# Laboratory Investigation on Roller Compaction Technique in Concrete Construction

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## ABSTRACT

Roller compacted concrete (RCC) is a concrete compacted by roller compaction. The concrete mixture in its unhardened state must support a roller while being compacted. The aim of this research work was to investigate the behavior and properties of roller compacted concrete when constructed in the laboratory using roller compactor manufactured in local market to simulate the field conditions. The roller compaction was conducts in three stages; each stage has different loading and number of passes of the roller. For the first stage, a load of (24) kg and (5) passes in each direction had been employed. For the second stage, a load of (104) kg and (10) passes in each direction were conducted. Finally, at the third stage, a load of (183) kg and (15) passes were adopted. Such procedure was in accordance to previous work conducted by the author. The effects of the type of coarse aggregate (crushed and rounded), fine aggregate (river and natural) and cement type (OPC and SRPC) on the mechanical properties of RCC were investigated. The effect of compaction method on compressive strength and indirect tensile strength was also discussed. A total of (26) roller compacted concrete slab samples of (380×380×100 mm) were prepared in the laboratory, Then, the slab specimens are taken out of the molds and immersed in the curing tank for (28) days. Core and Beam specimens were obtained from the slab samples for the determination of mechanical properties. Such properties include compressive, indirect tensile, flexural strengths using one point loading. It was concluded that the compressive strength of RCC using crushed aggregate is higher than that when using rounded aggregate in a range of (15-66) % for core specimens, while the compressive strength of RCC when using river sand is higher than that when using natural sand in a range of (9-26)% for core specimens. When river sand is implemented, RCC samples show higher indirect tensile strength than those with natural sand, such variation is within (7-8) %.

**Keywords:** roller compacted concrete, dense gradation, compressive strength, splitting tensile strength, flexural strength.

**المستخلص**

الخرسانة المرصوصة بالحدل تتمثل بكونها خرسانة ترص بالحادلات المدولبة حيث الخلطة الخرسانية في حالتها غيرالمتصلبة يجب ان تكون قادرة على تحمل حمل اسطوانة الحدل اثناء الرص. ان الغرض من هذا البحث هو التحري عن سلوك وخواص الخرسانة المرصوصة بالحدل تم تصنيعها مختبريا بأستخدام جهاز حدل صنع في الاسواق المحلية يشابه في هيكليته هيكلية الحادلة في الموقع من اجل ايجاد ظروف مشابه للظروف الطبيعية الموقعية. عملية الحدل تمثلت بثلاثة مراحل رئيسية كل مرحلة لها وزنها وعدد مرات مرور الحادله الخاصه بها حيث المرحلة الأولى كانت بوزن (٢٤) كغم وبعدد مرات مرور (٥) والمرحلة الثانية بوزن (١٠٤) كغم وبعدد مرات مرور (١٠) واما المرحله الأخيرة فكانت بوزن (١٨٣) كغم وبعدد مرات مرور (١٥). وقد كانت اتجاه الحدل بأتجاهين من اجل التخلص من المناطق الغير مرصوصة ولكل اتجاه ثلاثة مراحل رئيسية .تم اعتماد هذه الطريقة في الحدل استنادا لدراسة سابقة من قبل الباحث. تم دراسة تأثير نوع الركام الخشن (المكسر - المدور), نوع الركام الناعم (النهري- الطبيعي) ونوع السمنت المستخدم (العادي – المقاوم للكبريتات) على خواص الخرسانة المرصوصه بالحدل كما وتم اجراء مقارنة بين نتائج الخواص الميكانيكية (مقاومة الانضغاط ومقاومة الشد غيرالمباشر) لكل من النماذج التي تم رصها بواسطة المطرقه القياسيه وبين نماذج تم رصها بواسطة جهاز الحدل. تضمن الجزء العملي تهيئة (٢٦) بلاطة خرسانيه مرصوصه بالحدل بأبعاد (٣٨٠×٣٨٠×١٠٠ ملم) وتم استحصال النماذج والتي تتمثل (اللباب والاعتاب) من اجل اجراء الفحوص الخاصة بالخواص الميكانيكية. ان الخواص الفيزيائية للخرسانة المرصوصه بالحادلة المطلوبة في البحث هي مقاومة الانضغاط، مقاومة الشد غير مباشر (الأنشطار)، مقاومة الأنثناء (بنقطة تحميل واحدة). تم الاستنتاج بان مقاومة الانضغاط للخرسانة المحدولة تون اعلى عند استخدام الركام المكسر عند مقارنتها بالركام المدور وبما يتراوح مابين (15-66)% لعينات اللباب، بينما ادى استخدام الرمل التهري الى ارتفاع مقاومة الانضغاط بمعدل (9-26)% للخرسانة المحدولة عن تلك التي استخدم فيها الرمل الطبيعي. عند استخدام الرمل النهري لوحظ ارتفاع في مقاومة الشد غير المباشر بمقدار (7-8)% للخرسانة المحدولة عن تلك المقاومة عند استخدام الرمل الطبيعي.

