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Effect of Practical Curing MethodsOn the Properties of Roller Compacted Concrete

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ABSTRACT

Roller Compacted Concrete (RCC) is a technology characterized mainly by the use of rollers for compaction. This construction method permits considerable reduction in costs and construction time of dams and roads.It is necessary to study the curing of RCC especially in hot weather because RCC has no slump and has little W/C ratio. Therefore the primary scope of this research is to study the effect of various curing methods (continuous watering, wet burlap, nylon, sprinkling, curing cycles, and curing compound) after 24 hrs from casting on the physical properties of roller compacted concrete.

The mix proportion which was used in this investigation,was designed and laboratory tried on the basis of using 250 kg/m³ of Ordinary Portland Cement. This work involves preparing cylindrical specimens with (diameter of 150 mm by height of 300 mm) for measuring the compressive strength, splitting-tensile strength, and static modulus of elasticity. And it also includes prism specimens with (100×100×400 mm) for measuring the modulus of rupture (flexural strength).

Results show that the curing of RCC with continuous watering clearly improved the RCC properties. The results also indicate that the RCC specimens without curing (left in air) suffered from permanent loss of strengths ranging between 20 to 25 % when compared with continuous watering at age of 28 days.

Key words: Roller compacted concrete, curing methods, compressive strength, splitting tensile strength, modulus of rupture.

تأثير الطرق العملية للمعالجة على خواص الخرسانة المرصوصة بالحدل

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الخلاصة:

تعتبر الخرسانة المرصوصة بالحدل من التقنيات التي تملك بالدرجة الأكبر خاصية إستعمال الحادلات لرص الخرسانة إن إستعمال هذه الخرسانة يوفر الوقت والكلفة في إنشاء السدود والطرق. وبالنظر لكون الخرسانة المرصوصة بالحدل هي خرسانة بلا هطول، وذات محتوى مائي قليل ،ولإهمية المعالجة لهذا النوع من الخرسانة فإن من الضروري الإهتمام بدراسة طرق المعالجة للخرسانة المرصوصة بالحدل وخاصة في الأجواء الحارة، لذلك فإن الهدف الرئيسي من هذا البحث هو دراسة تأثير الأنواع المختلفة من المعالجة (المعالجة بصورة مستمرة بالماء، تغطية الخرسانة بالجنفاص المرطب، تغطيتها بالنايلون، الرش، تعريض الخرسانة لدورات متعاقبة من الترطيب والتجفيف و إستعمال مركبات المعالجة) بعد 24 ساعة من البدء بعملية الصب على الخواص الفيزيائية

وتضمن المنهاج العملي استعمال نسبة خلط والتي صممت مختبرياً على أساس إستخدام 250 كغم/م^3 من السمنت وتحضير نماذج فحص أسطوانية بإبعاد (قطر 150 ملم وطول 300 ملم) لغرض قياس مقاومة الإنضغاط ومقاومة الشد ومعامل المرونة الستاتيكي وفحص الإمتصاص،وإستخدام مواشير ذات أبعاد (100 ×100×400 ملم) لغرض فحص معامل التصدع (مقاومة الإنثناء).

وقد بينت النتائج بأن معالجة الخرسانة بصورة مستمرة بالماء يحسن من خواص الخرسانة المرصوصة بالحدل بشكل ملحوظ، كما أشارت النتائج إلى إن عدم معالجة الخرسانة المرصوصة بالحدل يؤدي إلى إنخفاض ملموس في مقاومة الإنضغاط ومقاومة الشد ومعامل التصدع يتراوح ما بين 20% إلى 25% مقارنة مع تلك الخرسانة المعالجة بصورة مستمرة بالماء وبعمر 28 يوم.

