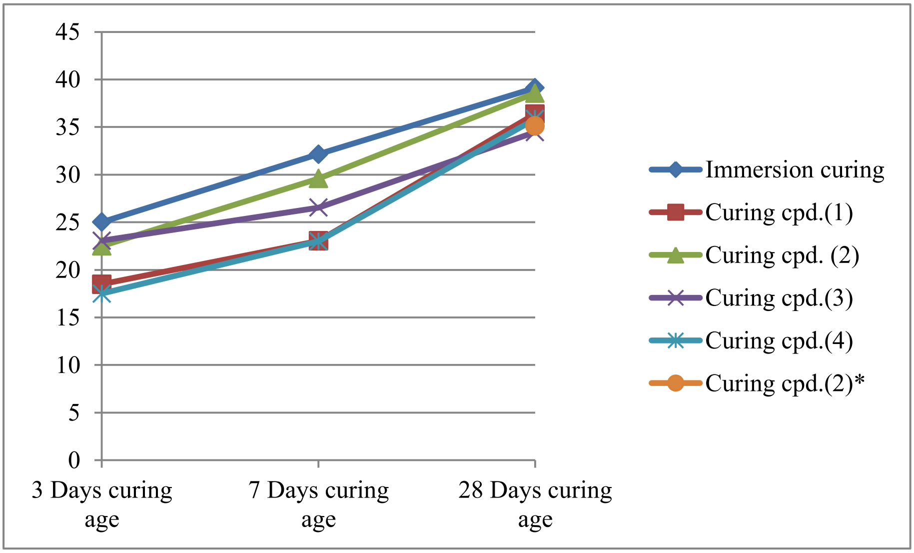

Fig. 1. C-25 concrete compressive strength test results

C-40 Compressive Strength Test Results for Samples in the Laboratory. In the Fig. 2, the results of compressive strength of each curing methods at 3, 7 and 28-days are shown. As shown in graph below P (3) shows high early strength at 3 days among curing compounds and at 28 days of P (3) is the lowest performer. Immersion curing results are the highest compressive strength at all the three testing ages.

For the three days C- 40 concrete grade compressive strength test results for immersion curing and curing compounds. And product (3), product (4), product (1) and product (2) compressive strengths could be understood as in their decreasing order.

The results of 7 and 28-days compressive strength show that the immersion curing (control group) exceeds the curing compounds compressive strength. From curing compounds product (4) is with the higher compressive strength followed by product (1), product (2) and product (3); respectively in both 7 and 28-days compressive strength results.

Generally, for samples conditioned in the laboratory, the samples with immersion curing scored higher compressive strengths than those with chemical compounds at 3, 7 and 28 days for both C-25 and C-40 concrete grades. As pointed out in various studies additional water curing is effective than water retaining method (such like curing compound curing method). This might be due to evaporation of water after placing of concrete. However, in this study the considered liquid membrane – forming concrete curing compounds are satisfying the required compressive strength.

Among the results of curing compounds, product (3) which is wax emulsion type, early compressive strength development was higher than the rest curing compounds, but the late age strength becomes lower and at 28 (in case of C-40) and at 7 (in case of C-25) days registered less compressive strength than all curing compounds. As the Constructor - Civil Engineering [4], states, wax compound loses its efficiency with time increment [4]. Thus, product three's strength might be affected due to this reason.

QCL group [2], indicated that the different types of curing compounds could have different curing effectiveness ability; for example, Wax emulsion "compares as curing well with others", Hydrocarbon resins "excellent curing". However, under extreme weather conditions, the membrane becomes brittle and breaks down under the action of sunlight and weathering, thus reducing its effectiveness [2]. In this study also, hydrocarbons resin which is product (1) curing compound has very good compressive strength as evidenced by the test results. The study on "An experimental investigation on self-curing concrete using different curing agent" by Karthick R, Amrin Sulthana [11], found that the curing compounds with sodium poly acrylate which form crystalline structures when dry showed that 8%, 11% more compressive strength gains than the conventional at 7 and 14 days, respectively; and 6% lesser at 28 days than conventional. The study also investigated paraffin wax coated curing compound effect on compressive strength and the results show that 17.5%, 19.6% and 20% lesser compressive strength than conventional methods at 7, 14 and 28 days; respectively [11]. In this research also, the field weather exposed samples, curing compound (4) which form microcrystal and which has sodium silicate, also resulted the highest compressive strength amongst the rest.