## INTRODUCTION

Roller-compacted concrete (RCC) is a lean no-slump, minimal shrinkage, almost dry concrete that is compacted in place by vibratory roller. RCC is a mixture of aggregates, cement and water. Supplementary cementing materials such as fly ash can also be used. Cement contents range from 60 to 360 kg per cubic meter. Mixing is done with conventional batch mixers, continuous mixers, or in some instances tilting-drum truck mixers, **(Kosmatka and Kerkhoff, 2002)**.

Roller compacted concrete is placed in layers thin enough to allow complete compaction, the optimum layers thickness ranges from 20 to 30 cm to ensure adequate bonding between the new and old layer or at construction joint, segregation must be prevented and high plasticity bedding mix must be used at the start of the placement, **(Shetty, 2009).** For effective consolidation, roller compacted concrete must be dry enough to support the mass of the vibrating equipment, but wet enough to allow the cement paste to be evenly distributed throughout the mass during mixing and consolidation process **(PCA, 2006)**.

In Japan, **Mamlouk and Zaniewski, (1999)** use RCC in construction. They find several advantages. These were:

1- The mix is economical because of the low cement content.
2- Formwork is minimal because of the layer construction method.
3- The low cement factor limits the heat of hydration, reducing the need for external cooling of the structure.
4- The placement costs are lower than conventional concrete methods due to the use of high-capacity equipment and rapid placement rates.
5- The construction period shorter than conventional concrete

## MATERIAL CHARACTERISTICS

### 1. Cement

Both ordinary Portland cement (OPC) and sulfate resisting cement (SRPC) manufactured in Iraq with a commercial name of (Tasluga, Al-jesser) are used for RCC mixes throughout the present work. This cement complied with the Iraqi specification **(IOS, No.5:1984).** Testing of cement is conducted in the National Center for Construction Laboratories and research. The physical properties and chemical analysis of the cement used are given in the **Tables (1)** and **(2)**.

### 2. Aggregate

#### 2.1 Coarse Aggregate

Two types of coarse aggregate (crushed and rounded) are used from Al-Nibaii in Iraq with a nominal size of (19 mm). The gravel is sieved through sieve size of (25 mm). The properties of two types of aggregate are shown in **Tables (3)**.

#### 2.2 Fine Aggregate

Two types of fine aggregates, (passing sieve No.4 BS.) natural sand (N.S) from Al-Akhaider in Iraq and river sand (R.S) from Toz-khirmato are used for RCC mixes. The fine aggregate is sieved through sieve size (9.5 mm) to separate the aggregate particles of diameter greater than (9.5mm). The physical properties and chemical properties of the sand for two types are listed in **Table (4).**

The desired weight of each size of aggregate is taken and combined to obtain the required gradation. The design over all gradation of aggregate is selected by using (**SCRB, 2004**) dense gradation usually used for asphalt concrete pavement in Iraq. **Table (5)** illustrates the combined gradation used throughout the investigation.

## DETIALS of EXPERIMENTAL WORK

### 1. Casting Molds preparation

All the slab test specimens used in this investigation are cast in steel molds to obtain a slab specimen having size of (380×380 mm) and a total depth of (100 mm) as shown in **Figure (1).**

### 2. Apparatus Description

The apparatus consists of steel skeleton as shown in **Figure (2).** It is designed to simulate steel roller which is usually used in the site for compaction. A solid cylinder 150 mm diameter, 360 mm in length and 15 kg in weight is fixed to the chase by two ball bearings to allow movement of the roller during compaction. The total weight of this apparatus is 24 Kg. It is supplied with a container capable of supporting standard steel weights up to (183 Kg).

