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Mechanical Properties for VHPC by (2:1 Proportion Method) as a New Method

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الملخص العربى :

تهدف هذه الدراسة إلى إنتاج VHPC للخرسانة عالية الأداء بدون أي مواد مضافة، فقط المواد الأساسية للخرسانة بالإضافة إلى الملدن المتفوق. حيث يتم تحقيق ذلك عن طريق استنباط مزيج أكثر كثافة مع محتوى منخفض من نسبة الأسمنت المائي مع الحفاظ على قابلية التشغيل والمتانة. تم استنباط طريقة جديدة من خلال العديد من التجارب تسمى (طريقة النسبة 2:1).يتمثل مفهوم طريقة النسبة 2: 1 في تحضير مزيج أكثر كثافة مع أحجام حبيبات الركام المتدرجة جيدا من الناعم إلى الخشن للحصول على VHPC بدون أي مواد مضافة ذات محتوى منخفض من نسبة الماء الي الأسمنت w / c في حدود 0.25 وكانت نسبة الملدن الى الاسمنت 1.34%. عند تطبيق(طريقة النسبة 2:1)، تم الحصول على كثافة عالية للخرسانة وصلت إلي 2550 كجم / م3.أدت هذه الكثافة العالية إلى تحسين الخصائص الميكانيكية للخرسانة حيث طورت مستو أداء الخرسانة من خرسانة عالية الأداء إلى مستوى عالي جدا في الأداء. عندما يتم تطبيق (طريقة النسبة 2:1) تم الحصول على متانة عالية (نفاذية 8 مم) وإجهاد ضغط أعلي من 100 ميجا باسكال، وإجهاد شد غير مباشر حوالي 6.5 ميجا باسكال، ومعامل مرونة 40 جيجا باسكال، ومعامل نشوة 10 ميجا باسكال بعمر 28 يوما.

Abstract

This study aimed to produce Very High-Performance Concrete VHPC without any additive materials, only the concrete basic materials in addition to Superplasticizer. This was achieved by making a very dense mix with low content water-cement ratio and keeping the workability and durability as they are. After too many mixed trials, a new method was adopted and called (the 2:1 Proportion Method). The concept of the 2:1 Proportion Method was to prepare a very dense mix with well-graded grain sizes from fine to coarse aggregates to get VHPC without any additive materials with low content of w/c ratio which was 0.25 and SP/c ratio was 1.34%. When applying the 2:1 Proportion Method, concrete with a density of about 2550 kg/m3 was obtained. The high density improved the mechanical properties of the concrete which developed the concrete from a High-Performance Concrete HPC level to a Very High-Performance Concrete VHPC level. When applying (the 2:1 Proportion Method), a highly Durable concrete could be obtained (Permeability of 8mm), At least, concrete with a

Compressive Strength of about 100 MPa, an Indirect Tensile Strength of 6.5 MPa, a Modulus of Elasticity of 40 GPa, and Modulus of Rapture of 10 MPa at age of 28 days could be obtained.

Keywords : HPC, VHPC, Density, Modulus of Elasticity, Modulus of Rapture.

1. Introduction

The global construction industry uses approximately 1.6 billion tons of cement and 10 billion tons of sand, gravel, and crushed rock annually [1]. And it will increase as the population increases. This statistic led Ecocem, 2011 to say that "concrete is the second most widely consumed resource in the world after water" [2]. Since the discovery of concrete, it has been the most common construction material extensively used in buildings, roads, bridges, and dams around the world. With the rapid development in the twenty-first century, civil engineers continue to adopt new construction materials to build higher, stronger, more durable, and aesthetic structures [3]. According to Holland (1993), "high-performance concrete possesses high strength, high durability, increased workability, high modulus of elasticity, and low permeability". These characteristics are derived from the benefits of using additives in combination with chemical admixtures, chemical contribution takes place mainly by acting as an efficient pozzolanic material which enables even distribution and higher volume of hydration products [4]. UHPC has significant advantages over normal concrete and high-performance concrete (HPC) in both strength and durability; the compressive strength of conventional concrete (C.C) is typically less than 50 MPa whereas the corresponding value for HPC is in the range of 50 to 100 MPa where the compressive strength in UHPC in the range of 120 to 150 MPa, capillary porosity as low as 1.5 percent and absence of interconnected pores that permit migration of water and chlorides [5]. According to DIN 1045-1 (DIN EN 206-1, 07.2001), ACI 318 (ACI 318R-02, 2003), and ACI 363 (ACI 363R-92, 2003), the compressive strength is classified as follows [6,7,8]:

1) Normal Strength Concrete (NSC) up to B 41/60 Mpa.
2) High Strength Concrete (HSC) B 41/60 to B 70/90 Mpa.
3) Very High Strength Concrete (VHSC) B 70/90 to B 120/150 Mpa.
4) Ultra High Strength Concrete (UHSC) B120/150 to B200/250 Mpa.
5) Super High Strength Concrete (SHSC) from B 200/250 Mpa.

2. Constituent Materials

The constituent materials needed to produce the **VHPC** mix are ordinary Portland cement, water, aggregate, and Superplasticizer. The coarse aggregate (Basalt type) size ranges from 2.36 mm to 19 mm and the fine aggregate ranges from 0.075mm to 2.36mm Where that material was tested and met the standard specification ASTM [9] as shown in (**table 1)**.

Table 1. Shows the Constituent Materials for the sample mix.

Item	Test	Tools	Mean Value
Cement Type	**Egyptian Cement (Cem type I) 52.5 R**		
Fineness	Blain	Device	3410 cm2/gr.
Setting times	Vicat	Device	Initial 110 min, Final 200 min.
Compressive Strength	Compression	Machine	54 MPa at 28 days.
Specific Gravity	Manufacturer Data		3.15
Water Type	**Drinkable Water**		
Coarse Aggregates Type	**(SEN 2 – SEN 1 – Fine) Basalt (BA)**		
Fineness Modulus (FM)	Analysis	Sieves	6.92
Specific Gravity	Specific Gravity	Basket	2.76
Absorption	Absorption	Oven	0.55 %
Abrasion and Impact	Los Angeles	Machine	18.72 %
BA SEN-2	**Grading Grain size**		**10 mm to 19 mm**
BA SEN-1	**Grading Grain size**		**4.75 mm to 9 mm**
Fine-BA	**Grading Grain size**		**2.36 mm to 4.75 mm**
Fine Aggregates Type	**(Sand – Powder)**		
Fineness Modulus (FM)	Analysis	Sieves	2.33
Specific Gravity	Specific Gravity	Lab Tube	2.64
Absorption	Absorption	Oven	1.35 %
Sand	**Grading Grain size**		**0.3 mm to 2.36 mm**
Powder	**Grading Grain size**		**0.075 mm to 0.3 mm**
Superplasticizer Type	**Egyptian Sika ViscoCrete® 3425**		
Specific Gravity	Manufacturer Data		1.08 – 1.09

3. aterials proportion according to the (2:1 Proportion Method).

Too many mixes were done (more than 1500 trial mixes), which lead to knowing a new method obtained for the proportion of materials called **(the 2:1 Proportion Method).**
The 2:1 Proportion Method concept is to prepare a **very denser** mix with well-graded grain sizes from fine to coarse to get up **VHPC** without any additive materials, except a superplasticizer added to the basic concrete materials with low content of w/c ratio which was **0.25**.

Table 2. Shows the proportions of materials by weight of cement.

Material	**Proportion**
Cement	1.0000
Water	0.2500
Coarse aggregate	1.3067
Fine aggregate	0.6933
Superplasticizer	0.0134

Table 3. Shows the final proportions of materials for 1 m3.

Material	**Weight (Kg)**
Cement	750
Water	190
Superplasticizer **SP**	10
BA SEN-2 from (10 mm to 19 mm)	667
BA SEN-1 from (4.75 mm to 9 mm)	333
Fine BA, (2.36 mm to 4.75 mm)	333
Sand S, (0.3 mm to 2.36 mm)	111
Powder P, (0.075 mm to 0.3 mm)	56
Total	**2450**

Table 4. Shows all materials proportions have (2:1) proportions.