In general, the compressive strength test results of all curing compounds were fulfilled the desired compressive strengths at all 3, 7, and 28 days.

C-25 Compressive Strength Test Results for Samples Exposed to Field Weather Conditions. The results of C -25 under field weather conditions in compressive strength for 3, 7 and 28 - days also shown in the Fig. 3. In this case, the conventional (water

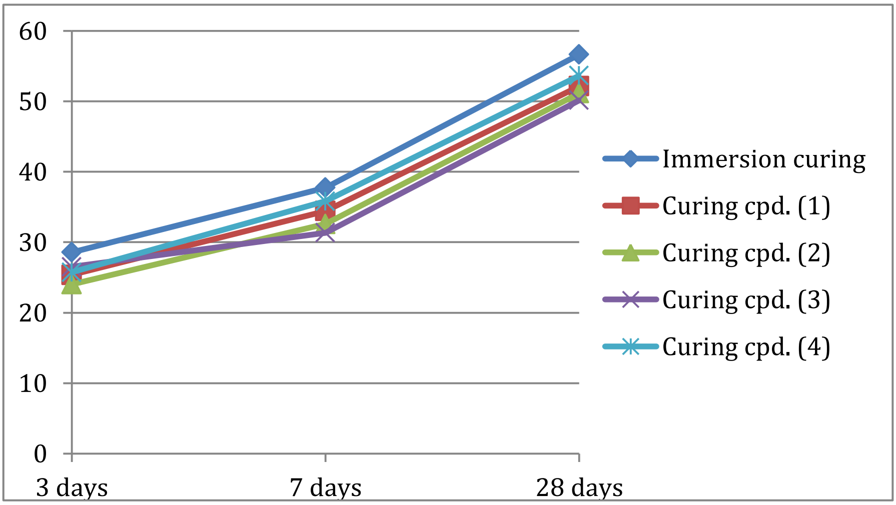

Fig. 2. C-40 concrete compressive strength test results

sprinkling and plastic sheet covering) curing methods have higher compressive strength at all the three testing ages.

At three day testing, from the two conventional curing methods, plastic sheet covering was found to score the highest compressive strength followed by water sprinkling, product (4) is with the highest compressive strength scorer among the curing compounds followed by product (3) and products (1) and (2) have less compressive strengths from all the curing compounds in their decreasing order.

The 7 and 28 days compressive strength also shows the highest strength for plastic sheet covering followed by water sprinkling method. From the curing compounds, curing compound (4) has the highest compressive strength; product (2) is the next one which is followed by product (1), and product (3) is the least in compressive strength series at 7 and 28 days. Figure 3 below shows C-25 compressive strength test results for samples exposed to field weather conditions.

C-40 Compressive Strength Test Results for Samples Exposed to Field Weather Conditions. Figure 4 shows the results of C - 40 under field weather conditions cured samples compressive strength for 3, 7 and 28 - days.

The 3, 7 and 28 - days compressive strength of C-40 concrete shows that plastic sheet covering have highest compressive strength followed by water sprinkling. From the curing compounds, product (4), (1), (2) and (3) compressive strengths followed in their decreasing order.

For the samples exposed to field weather conditions plastic sheet and water sprinkling have both registered higher strengths than curing compounds. Previous studies on curing compounds also reported that conventional curing methods are more effective than liquid membrane-forming curing compounds. According to a study by Dinesh W. et al. [9], in their study of —Effectiveness of curing compound on concrete conclude that the strength of membrane curing is not efficient as compared to conventional curing [9].