### Mix Design and Proportions

The concrete mix is designed according to **(ASTM D-1557)** standard. This proportioning method involves establishing a relationship between the density and moisture content of the mix by compaction of the mix in steel molds of (101.6 diameter × 116.4 high mm). A moisture-density test is used to determine the optimum

moisture content and maximum density of RCC mixtures for each mix as shown in **Figures (3-a), (3-b).** Five different percentages of cement content are used (10, 12, 14, 16, 18) by weight of oven dried aggregate and six different percentages of moisture content of a range of ( 4-8%) with 1% increment are used to determine the dry density-moisture content relationships. The types of mixes are shown in **Table (6)** After mixing thoroughly, the materials are placed by filling these cylinders in five layers and compacting each layer with (25) blows of a modified Proctor hammer (4.5 kg) falling from (450 mm) height according to (**ASTM D-1557)** (modified proctor) test method. A total of 48 cylinder samples of size (100 diameter × 115 high mm) were prepared by using hammer compaction.

## COMPACTION

Compaction is achieved by placing the slab mold on vibrating table. The slab mold is subjected to three cycles of (8 seconds) vibration for each. The influence of this compaction is to create some initial compactive effort to the freshly laid surface, which is usually the case when using paving machine; then, the concrete mix is compacted using a roller device as shown in **Figure (4).**The design of rolling process is conducted in three stages after many trials on slab samples to obtain the designed dry density. The rolling sequence was in accordance to that adopted by **Sarsam (2002).** At the first stage, a total load of (0.66 kg/cm width) is implemented with five passes of the roller. The concrete is settled in a level position and completely fill the slab mold and gives a level surface. This can represent the initial compaction in the field. At the second stage, the load is increased to (2.9 kg/cm width) with ten passes, in each direction. This may simulate the intermediate field compaction. At the final stage, the load is further increased to (5 kg/cm width) with 15 passes of the roller, each horizontal direction was subjected to (15) passes. This represents the finishing compaction in the field. At this stage, the slab surface is smooth and level. For other parameters the number of passing of the roller are changed to determine the variations of the mechanical properties of RCC with number of passing.

## Obtaining Drilled Cores, Sawed Beams and Cubes

A total of (26) samples were constructed using the roller device. **Figure (5)** shows part of the slabs obtained. The coring process (Hilti Diamond Coring System DD-250EE) is carried out according to **(ASTM C42-03),** set perpendicular to the laid surface of the RCC. The cylinders are cored from the slabs using a 72 mm diameter diamond core bit. Wet concrete diamond sawing process is used to cut the slabs to obtain beams and cubes. A total of 96 core specimens of (60 diameter × 100 high mm) are obtained from slabs specimens, 80 cubes of (100×100×100 mm) are also obtained from slab specimens, and 80 beams of (70×100×380 mm) are also obtained from slabs specimens, using mechanical diamond saw. **Figures (6), (7)** Shows part of the samples obtained.

## Testing Hardened Concrete

### 1. Compressive Strength

Compressive strength test is carried out according to **(ASTM C-39 -01),** using a digital testing machine with a capacity of (2000 kN). Two core specimens of (60 diameter × 100 high mm) are tested from each mix. The compressive strength is then calculated by using **equation (1)** as follows:

$$\sigma = P/A \qquad (1)$$

Where;
σ: Compressive strength, MPa
p: Maximum applied load,(N)
A: Surface area, ($mm^2$).

### 2. Splitting Tensile Strength

Splitting tensile strength test is carried out according to **(ASTM C496-96),** using a digital testing machine with a capacity of (2000 kN). Two core specimens of (60 mm diameter ×100 mm height) are obtained from each mix, for the determination of splitting strength. The average of two test specimens is taken. The splitting tensile strength is then calculated by using **equation (2)** as follows:

$$f_{sp} = 2p/ \pi DL \qquad (2)$$

Where;
$f_{sp}$: Splitting tensile strength, (MPa)
p : Maximum applied load,(N)
D: Diameter of concrete cylinder, (mm)
L: Length of concrete cylinder, (mm)

### 3. Flexural Strength

The flexural strength test is carried out according to (**ASTM C78- 02).** The flexural strength of (380×100×70 mm) beam specimens is determined by applying point loads at one-third span over a

length of (380 mm).The flexural strength is then calculated by using **equation (3)** as follows:

$F_r = PL/bd^2$ (3)

Where;
Fr = modulus of rupture, (MPa)
P= maximum applied load, (N)
L= span length, (mm)
d= depth of the specimens, (mm)
b= width of the specimens, (mm).