2	**Total agg.**	**Coarse agg.**	**SEN-2**	**SEN-2**	**Fine BA**	**Sand**
1	**Cement**	**Fine agg.**	**SEN-1**	**Fine BA**	**Total Sand**	**Powder**

Basalt (SEN-2, SEN-1, and Fine) **Total sand (Sand and Powder)**

Figure 1. Shows the aggregate graded grain size.

4. Mechanical Properties Tests Result and Discussions

4.1 Workability Property

4.1.1 Slump Test Result :

The slump test was **100 mm** as shown in **figure 2**.

4.2 Durability Property

4.2.1 Permeability Test Result :

The test shows the water depth penetration was **8 mm** as shown in **figure 3**.

Figure 2. Shows the slump test.

Figure 3. Shows the water depth penetration

4.3 Density

4.3.1 Unit Weight Tests Result :

Nine cubes 150 *150 *150 mm (volume for each = 3.375 Litter) divided into 3 groups were used which tested for unit weight at ages 7, 28, and 56 days, and the average Weight and Density at each age are listed in the **table (5).**

Table 5. Shows the average concrete Density at 7, 28, and 56 days.

groups, no.	Age (day)	Average Weight (g)	Average Density (kg /m3)
1	7	8580	2542.22
2	28	8610	2551.11
3	56	8630	2557.04
Average		8606.67	2550.12

4.4 Compressive Strength (fc) Property

4.4.1 Compression Tests Result :

Nine cubes 150 *150 *150 mm (Area for each = 225 cm2), each of them tested by compression machine every three cube specimens as a group at ages 7, 28, and 56 days were used as follows.

Table 6. Shows average Compressive Strength (fc) at age of 7, 28, and 56 days.

Age.	Avg. Failure Load (KN)	Avg. (fc) MPa	Failure Shape
7	1822	80.98	Normal
28	2403.33	106.81	Normal
56	2636.67	117.19	Normal

4.5 Indirect Tensile Strength (ft) Property

4.5.1 Splitting Cylinder Tests Result :

Three cylinders 150 mm diameter * 300 mm height were used, each of them tested by compression machine at ages 7, 28, and 56 days as shown in **table (7)**.

Table 7. Shows the Indirect Tensile strength Tests Result (ft).

Age	Failure Load (KN)	(ft) MPa	Failure Shape
7	345	4.88	Normal
28	482	6.82	Normal
56	508	7.19	Normal

4.5.2 Indirect Tensile Strength (ft) as a function of Compressive Strength (fc) :

ACI Committee 363 R-92 [8] recommended the relation between splitting cylinder strength (ft) and compressive strength (fc) of high-performance concrete expressed as **[ft = 0.59 (fc)^0.5],** where (ft) is the splitting tensile strength, and (fc) is the compressive strength of cylinders, both in Mega Pascal. The compressive strength in the mix was tested by cubes, not cylinders, to convert compressive strength from cube to cylinder: (**fc)cube = 1.25 (fc) cylinder**.

The comparison between the results of (tested and calculated) for Indirect Tensile Strength according to the ACI empirical equation are shown in **table (8)** and **figure (4).**

Table 8. Shows the Indirect Tensile Strength with Standard Limits.

Age	Cube (fc) MPa Tested	Cylinder (fc) MPa Converted	ACI 363 R-92 (ft) MPa Calculated	Mix (ft) MPa Tested
7	**80.98**	**64.78**	**4.75**	**4.88**
28	**106.81**	**85.45**	**5.45**	**6.82**
56	**117.19**	**93.75**	**5.71**	**7.19**

4.5.3 Adjustment of the relationship between Indirect Tensile Strength and Compressive Strength :

The results in **table (8)** show the tested **Indirect Tensile Strength** and the tested **Compressive Strength** at different ages and the relationship between them is shown in **figure (5).** Through this relationship, the (fc) to (ft) ratio can be predicted by the empirical following equation:

$$f_t = 0.08\,(f_c) \quad \ldots\ldots\ldots \text{(eq. 1)}$$

Where, (f_t) is the splitting tensile strength, and (fc) is the compressive strength of cylinders, both in Mega Pascal (MPa).