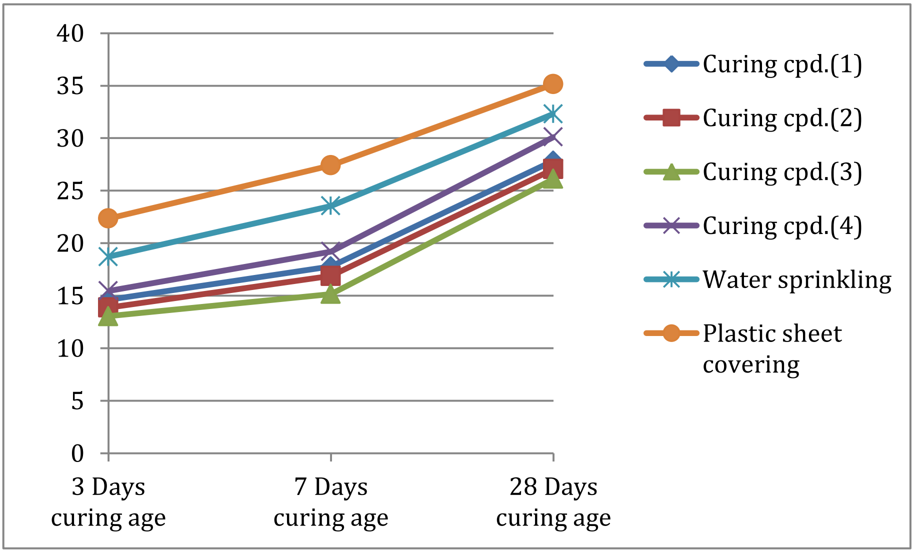

Fig. 3. C-25 concrete compressive strength for samples exposed to field weather conditions

Additionally, D. Gowsika, et al. [12], also in their study of -Experimental study on curing methods of concrete‖ investigated the effect of curing compound on strength for M 20 grade of concrete and the results of the comparisons between curing compounds and different other curing method for 7 and 28 days compressive strength was the membrane curing compound is the least effective method following air drying than those given conventional curing [12].

However, the compressive strength tests of all curing compounds achieved the desired compressive strength. Among the curing compounds in case of samples exposed to field weather conditions, product (4) which has sodium silicate which creates a film of adhering microcrystalline nature leading to highest compressive strength.

3.3 Water Absorption Test Results

Water Results of water absorption tests of C-25 grade of concrete on the in lab cured samples: Water absorption test results show that the immersion curing method has less percentage of water absorption than the curing compounds. Absorption is cause of degradation of concrete structures related with the quality and durability of concrete. One of the variables that control the degradation process in the concrete is effectively reduced water absorption. In unsaturated concrete, the rate of ingress of water or other liquids is largely controlled by absorption due to capillary rise [13]. Less water absorption indicates the ability of concrete to protect the entrance of liquids and other aggressive substances to its inside.

Products (1), (2) and (4) have less amount of water absorption value respectively from the curing compounds, with very close values to each other. Product (3) is the curing compound with higher absorption. According to Comite Euro-International du

