"Effect of Water to Powder Ratio on Some Mechanical Properties of SCC"

,, تأثير نسبة الماء إلى المسحوق على بعض الخواص الميكانيكية للخرسانة ذاتية الرص ،،

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ABSTRACT

The aim of this study is to find the effect of water to powder ratio on some of the mechanical properties of self-compacting concrete (SCC) made from locally available materials. To determine the workability, different test methods are adopted in this research such as slump-flow, T50 slump-flow, L-box, U-box and V-funnel. The mechanical properties studied are compressive strength, splitting tensile strength, flexural strength and static modulus of elasticity. Two non-destructive test methods, ultra-sonic pulse velocity and Schmidt rebound hammer test are tested also.

Based on the results of this work, it is possible to produce SCC from locally available materials that satisfy the requirements of this type of concrete. It can be stated that SCC produced is sensitive to water to powder ratio. The results obtained from this study indicate that increasing W/P ratio from (40-62) % decreases the compressive strength by 23 %, splitting tensile strength by 20 %, flexural strength by 46 %, static modulus of elasticity by 9 %, ultra-sonic pulse velocity by 13 % and rebound number by 15%.

الخلاصة:

تهدف هذه الدراسة لبيان تأثير نسبة الماء إلى المسحوق على بعض الخواص الميكانيكية للخرسانة ذاتية الرص والمصنوعة من المواد المتوفرة محليا. استخدمت عدة طرق لقياس قابلية التشغيل منها فحص الانسياب, زمن الانسياب, الصندوق على شكل حرف L, الصندوق على شكل حرف U, القمع على شكل حرف V. الخواص الميكانيكية التي تمت دراستها هي: مقاومة الانضغاط, مقاومة الانشطار, مقاومة الانثناء ومعامل المرونة الثابت. بالإضافة إلى طريقتان لا اتلافيتان هما: الموجات فوق الصوتية ورقم ارتداد المطرقة.بناءا على نتائج وظروف العمل, من الممكن إنتاج خرسانة مرصوصة ذاتيا من المواد المتوفرة محليا والمكونة لهكذا نوع من الخرسانة وان الخرسانة الناتجة تكون حساسة لنسبة الماء إلى المسحوق. كما أثبتت النتائج المستحصلة من هذه الدراسة بأن زيادة نسبة الماء إلى المسحوق من (40-62) % يقلل من مقاومة الانضغاط بنسبة 23 %, مقاومة الانشطار بنسبة 20%, مقاومة الانثناء بنسبة 46%, معامل المرونة الثابت بنسبة 9%, سرعة الموجات فوق الصوتية بنسبة 13% ورقم الارتداد بنسبة 15%.

INTRODUCTION

SCC was first developed in Japan 1980 in order to reach durable concrete structures [(1)]. In recent years, a lot of study was done on how to improve the performance of concrete, especially on topics regarding how to increase the strength, durability and flow ability of concrete. High strength concrete has become one of the hottest topics since 1980, and it is now possible to have structures that are built with concrete over 100 MPa compressive strength [(2)].

SCC has been described as "the most revolutionary development in concrete construction for several decades "[(3)]. SCC describes a concrete with the ability to compact it self only by means of its own weight without the requirement of vibration .It fills all voids, even in highly reinforced concrete members and flows free of segregation nearly to level balance [(4)]. Due to its specific properties, SCC may contribute to significant improvement of the quality of concrete structures and open up new fields for the application of concrete. It can be used in repair applications, hard to reach areas, areas with congested reinforcement such as columns and walls, durable concrete, fair face concrete, pumped concrete for long distances besides all other normal concrete applications.

SCC is different from the conventional concrete in that it has a lower viscosity and, thus, a greater flow rate even when pumped [5].

[Collepardi M.] [6] mentioned "the term Self-Compacting Concrete (SCC) refers to a special type of concrete mixture, characterized by high resistance to segregation that can be cast without compaction or vibration". Thus, the main agents to make a SCC are fillers, especially in concretes with higher w/p than 0.45, which increases the need of plasticizers, and use of co-polymer plasticizing admixtures with a stabilizer included (thickening agent) [7]. In addition, the focus on cost entails not to use lower w/p than required for e.g. environmental reasons [Johansen K. and Hammer T.] [8].