## Result and Discussions

### 1. Compressive Strength

**Figure (8)** show the relationship between compressive strength and cement content of crushed and rounded aggregates for core specimens. When crushed aggregates are implemented higher compressive strength is obtained for all range of cement content. When core specimens are tested, 16% cement shows compressive strength higher than that of rounded aggregate by a range of (18-51) %. **Figure (8)** show the relationship between compressive strength and cement content of ordinary and Sulphate resisting Portland cement for core specimens. These results show that the compressive strength when used Sulphate resisting Portland cement work better in RCC mixes rather than when use ordinary Portland cement, when Sulphate resisting Portland cement are implement high compressive strength could be obtained for all of the cement percentage used, when core specimen were tested, 16% cement shows of compressive strength higher than that of ordinary Portland cement by a range of (24-29) %. **Figure (9)** show the relationship between compressive strength and cement content of river and natural fine aggregate for core specimens. These results show that the compressive strength when used river sand typically work better in RCC mixes rather than when use natural sand, when river sand is implement high compressive strength was obtained for all of the cement percentage used, when core specimen are tested, 16% cement shows of compressive strength higher than that of natural sand by a range of (8-18) %. Such result agrees well with Sarsam (2002) findings.

### 2. Splitting Tensile Strength

**Figure (10)** shows the relationship between the splitting tensile strength and cement content of crushed and rounded aggregates for core specimens. It is clear from the test results that the splitting tensile strength for crushed aggregate show superior tensile strength when compared with rounded aggregate. **Figure (11)** shows the relationship between the splitting tensile strength and cement content of ordinary and Sulphate resisting Portland cement for core specimens.
It is clear from the test results that the splitting tensile strength for Sulphate resisting Portland cement show superior tensile strength when compared with ordinary Portland cement. **Figure (12)** shows the relationship between the splitting tensile strength and cement content of river and natural fine aggregates for core specimens. It is clear that the splitting tensile strength for river sand show superior tensile strength when compared with natural sand.

### 3. Flexural Strength

**Figure (13)** present the relationship between flexural strength and cement content for center point loading of crushed and rounded coarse aggregates. Flexural strength of crushed aggregate shows higher values than rounded aggregate. When testing beam specimens under center point loading with 16% cement, the flexural strength was higher than of rounded aggregate by a range of (30-50) %. **Figure (14)** show the relationship between Flexural strength and cement content for center point loading of ordinary and Sulphate resisting Portland cement. Flexural strength of Sulphate resisting Portland cement shows higher values than ordinary Portland cement. When Sulphate resisting Portland cement is implementing, high flexural strength could be obtained for all range of cement content. When testing beam specimens by center point loading with 16% cement, shows of flexural strength higher than of ordinary Portland cement by a range of (26-34) %. **Figure (15)** shows the relationship between Flexural strength and cement content for center point loading of river and natural fine aggregates respectively. Flexural strength of river sand show higher values than natural sand. When river sand are implement, high flexural strength could be obtained for all of the cement percentage used, when beam specimens were tested by center point loading with 16% cement, shows of flexural strength higher than of natural sand by a range of (6-16) %. Such result agrees well with Sarsam (2002) findings.

## CONCLUSIONS

The following conclusions can be drawn out of the experimental work of the present study.

1- The percentage of 16% for cement content is the ratio for the best rates to another 10%, 12% that was used in the various mixtures that were used which gave better results in terms of compressive, splitting tensile and flexural strength.

2- The compressive strength of RCC using crushed aggregate is higher than of using rounded aggregate in a range of (15-66) % for core specimens.

3- The compressive strength of RCC when using river sand is higher than when using natural sand in a range of (9-26)% for core specimens.

4- Sulphate resisting cement shows higher compressive strength than ordinary Portland cement. Such variations are within (40-50) % for core specimens.

5- The indirect tensile strength for RCC when crushed aggregates are implemented is higher than that when using rounded aggregates, such variations are within (10-32) %.