INTRODUCTION

Roller compacted concrete (RCC) is a new technology characterized mainly by the use of rollers for compaction. RCC is a construction technology, not a design criterion nor a design technology, that uses concrete of no-slump consistency in its unhardened state which is transported, placed, and compacted using earth and rock fill construction equipment.[(1)]

It differs from granular soil cement, which may use similar placement method, primarily in that it contains coarse aggregates and develops properties similar to conventionally placed concrete.[(2)]Conventional concrete cannot generally be reproportioned for use as RCC by any single action such as altering the proportions of mortar and coarse aggregate, reducing the water content, changing the water-cementitious materials ratio, or increasing the fine aggregate content.[(3)]

The major advantages of roller compacted concrete are cost savings over conventional concrete pavements by 20 to 30 percent or more have been realized, [(4)] and for dams approximate cost saving in RCC ranges from 25 to 50 percent which is less than conventionally placed concrete.[(1,4)]

RCC has been also used in Iraq in mid eighties, below the foundations of the Medical Drug Factory near Mosul and in the AL-Adiam Dam. [(5)]

RCC construction may require extra care because of the following reasons: [(6)]

- A very low mixing water content,
- A high production rate,
- A large exposed area characteristic of flat work.

Thus curing is particularly critical with RCC to prevent a loss of surface moisture and thereby a loss or dusting of the surface cement and aggregate. There is so little water available for hydration of cement that any loss of moisture is undesirable. [(7)]

The water curing is recommended for RCC pavement application and water curing is accomplished by spray truck for 7 days (aminimum period) under normal climate conditions.[8,9]

In the field of effect the curing by using lime saturated water on mechanical properties of RCC, the results shows an improvement on compressive, splitting tensile and flexural strength at 180 days by average value 22% than that at 28 days compared with that cured in water.[10]

In this investigation, the main objective has been conducted to determine the effective of various curing methods on the physical properties of roller compacted concrete.

Experimental Program

Materials

- **Cement**

Ordinary Portland cement manufactured in Lebanon was used in all mixes in this investigation. Its chemical composition and physical properties were found to satisfy the limits of the Iraqi specification No.5/1984.

- **Aggregate**

Coarse aggregate

The coarse aggregate used in mixtures ranged from (4.75-19) mm; the aggregates were obtained from AL-Nibaai region.

Fine aggregate

A natural sand of maximum size 4.75mm was brought from AL-Ukhaider region with grading conforming to Iraqi specification No. (45)-1984, zone (2).

These types of aggregate were combined together, and in order to satisfy the requirement of the combined aggregate grading the final combination grading test results conform to the ACI 207-5R recommendation for combined grading of RCC as shown in Table (1).

- **Water**

Potable water was used throughout this investigation for mixing and curing.

Mixes ,mixing and preparation of specimen

Mixture proportions were performed in accordance with procedures outlined in ACI committee 207-5R-89. Many trial mixes were carried out to select suitable mix, the final mix had the following constituents.

Cement content= 250 kg/m^3, Water content =120.6 kg/m^3

Fine aggregate = 817.7 kg/m^3, Coarse aggregate= 1248 kg/m^3

The raw materials were dry mixed for about one minute, then the constituents were mixed wet before about three minutes until homogenous concrete was obtained (generally mixing time for RCC was initially set at 4 minutes)[11].

The specimens of RCC were prepared by using cylinder steel mould of size 150×300 mm for testing compressive strength, splitting tensile strength and modulus of elasticity and for the flexural strength prisms of 100*100*400mm was used.Soil compaction equipment was used automatically to compact the specimens for Proctor and C.B.R tests and then the concrete was placed in three equal layers if cylinder moulds were used and in two layers for prisms. Each layer received 56 blows according to ASTM D-1557 (Modified Proctor) test method. After casting, the moulds were covered with nylon sheet and then remolded for curing.

Curing

After remolding, RCC specimens for curing at (24 hrs) from casting were cured in the different methods which consist of:

1. continuous watering.
2. leaving the specimens in normal conditions.
3. sprinkling with water four times daily.
4. covering the specimens with wet burlap.
5. covering with nylon.
6. subjecting the specimens to alternating wetting and dryingcycles (Two days in water followed by two days in air).
7. using liquid membrane-forming compounds.

Experimental Tests

- **Compressive Strength Test**

The compressive strength was determined from cylinder of (150*300) mm specimen's according to ASTM C-39.

- **Splitting Tensile Strength Test**

The splitting tensile strength was carried out on cylinder of (150*300) mm specimen according to ASTM C-496 standard.

Splitting tensile strength (MPa) $=\frac{2P}{\pi DL}$

Where:

P: Maximum applied load (N).

D: diameter of cylinder (mm).

L: length of cylinder.