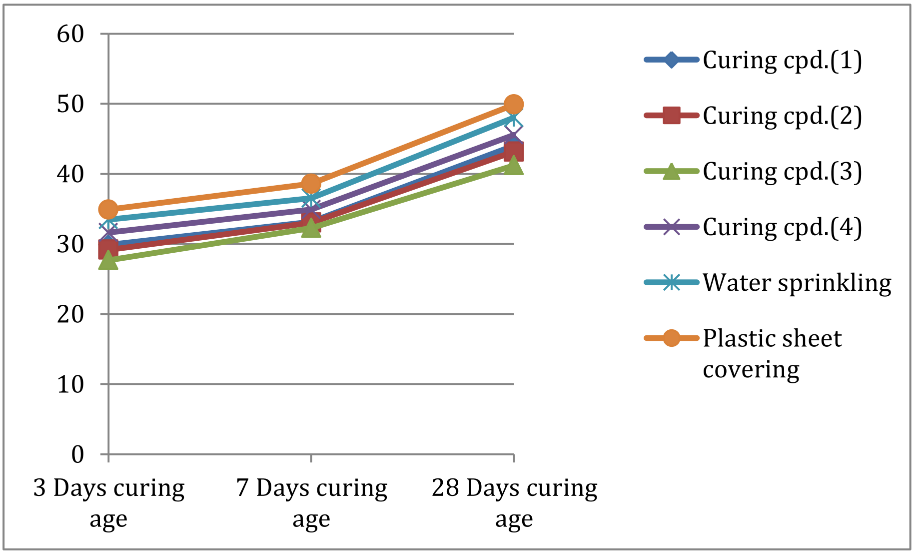

Fig. 4. For C-40 concrete compressive strength for samples exposed to weather test

Beton (CEB 192, 1989), concrete may be classified as good, average and poor, and the values of classification ranges proposed by CEB 192 are, from 0 – 3% good, >3% - 5% average and >5% - 7% poor concrete quality [14]. With the above in mind, Table 2 shows that immersion curing method with a result of 2.08% signifies a good concrete quality in the C-25 grade of concrete. Curing compounds (1), (2) and (4) have 4.05% and 4.06% absorption value respectively; which fall under average concrete quality. However, curing compound (3) has absorption value of 5.64%, which could be taken as a concrete of poor quality.

Table 2. Water absorption of C-25 samples cured in lab

Description	Average mass after oven drying (g)	Average mass after immersion to water, (g)	% of absorption
Immersion curing	8,926.33	9,111.66	2.08
Curing cpd. (1)	8,546.50	8,892.33	4.05
Curing cpd. (2)	8,506.16	8851.00	4.06
Curing cpd. (3)	8479.80	8958.80	5.64
Curing cpd. (4)	8378.30	8861.00	4.06

Results of Water Absorption Tests of C-40 Grade of Concrete for the in Lab Cured Samples. Medeiros – Junior et. al [13], had observed the relationship between water/cement ratio and water absorption through immersion, and the lower water/cement ratio results small water absorption value [13]. In this study also water absorptions in C-40 is less than in C-25 concrete grade. Where more water is not consumed by hydration reaction the microscopic pores cause higher water absorption thus, lower water/cement ratio result in lower water absorption [13].

As shown in Table 3, immersion curing method shows less percentage of water absorption. Curing compound product (4) has less water absorption than other curing compounds and product (1) and (2) results in the next less water absorption among the curing compounds; respectively. Product (3) shows the highest water absorption from all other. According to classification of Comite Euro-International du Beton (CEB 192, 1989) [14], immersion curing method which scored 1.86% is the range under good concrete quality, and curing compound (1), (2) and (4) have 3.84%, 3.93% and 3.07% absorption values respectively; which are under average concrete quality. Curing compound (3) has 4.46%, which is taken as an average among the established concrete qualities, but has the highest value.

Table 3. Water absorption for C-40 by samples cured in lab

Description	Average mass after oven drying, (g)	Average mass after immersion to water, (g)	% of absorption
Immersion curing	8846.25	9010.50	1.86
Curing cpd. (1)	8720.86	9,055.83	3.93
Curing cpd. (2)	8648.50	8,988.16	3.84
Curing cpd. (3)	8443.50	8905.17	4.46
Curing cpd. (4)	8451.30	8939.80	3.07

Results Water Absorption Test on C-25 Grade of Concrete Field Weather Exposed Samples. In the case of samples exposed to field weather, for C-25 grade of concrete, plastic sheet covering and water sprinkling techniques of curing show less percentage of water absorption. Also curing compound products (4), (1) and (2) have the sequential less absorption values; respectively. And product (3) result indicates high water absorption than the rest.

According to the classification of Comite Euro-International du Beton (CEB 192, 1989) [14], of concrete quality water sprinkling and plastic sheet covering curings are classified under good quality concrete; having 4.78 and 4.75% water absorptions; respectively. However all curing compounds have >5% absorption and these values show indicate poor concrete quality (Tables 4 and 5).