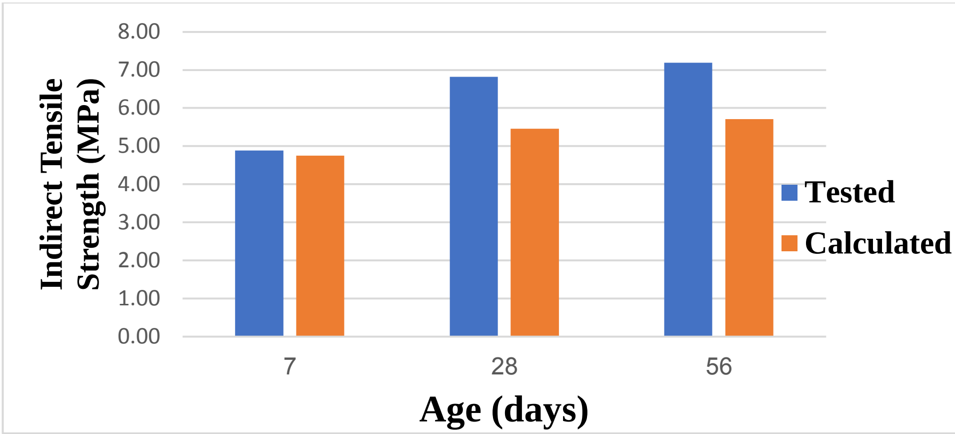

Figure 4. Shows the Indirect Tensile Strength with Standard Limits.

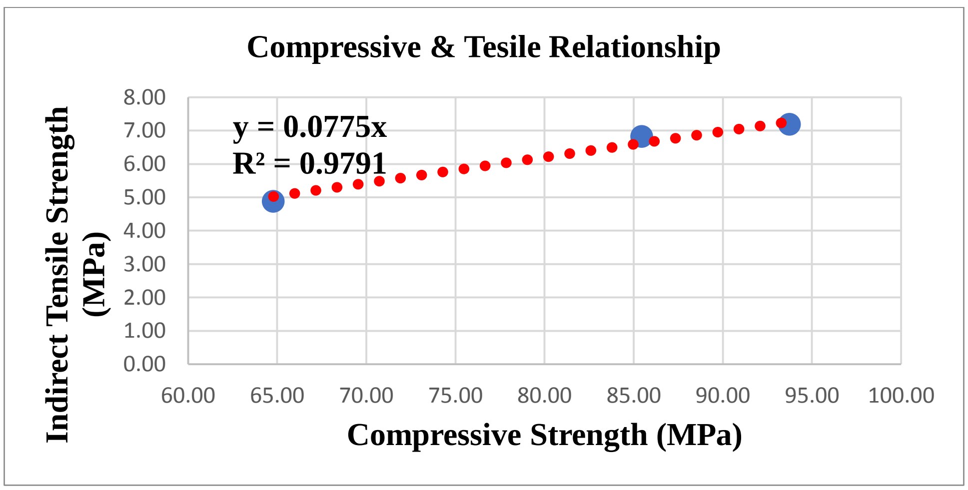

Figure 5. The relationship between Indirect Tensile Strength and Compressive Strength.

4.6 Modulus of Elasticity (En) Property

4.6.1 Modulus of Elasticity Tests Result :

Three cylinders 150 mm diameter * 300 mm height each of them using strain-measuring equipment, and a compression machine were tested at ages 7, 28, and 56 days. Where the test was done by taking 90% of the cylinder compressive strength results {(fc) cylinder} at that age to avoid failure.

Table 9. Shows the Stress-Strain responses of 7, 28, and 56 days.