RESEARCH SIGNIFICANCE

The main purpose is to evaluate the effect of water to powder ratio (w/p) on some of the mechanical properties of SCC. Then, a comparison will be made between the properties of SCC and reference normal mix.

THE EXPERIMENTAL PROGRAM

To determine the workability, different test methods are adopted such as slump-flow, $T_{50\ cm}$, L-box, U-box and V-funnel. The mechanical properties studied are, compressive strength, splitting tensile strength, flexural strength and static modulus of elasticity. Further more, two non-destructive test methods, the ultrasonic pulse velocity and Schmidt rebound hammer tests are used for four series of SCC mixes, namely S_{30}, S_{40}, S_{51} and S_{62}. These w/p ratios were chosen to adequate fresh requirements of this type of concrete. The proportions of concrete mixes are summarized in Table (1).

Table (1): Mix proportions (Kg/m^3).

Mix Notation	Cement (kg/m^3)	Filler (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	w/p (%)	SP by wt of cement (%)
S_{30}	400	80	912	760	30	4
S_{40}	400	80	912	760	40	4
S_{51}	400	80	912	760	51	4
S_{62}	400	80	912	760	62	4
Ref. mix	400	--	912	760	40	--

MATERIALS

1. Cement

Ordinary Portland Cement (O.P.C.) manufactured by the new cement plant of Kufa was used throughout this investigation. This cement complied with the Iraqi specification No.5/1984. The chemical composition and physical properties are presented in Tables (2) and (3).

Table (2): Chemical composition of the cement. The tests were made in the constructional materials lab of Babylon University.

Oxide	%	IQS No.5:1984
CaO	60.79	
SiO_2	20.75	
Al_2O_3	6.20	
Fe_2O_3	3.00	
MgO	4.11	≤ 5.0
SO_3	2.32	≤ 2.8
Free lime	0.51	
L.O.I	2.00	≤ 4.0
Compound Composition	**%**	**IQS No.5:1984**
C_3S	37.26	
C_2S	31.39	
C_3A	11.35	
C_4AF	9.12	
L.S.F	0.88	0.66-1.02

Table (3): Physical properties of cement. The tests were made in the constructional materials lab of Babylon University.

Physical properties	Test results	IQS No.5:1984
Fineness, Blaine, cm^2/gm	3124	≥ 2300
Setting time, Vicat method		
Initial; hrs: min	1:45	≥ 0.45
Final ; hrs: min	3:46	$\leq 10:00$
Compressive strength MPa		
3 days	20	≥ 15
7 days	27	≥ 23
28 days	33	

2. Fine Aggregate

Natural sand from AL-Akaidur region was used. The results of physical and chemical properties of the sand are listed in Table (4). Its grading conformed to the IQS No.45/84 zone 3.

Table (4): Properties of fine aggregate. The tests were made in the constructional materials lab of Babylon University.

Sieve size (mm)	Passing %	IQS No.45/1984
10.00	100	100
5.00	100	89-100
2.36	94	60-100
1.18	84	30-100
0.60	66	15-100
0.30	37	5-70
0.15	3	0-15
Properties	**Results**	**IQS No.45/1984**
SO_3 %	0.432	≤0.5
Clay %	2.3	≤3.0
Specific gravity	2.65	
Absorption %	1.6	

3. Coarse Aggregate

The coarse aggregate was AL-Nibaee gravel with a maximum size of 14 mm. The friction between the aggregate limits the spreading and the filling ability of SCC, this is why the maximum coarse aggregate size is chosen to be 14 mm, as shown in Table (5). The coarse aggregate is complying with IQS No.45/84.

Table (5): Properties of coarse aggregate. The tests were made in the constructional materials lab of Babylon University.