- **Flexural Strength Test (Modulus of Rupture)**

The flexural strength was determined by using (100*100*400) mm specimen and applying point loads at one-third span over a length of 300 mm according to ASTM C - 78.

Therefore the modulus of rupture was calculated using the following equation

$f_{r} = PL/_{bd^2}$

Where:

Fr: modulus of rupture (MPa).

P: maximum applied load (N).

L: span length (mm).

d: depth of the specimen (mm).

b: width of the specimen (mm).

- **Static Modulus of Elasticity**

The elastic modulus was obtained from unaxial compression tests and was carried out according to ASTM C-469.

- **Water Absorption**

The water absorption test was carried out according to B.S.-1881-Part-5-1970.

Result and Discussion

Compressive Strength

Table (2), and Figs (1) and (2) show the relationship between the compressive strength and age of the Roller Compacted Concrete specimens cured in different methods (Continuous Curing, Without Curing (Left under Laboratory Conditions), Sprinkling, Wet Burlap, Covering with Nylon, Alternate Wetting and Drying Cycle, and Curing Compound).

The results show also that there is no significant difference in compressive strength values until 3 days for all methods of curing; this may be due to the presence of water in the capillaries at early ages which help to continue the hydration process [(12)]. While at 28 days, there is a noticeable increase in the compressive strength for samples cured with continuous watering, and there is a difference in the trend of the compressive strength among other types of curing, where there is an increase in the compressive strength for samples cured with wet burlap greater than other types of curing. It can be noticed also that the compressive strength of the samples cured with curing compound membrane is the same as that of nylon curing. This is because of their performance similarity, which will effectively prevent evaporation of water from the concrete but will not allow ingress of water to replenish that lost by self-desiccation [(13).]

From the results, it is observed that the samples without curing result in permanent loss of strength at 28 days age of between 20 to 25% when compared with the continuous curing specimens. This higher percent may be due to very low mixing water content, thus heat of hydration of the cement quickly decreases from internal self desiccation[(14).] At 180 days age and more there is an increase of compressive strength in the RCC samples with all types of curing observed in comparison with RCC samples without curing, this increase was 55, 33, 56, 43, 38, and 42% for continuous watering, sprinkling, wet burlap, nylon, curing cycles, and curing compound, respectively. This is probably due to a continuous hydration process when new water becomes available.

The strengths of other curing methods expressed as percentage of water-cured strength, referred to as "strength ratio" is plotted in Fig (3).

Splitting-Tensile Strength

Figs (4) and (5) represent the relationship between splitting-tensile strength of RCC cured with different methods at 24 hours after casting and age,As can be seen from figures, the trends of curves are similar to that of compressive strength.

The splitting tensile strength at 180 days age increased by 54% thespecimens cured with continuous watering. over those of 28-day, 39 % for burlap, 50% for nylon curing, 39% for curing cycles, 41%for curing compound and36 % for sprinkling.

Flexural Strength (Modulus of Rupture)

The modulus of rupture (ultimate flexural strength) results of RCC specimens cured with different methods are plotted in Figs (6) and (7). From the results one can derive the following points:

1- At 180 day age, the flexural strength surpasses the 28-day results by 47% for continuous watering. 31 % for wet burlap, 33% for sprinkling, 32 % for nylon curing, 39 % for curing cycles, and 35 for curing compound.

2- The flexural/compressive strength ratio is in the average of 0.154, whereas the average of flexural/splitting tensile strength ratio is about 1.57. These results are in agreement with those of other studies on roller compacted concrete, which indicate that the flexural/compressive strength ratio ranges from 0.153 to 0.232, whereas the average flexural/splitting-tensile strength ratio was about 1.55 (10,15)

Static Modulus of Elasticity

Table (3.) shows the results obtained from static modulus of elasticity tests of Roller Compacted Concrete specimens. It can be noticed also that there is a noticeable increase in static modulus of elasticity for samples cured with continuous watering, and there is a difference in the trend of static modulus of elasticity among other curing methods, where there is an increase in static modulus of elasticity for samples cured with wet burlap greater than other curing methods.