Age.	Peak Stress (MPa)	Max. Strain ΔL/L
7	55	0.005
28	20	0.0037
56	30	0.0035

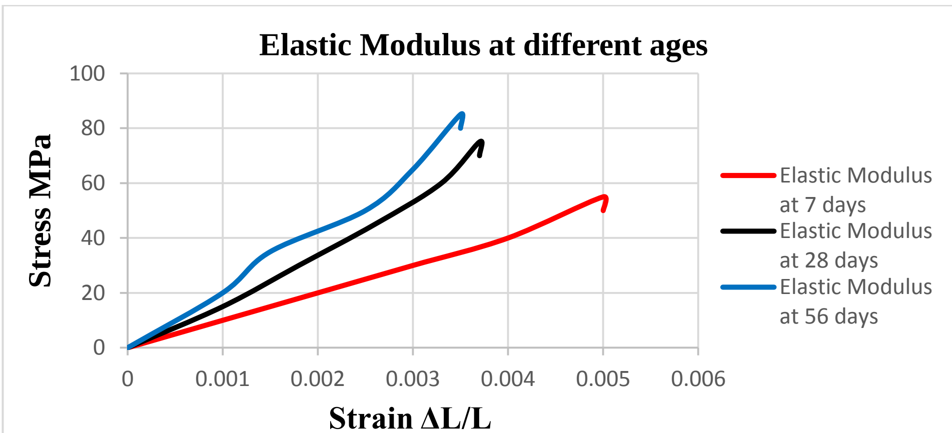

Figure 6. Shows the Stress-Strain diagram for 7, 28, and 56 days.

4.6.2 Modulus of Elasticity (En) as a function of Compressive Strength (fc) :

ACI Committee 318 predicts the compressive strength at any time as mentioned in the equation **En = 4700 (fc)^0.5,** where (En) is the Modulus of Elasticity, and (fc) is the compressive strength of cylinders, both in mega Pascal.

The comparison between the results of (tested and calculated) for Modulus of Elasticity according to the ACI empirical equation are shown in **table 10 and figure 7**.

Table 10. Shows the Modulus of Elasticity with Standard Limits.

Age	Cube (fc) MPa Tested	Cylinder (fc) MPa Converted	ACI 318 (En) GPa Calculated	Mix (En) GPa Tested
7	80.98	64.78	37.83	37.50
28	106.81	85.45	43.45	42.00
56	117.19	93.75	45.51	44.00

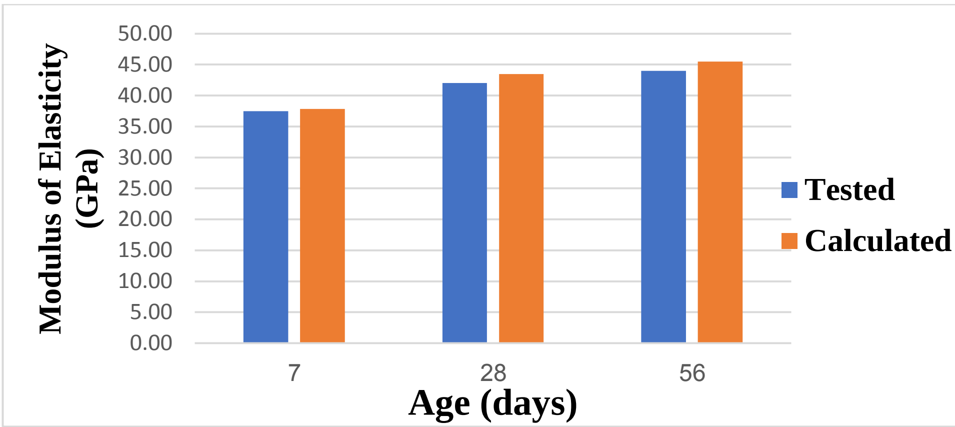

Figure 7. Shows the Modulus of Elasticity with Standard Limits.

4.6.3 Adjustment of the relationship between Modulus of Elasticity and Compressive Strength.

The results in **table 10** show the tested **Modulus of Elasticity** and the tested **Compressive Strength** at different ages and the relationship between them is shown in **figure 8**. Through this relationship, the (fc) to (En) ratio can be predicted by the empirical following equation:

En = 500 (fc) ……. (eq. 2)

Where, (En) is the Modulus of Elasticity, and (fc) is the Compressive Strength of cylinders, both in Mega Pascal (MPa).