Results of Eater Absorption Test on C-40 Grade of Concrete Field Weather Exposed Samples. For C-40 grade of concrete, plastic sheet covering and water sprinkling techniques have lower water absorption values. Product (4), (1), (2) and (3) have the sequential less absorption values; respectively. Depending on (CEB 192, 1989) [14], concrete quality classification in regard to water absorption value [14], all curing compounds results come under poor concrete quality; whereas, water sprinkling and plastic sheet covering curing have absorption value classified as an average concrete quality.

Table 4. Water absorption of C-25 concrete grade for samples exposed under field weather conditions

Description	Average mass after oven drying (g)	Average mass after immersion to water, (g)	% of absorption
Curing cpd. (1)	8023.80	8540.70	5.94
Curing cpd. (2)	8068.30	8657.00	6.04
Curing cpd. (3)	8038.50	8541.50	6.76
Curing cpd. (4)	8125.20	8609.70	5.89
Water sprinkling	8349.70	8746.80	4.78
Plastic sheet	8351.80	8751.20	4.75

Table 5. Water absorption of C-40 grade of concrete for samples exposed under field weather conditions

Description	Average mass after oven drying, (g)	Average mass after immersion to water, (g)	% of absorption
Curing cpd. (1)	8252.80	8702.30	5.60
Curing cpd. (2)	8346.50	8780.70	5.46
Curing cpd. (3)	8191.00	8671.20	6.08
Curing cpd. (4)	8191.00	8591.30	5.20
Water sprinkling	8245.80	8618.50	4.51
Plastic sheet	8566.20	8937.80	4.33

3.4 Cost Comparison Between Curing Compounds and Conventional Curing Methods

The curing methods used in this study for comparisons are water sprinkling, burlap covering and chemical curing compounds. As shown in Table 6, water sprinkling curing method has less total cost than using burlap and curing compounds. The next one is covering with burlap and using curing compound is costlier than the rest. In places where water for construction is transported from far-off distances and for the additional curing days the cost of water sprinkling and burlap covering might be increased. Since where shortage of water is a challenge transport and water cost increase; and also if curing period increases by more than seven days (minimum requirements of ASTM 308 1-98 [15]) material and manpower cost increases as well. The costs shown in Table 6, are based on Bahir Dar City market and obtained through own survey.

Table 6. Cost of each curing methods

	Cost of each curing methods (Birr/m^2)		
Work item	Water sprinkling	Burlap covering	Curing compounds
Manpower cost (for curing)	0.24	0.24	0.121
Manpower cost (for covering)	–	2.1	–
Water cost	2.94	2.94	–
Burlap cost	–	5	–
Curing compound cost	–	–	18
Transport cost	–	–	0.4
Total cost	3.04	10.52	18.5

4 Conclusions

Based on the results, analysis and discussion of all the performed tests and related complied relevant data the following conclusions are drawn.

- The drying time of curing compounds is from 1 h -2 h.
- All curing compounds did not deleteriously react with the concrete produced since there was no any softening of the liquid membrane-forming compound-treated surfaces.
- Based on the compressive strength test results, in case of both samples cured in laboratory and field weather conditions, all curing compounds were effective at 3, 7, and 28 days for both C-25 and C-40 concrete grades since all samples achieved expected strength.
- However, curing compounds have smaller compressive strengths and higher water absorptions than immersion (control group), water sprinkling and plastic sheet coverings curing.
- The compressive strength between mean of curing compounds and non-chemical curing method results show a statistically significant difference.
- All curing compounds results poor concrete quality at field and average in lab in both concrete grades, except Product (3) which results poor both at field and in lab, depending water absorption results.
- Water sprinkling and covering with plastic sheet results average concrete quality in both concrete grades and the control group results good concrete quality in both concrete grades.
- The cost comparison between those curing methods indicate that water sprinkling has less total cost than burlap covering and curing compounds. And cost of burlap covering is economical than curing compounds.

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