It can be observed from this table that there is an increase of static modulus of elasticity in the RCC samples with all types of curing observed in comparison with RCC samples without curing, this increase was 21.6, 2.3, 9.5, 2.8, 1.8, and 2.3% for continuous watering, sprinkling, wet burlap, nylon, curing cycles, and curing compound, respectively. This is probably due to continuous hydration process leading to enhance the quality of paste.

Absorption

The results obtained from measurement of water absorption of RCC specimen are shown in Table (4). It can be seen that the percentage of the absorption for the specimens without curing is greater than that of other types of curing. This may be attributed to the internal cracking in the paste that results from drying, and this cracking contributes substantially to the continuity of the pore system leading to increase in absorption (11). While the lowest overall absorption is for the continuous watering specimens; this may be due to the fact that the continuous hydration of the cement results in gel development which reduces the size of the capillary pores and increases the water tightness of the concrete (13).From the results, it can be observed also that the specimens cured with curing cycles have higher percentage of absorption as compared with other types of curing (except without curing), where curing cycles may considerably impoverish water availability to hydration.

Conclusions

Based on the results and discussions, the following conclusions can be drawn:

1- Continuous water curing has substantially greater effect on compressive strength, splitting-tensile strength, modulus of rupture, and static modulus of elasticity of RCC specimens than other curing methods.

2- The specimens of RCC cured with wet burlap have higher strength than that cured with other curing methods (except continuous watering).

3- The specimens without curing (left in air) result in a permanent loss of strength of between 20 to 25% at 28 days when compared with the continuous curing specimens.

4- Generally the overall percentage of absorption remains in the range of 3.62 to 4.5%, the percentage of absorption specimens without curing is greater than other curing methods, the value is 4.5%.

5- The efficacy of curing compound method in improvement of properties of RCC was less than that of other methods.

Table (1) Grading of combined aggregates for RCC.

Sieve Size	%Passing	Limits according toACI 207-5R
25 mm	100	100
19 mm	96	82-100
12.5 mm	84	72-94
9.5 mm	69	66-84
4.75 mm	52	50-70
2.36 mm	47	38-56
1.18 mm	44	28-46
600 μm	40	18-38
300 μm	28	12-27
150 μm	14	6-18
75 μm	5	2-8

Table (2): Compressive Strength of RCC of Cured in Various Methods after 24 hours from casting

Curing Method	Compressive Strength (MPa)				
	3 days	7 days	28 days	90 days	180 days
Continuous Watering	8.1	12.7	17.7	19.24	23.36
Without Curing	7.3	11.52	14.35	14.9	15.03
Sprinkling	7	10.61	15	18.06	20
Wet Burlap	8.2	13.71	16.78	19.5	23.4
Nylon	8.5	12.48	15.03	19.27	21.5
Curing Cycles	8.28	12.3	14.8	18.54	20.74
Curing Compound	8.3	12.54	15	19	21.31

Table (3): Static Modulus of Elasticity of RCC of Cured in Various Methods after 24 hours from casting

Curing Method	Static Modulus of Elasticity (GPa) at 28 days
Continuous Watering	21.9
Without Curing	19.45
Sprinkling	19.9
Wet Burlap	21.3
Nylon	20
Curing Cycles	19.8
Curing Compound	19.9

Table (4): Absorption of RCC Cured in Various Methods after 24 hours fromcasting

Curing Method	Absorption (%) at 28 days
Continuous Watering	3.8
Without Curing	4.5
Sprinkling	3.92
Wet Burlap	3.9
Nylon	4
Curing Cycles	4.2
Curing Compound	3.62