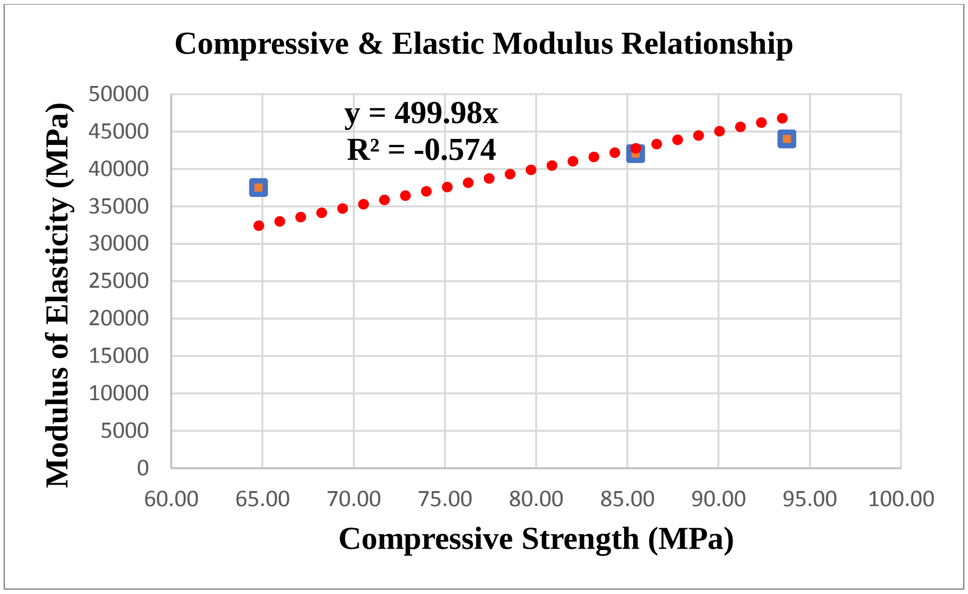

Figure 8. The relationship between Modulus of Elasticity and Compressive Strength.

4.7 Flexural Strength (Modulus of Rupture) (fr) Property

4.7.1 Flexural Strength Tests Result :

Nine concrete prisms 100*100*500 mm were used, each of them tested by compression machine with three points flexural test (Center-point loading) at ages 7, 28, and 56 days as shown in the following:

Table 11. Shows the Modulus of Rapture (fr) at age of 7, 28, and 56 days.

Age.	**Avg. Failure Load (KN)**	**Avg. (fr) MPa**	**Failure Shape**
7	**570**	**7.60**	Normal
28	**791**	**10.55**	Normal
56	**835**	**11.13**	Normal

4.7.2 Modulus of Rapture (fr) as a function of Compressive Strength (fc):

ACI Committee 363 R-92 recommended the relation between the modulus of rapture (fr) and compressive strength (fc) of high-performance concrete expressed as: [**fr = 0.94 (fc) ^0.5],** where (fr) is the modulus of rapture, and (fc) is the compressive strength of cylinders, both in Mega Pascal.

The comparison between the results of (tested and calculated) for Modulus of Rapture and the according to the ACI empirical equation are shown in **table 12 and figure 9.**

Table 12. Shows the Modulus of Rapture with Standard Limits.