6- When river sand is implemented, RCC samples show higher indirect tensile strength than those with natural sand, such variation is within (7-8)%.

7- When Sulphate resisting cement is implemented, RCC samples show higher indirect tensile strength than those with ordinary Portland cement, such variation is within (51-56) %.

8- The flexural strength of RCC using crushed aggregate is higher than that with using rounded aggregate in a range of (30-50) % for center point loading.

10- The flexural strength of RCC using river sand is higher than that when using natural sand in a range of (0-4) % for center point loading.

11- The flexural strength of RCC when using Sulphate resisting cement is higher than that with using ordinary Portland cement in a range of (26-34) % for center point loading.

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**Table (1) Physical properties of cement**

| Physical Properties | Test Result | | IQS (No.5:1984) limits | |
|---|---|---|---|---|
| | O.P.C | S.R.P.C | O.P.C | S.R.PC |
| Specific Surface area, Blaine method, $m^2/Kg$ | 258 | 357 | ≥230 | ≥ 250 |
| Setting time, Vicat Method<br>Initial setting , hr : min<br>Final setting , hr : min | 2:35<br>4:45 | 1:30<br>4:10 | ≥ 45 minutes<br>≤ 10 hours | |
| Compressive strength MPa<br>3-days<br>7-days | 15.8<br>20.3 | 18.3<br>23.8 | ≥15<br>≥23 | |

**Table (2) Chemical composition of cement**

| Oxide | Percentage (%) | | IQS (No.5:1984) limits | |
|---|---|---|---|---|
| | O.P.C | S.R.P.C | O.P.C | S.R.P.C |
| Cao | 55 | 60.63 | ----- | ----- |
| $SiO_2$ | 18.33 | 21.63 | ----- | ----- |
| $Fe_2O_3$ | 3.28 | 4.76 | ----- | ----- |
| $Al_2O_3$ | 5.88 | 4.19 | ----- | ----- |
| MgO | 1.93 | 2.72 | ≤ 5 | ≤ 5 |
| $SO_3$ | 1.87 | 2.04 | ≤ 2.8 | ≤ 2.5 |
| L.O.I | 2.36 | 1.94 | ----- | ----- |
| I.R | 0.15 | 0.92 | ≤ 1.5 | ≤ 1.5 |
| L.S.F | 0.89 | 0.86 | 0.66-1.02 | 0.66-1.022 |
| Compound Composition | Percentage (%) | | IQS (No.5:1984) limits | |
| $C_3S$ | 35 | 42.6 | ----- | ----- |
| $C_2S$ | 26.21 | 29.95 | ----- | ----- |
| $C_3A$ | 10.03 | 3.06 | ----- | 3.5 |
| $C_4AF$ | 9.97 | 14.47 | ----- | ----- |
| $C_3S/C_2S$ | 1.35 | 1.42 | ----- | ----- |

**Table (3) Properties of coarse aggregate**

| properties | Test results | | IQS (No.5:1984) limits |
|---|---|---|---|
| | crushed | rounded | |
| Sulphate content $SO_3$ (%) | 0.08 | 0.08 | ≤ 0.1 |
| Specific gravity | 2.68 | 2.63 | ----- |
| Absorption (%) | 1 | 1.5 | ----- |

**Table (4) Properties of fine aggregate**

| Properties | Test results | | IQS (No.5:1984) limits |
|---|---|---|---|
| | Natural sand | River sand | |
| Sulphate content $SO_3$ (%) | 0.45 | 0.1 | ≤ 0.5 |
| Specific gravity | 2.42 | 2.6 | ----- |
| Absorption (%) | 3.31 | 2.25 | ----- |

**Table (5) Combined gradation used for RCC, Sarsam(2002)**

| Sieve Size (mm) | % Finer by weight |
|---|---|
| 25.4 (1 inch) | 100 |
| 19.0 (3/4 inch) | 100 |
| 12.5 (1/2 inch) | 85 |
| 9.5 (3/8 inch) | 76.5 |
| 4.75 (No. 4) | 62.5 |
| 0.3 (No.50) | 26.5 |
| 0.075 (No. 200) | 9 |