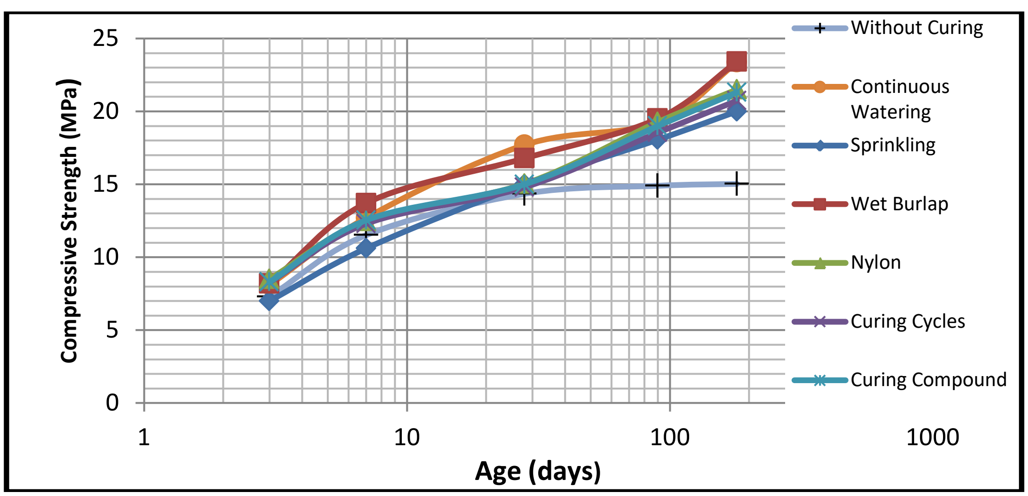

Figure (1): Compressive strength of RCC cured in various methods (24 hours after casting)

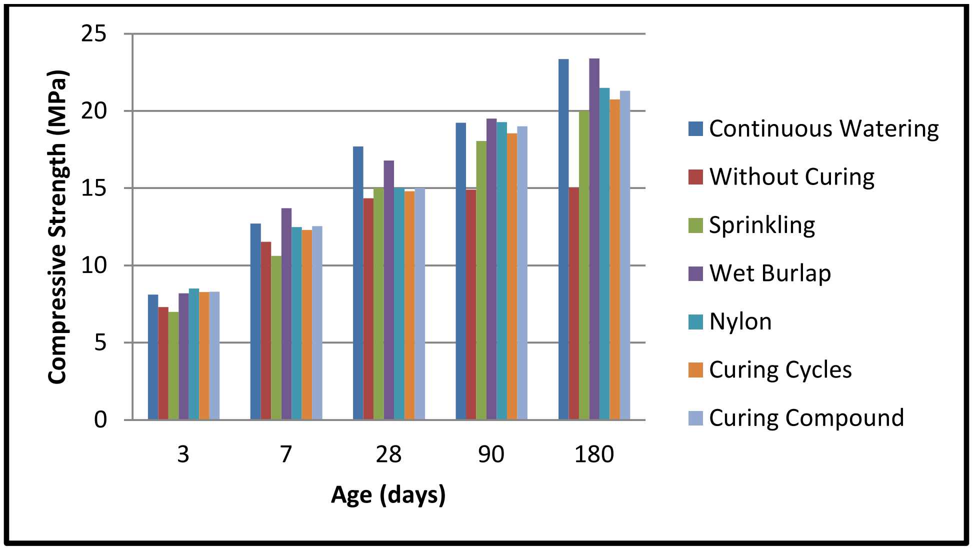

Figure (2): Effect of curing on the compressive strength of RCC cured in various methods (24 hours after casting)

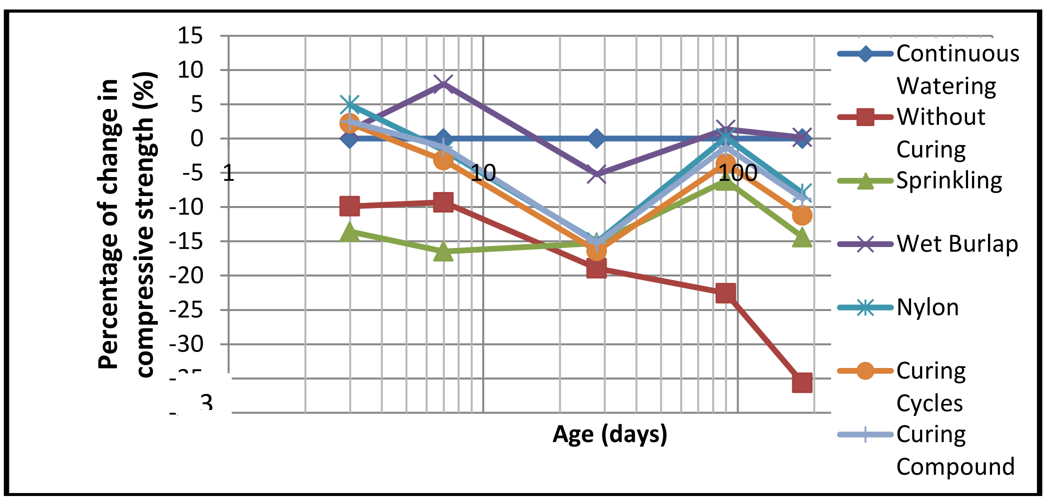

Figure (3): Compressive strength of all types of curing as a percentage of the continuous watering curing RCC specimen