Age	Cube (fc) MPa Tested	Cylinder (fc) MPa Converted	ACI 363 R-92 (fr) MPa Calculated	Mix (fr) MPa Tested
7	**80.98**	**64.78**	**7.57**	**7.60**
28	**106.81**	**85.45**	**8.69**	**10.55**
56	**117.19**	**93.75**	**9.10**	**11.13**

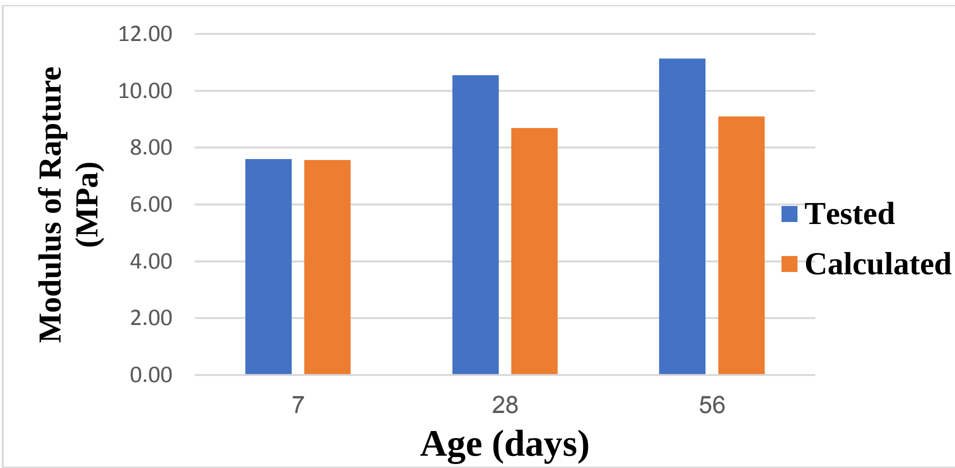

Figure 9. Shows the Flexural Strength with Standard Limits.

4.7.3 Adjustment of the relationship between Flexural Strength and Compressive Strength:

The results in **table 12** show the tested **Flexural Strength (Modulus of Rapture)** and the tested **Compressive Strength** at different ages and the relationship between them is shown in **figure 13**. Through this relationship, the (fc) to (ft) ratio can be predicted by the empirical following equation:

fr = 0.12 (fc) ……… (eq. 3)

Where, (fr) is the flexural strength (Modulus of Rapture), and (fc) is the compressive strength of cylinders, both in Mega Pascal (MPa).

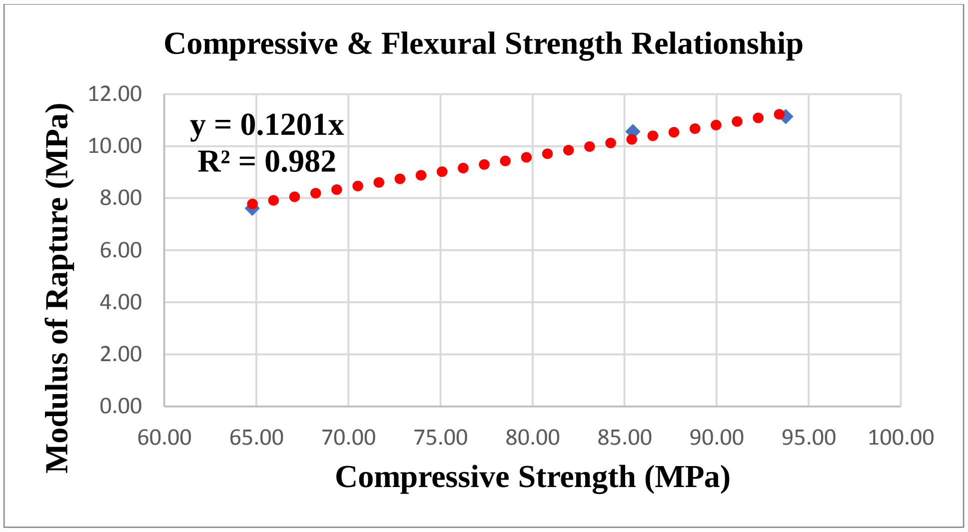

Figure 10. The relationship between Flexural Strength and Compressive Strength.

5. Summary Results.

Table 13. Shows the Final Results for Mechanical Properties Tests.