**Figure (1) Molds details of slab specimens**

**Figure (2) General view of apparatus**

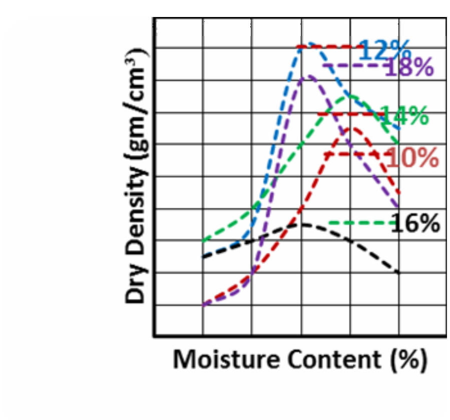


**Figure (3-a) Dry density-moisture content relationship, natural sand and OPC for different cement content**

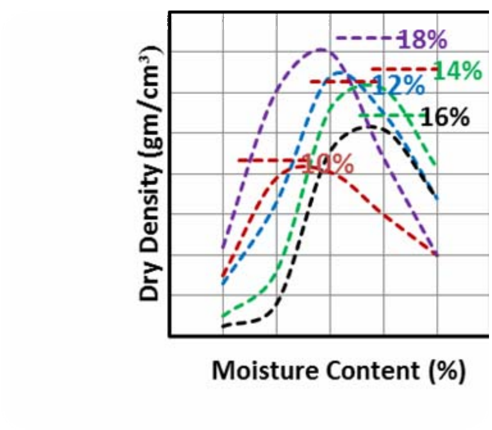


**Figure (3-b) Dry density-moisture content relationship, natural sand and OPC for different cement content**

**Table (6) Design mixes implemented**

| Mix Symbol | Type of Mixes |
|---|---|
| Crushed-1 | Crushed Aggregate + River Sand + Ordinary Portland cement |
| Crushed-2 | Crushed Aggregate + Natural Sand + Ordinary Portland cement |
| Rounded-1 | Rounded Aggregate + River Sand + Ordinary Portland cement |
| Rounded-2 | Rounded Aggregate + Natural Sand + Ordinary Portland cement |
| River-1 | Rounded Aggregate + River Sand + Ordinary Portland cement |
| River-2 | Rounded Aggregate + River Sand + Sulphate Resisting Portland cement |
| Natural-1 | Rounded Aggregate + Natural Sand + Ordinary Portland cement |
| Natural-2 | Rounded Aggregate + Natural Sand + Sulphate Resisting Portland cement |
| Ordinary-1 | Crushed Aggregate + River Sand + Ordinary Portland cement |
| Ordinary-2 | Crushed Aggregate + Natural sand + Ordinary Portland cement |
| Sulphate-1 | Crushed Aggregate + River sand + Sulphate Resisting Portland cement |
| Sulphate-2 | Crushed Aggregate + Natural sand + Sulphate Resisting Portland cement |

**Figure (4) Casting and compaction in process**

**Figure (5) Slab samples constructed**

**Figure (6) Core specimens obtained**

**Figure (7) Beam specimens obtained**

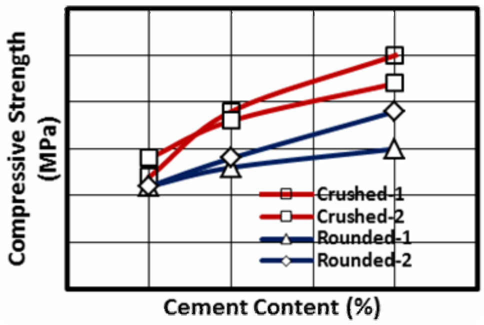


**Figure (8) Variation in compressive strength**

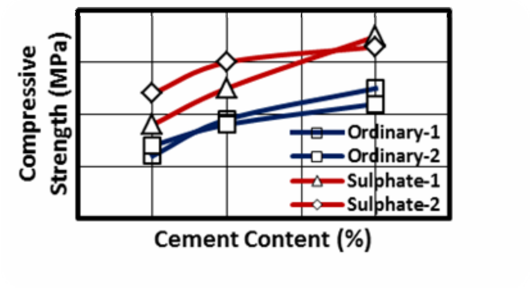


Figure (9) Variation in compressive strength with cement content using (O.P.C) and(S.R.P.C) for core specimens