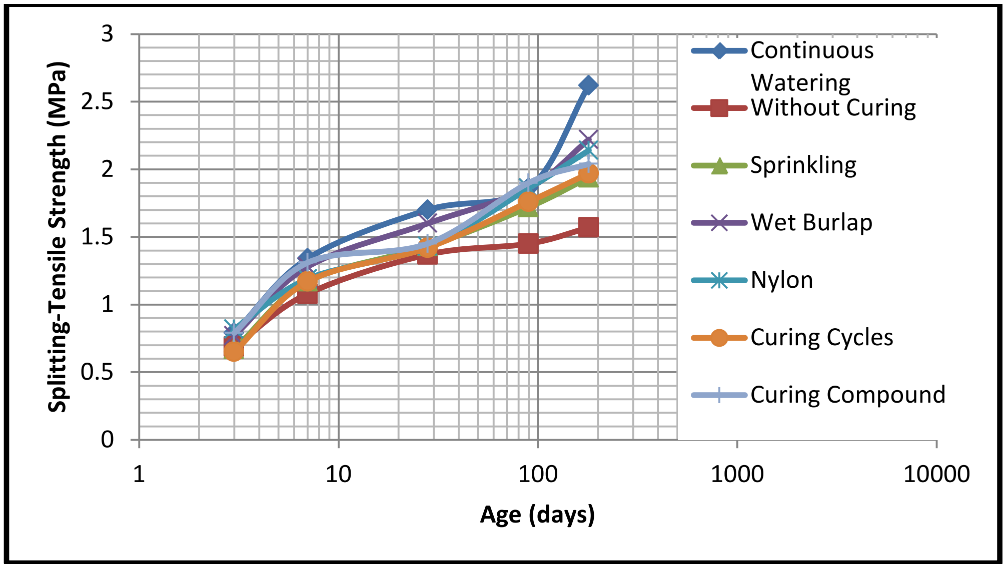

Figure (4): Relationship between splitting-tensile strength of RCC cured in various curing methods and age

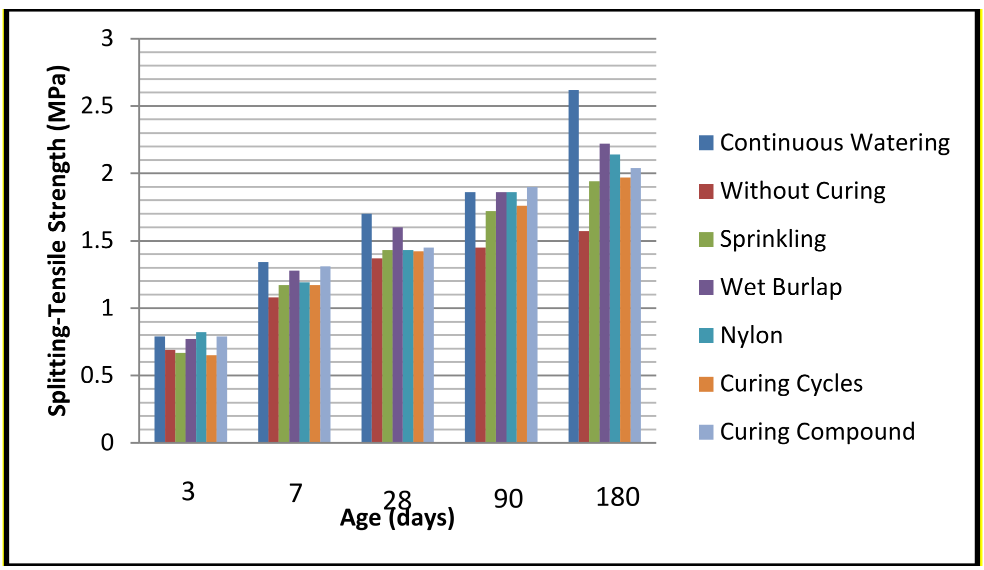

Figure (5): Effect of curing on the splitting-tensile strength of RCC of cured in various methods (24 hours after casting)