Item	Mold	Test	Tools	Mean Value
Workability	Cone	Slump	Cone	100 mm
Consistency	ACI Classification according to Slump			Plastic
Durability	Cube	Permeability	Machine	8 mm
Weight	Cube	Cube weight	Cube	8606 kg
Density	Cube	Unit weight	Cube	2550 kg/cm3
Compressive strength	Cube	Compression	Machine	106.81 MPa at 28 days
Indirect Tensile strength	Cylinder	Compression	Machine	6.82 MPa at 28 days
Modulus of Elasticity	Cylinder	Compression	Machine	42 GPa at 28 days
Flexural strength	Prism	3point loading	Machine	10.55 MPa at 28 days

6. Discussion :

Too many mixes were done (more than 1500 trial mixes) which lead to knowing a new method obtained for the proportion of materials called **(the 2:1 Proportion Method).**

The 2:1 Proportion Method concept is to prepare a **very denser** mix with very well-graded grain sizes from fine to coarse to can get up **VHPC** without any additive materials.

The average unit weight was **2550 kg** in one cubic meter of concrete mix, which means that the mix was denser than conventional concrete (**2200** to **2400 kg**) because of a very good graded grain size from fine to coarse according to the new method **(the 2:1 Proportion Method).**

The slump test has a normal shape and good value and the **consistency is "Plastic"** according to **ACI 211.1 (slump 75 – 125 mm)** [10], where the slump value was **100** mm because the Basalt **BA** is non-recycled aggregate and its water absorption percentage is very low which was **0.55%.**

The permeability test value indicates that the mix was high durability properties because the minimum cover for any item of concrete reinforcement is **25 mm,** where the depth penetration value was **8** mm in the mix. The reason for a good penetration value (small value of depth penetration) is the mix hasn't had large **voids** between the grain, while grain size was graded very well from fine to coarse by applying the new method **(the 2:1 Proportion Method)**.

The average compressive strength at 28 days **(fc)28** obtained was **106.81 MPa** this result was classified as a Very High-Strength Concrete **VHSC** and this led to **Very High-Performance Concrete VHPC**. That was achieved by applying the new method (2:1 Proportion Method) because the mix was denser and low content water-cement ratio which was **0.25**.

The Indirect Tensile Strength at 28 days **(ft)28** obtained by cylinder test was **6.82 MPa,** this result is classified as **Very High-Performance Concrete VHPC**. The results were achieved by applying the new method **(2:1 Proportion Method).** From the results, the (fc) to (ft) ratio can be predicted by **(ft) = 0.08 * (fc),** where (ft) is the splitting tensile strength, and (fc) is the compressive strength of cylinders, both in Mega Pascal (MPa).

The Elastic Modulus results show at age **7 days** the deformation of the specimen was increasing rapidly and the max strain at peak stress load was **(0.005),** which was more than the specimen tested at age **28 and 56 days**, where the max strain at peak stress load was **(0.0037)** and (**0.0035)**, respectively, the reason for that is concrete at the age of **7 days** doesn't complete in its behavior from the side of the chemical reactive and mechanical properties. The results show at age **28 days** and **56 days** the deformation of the specimen gradually increased and the max strain at peak stress load was approximately the same value, the reason for that is the concrete at age **28 days** was approximately completed in its behavior from the side of the chemical and mechanical properties. The Modulus of Elasticity **(En)** at 28 days **(En)28** was **42 GPa,** this result is classified as **Very High-Performance Concrete VHPC**. The results were achieved by applying the new method **(2:1 Proportion Method).** From the results the (fc) to (En) ratio can be predicted, where **(En) = 500 * (fc),** where (En) is the modulus of elasticity, and (fc) is the compressive strength of cylinders, both in Mega Pascal (MPa).

The Flexural Strength (Modulus of Rapture) at 28 days **(fr)28** obtained by Prism test was **10.55 MPa,** this result is classified as **Very High-Performance Concrete VHPC**. The results were achieved by applying the new method **(2:1 Proportion Method).** From the results the (fc) to (fr) ratio can be predicted, where **(fr) = 0.12 * (fc),** where (fr) is the modulus of rapture, and (fc) is the compressive strength of cylinders, both in Mega Pascal (MPa).

CONFLICT OF INTEREST

The authors have no financial interest to declare in relation to the content of this article

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