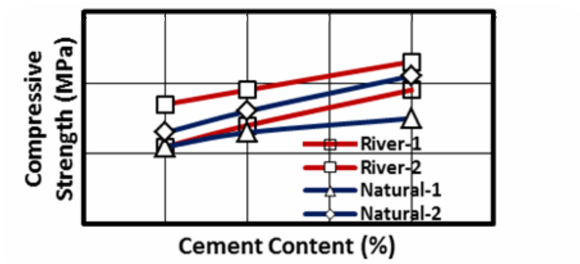


Figure (10) Variation in compressive strength with cement content using river and natural sand for core specimens

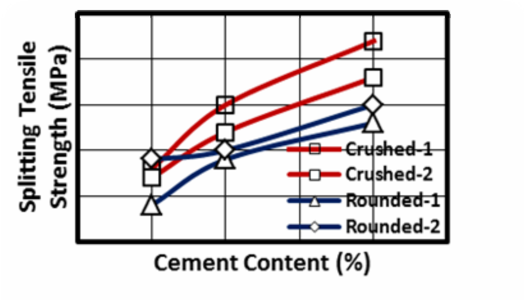


Figure (11) Variation in splitting tensile strength with cement content using crushed and rounded aggregates for core specimens

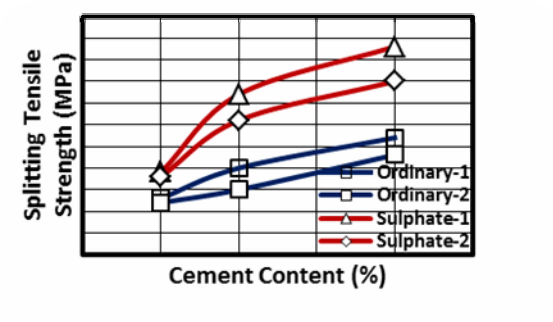


Figure (12) Variation in splitting tensile strength with cement content using (O.P.C) and (S.R.P.C) for core specimen

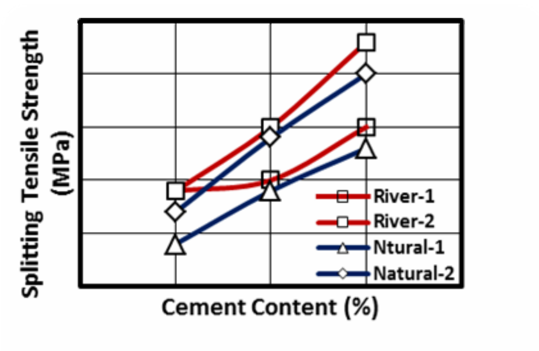


Figure (13) Variation in splitting tensile strength with cement content using river and natural sand for core specimens

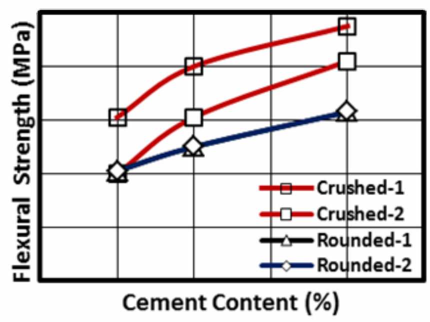


Figure (14) Variation in flexural strength with cement content using crushed and rounded aggregates for center point loading

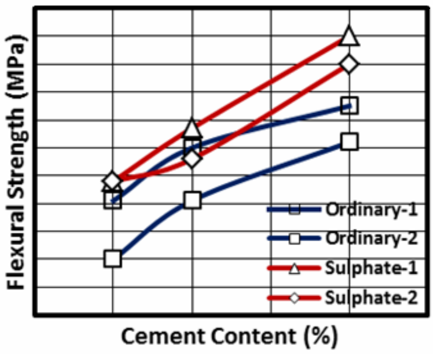


**Figure (15) Variation in flexural strength with cement content using (O.P.C) and (S.R.P.C) for center point loading**

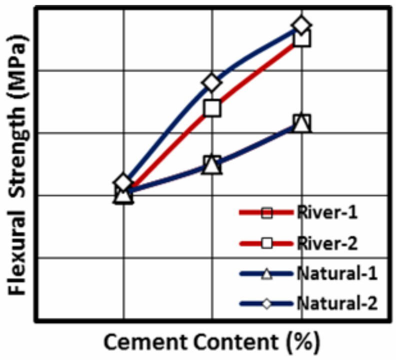


**Figure (16) Variation in flexural strength with cement content using river and natural sand for center point loading**