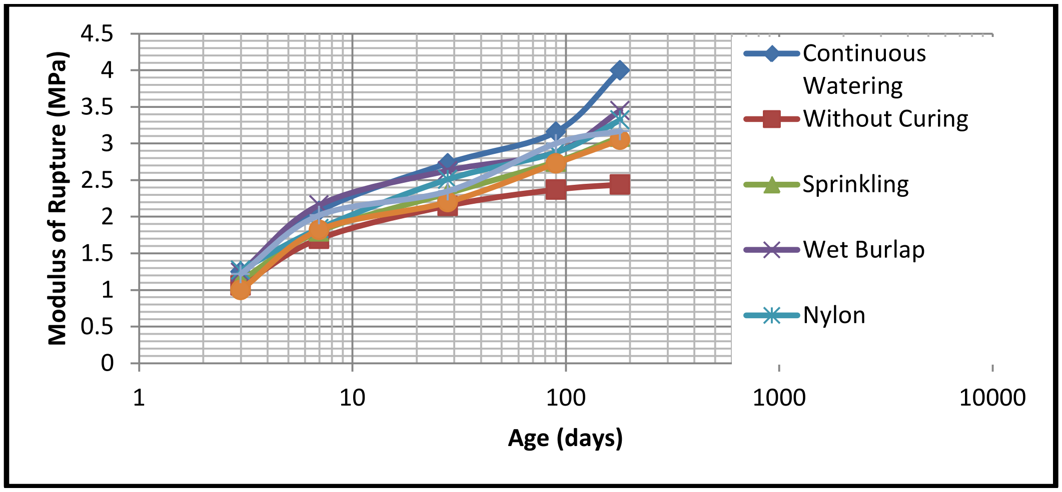

Figure (6): Effect of various curing methods on the modulus of rupture of RCC specimen

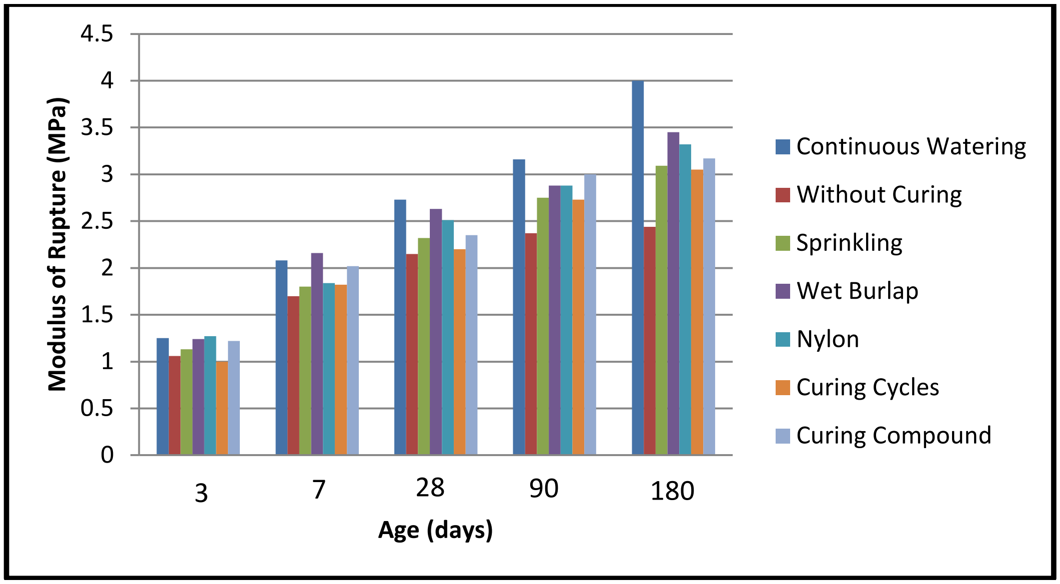

Figure (7): Effect of curing on the modulus of rupture of RCC cured in various methods (24 hours after casting)

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