Sieve size In (mm)	Passing %	IQS No.45/84 Limitations
40	100	100
20	100	100
14	97	90-100
10	84	50-85
5	6	0-10
pan	0	0
Properties	**Results**	**IQS No.45/84**
SO_3 %	0.0799	≤ 0.1
Clay %	0.6	≤ 1.0
Specific gravity	2.64	
Absorption %	0.7	

4. Super-plasticizer

To achieve high workability needed to produce SCC, super-plasticizers (carboxilated polyether) were used. A super-plasticizer known as Ura-plast SF was used in producing SCC. According to ASTM C494-92, this SP is classified as type G, because it has a retarding effect on the SCC. The typical properties of SP are shown in Table (6).

Table (6): Properties of Super Plasticizer.

Main Action	Concrete Super-plasticizer
Subsidiary effect	Hardening retarder
Form	Viscous liquid
Color	Dark brown
Relative density	1.1 at 20 ^{0}C
Viscosity	128+/-30 cps at 20 ^{0}C
PH value	6.6

5. Limestone powder

Limestone powder, which has been brought from a chemicals bureau, is used to increase the amount of powder content (cement + filler) in the SCC mixes. Particle size less than 0.125 mm was used to increase the workability and density of the SCC. The chemical composition of limestone powder is shown in Table (7).

Table (7): Chemical composition of limestone powder. The tests were made in the environmental lab of Babylon University.

Oxide	%
CaO	52.76
SiO_2	1.40
Al_2O_3	0.70
MgO	0.10
Fe_2O_3	0.17
SO_3	2.91
L.O.I	40.60

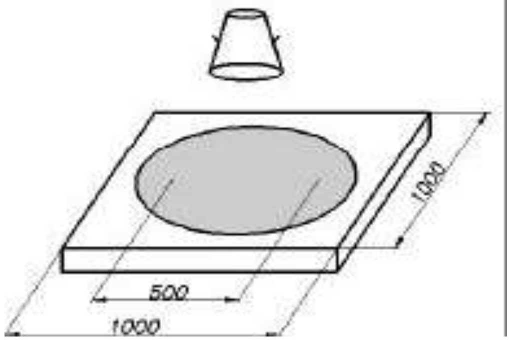
TEST PROCEDURES

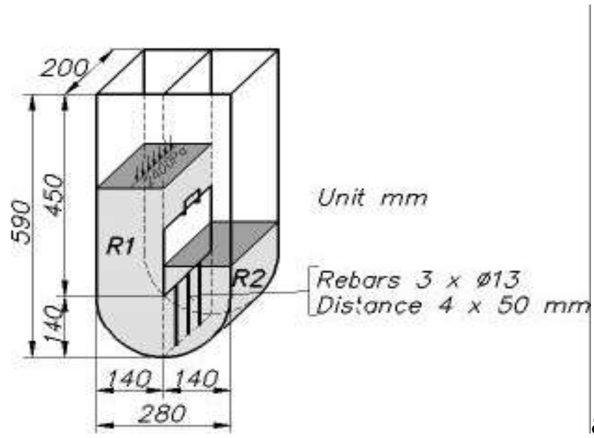
1.Fresh Tests

The SCC tests are not appropriate for the reference mix, which were therefore assessed by the BS 1881 slump test. The workability of SCC can be characterized by the following properties:

•filling ability.
•passing ability.
•segregation resistance.

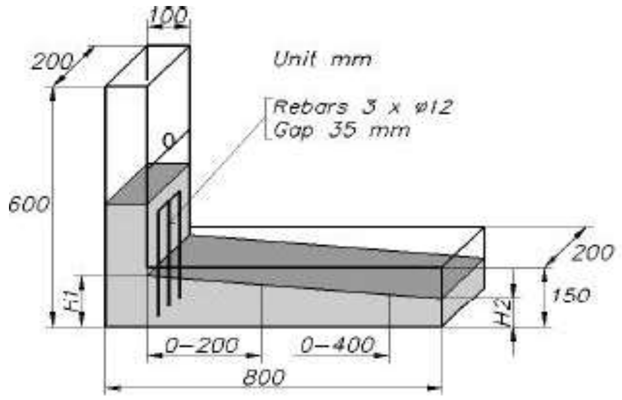
In order to evaluate the filling ability, passing ability and segregation resistance of the fresh concrete, slump-flow, T50 cm, L-box, U-box and V-funnel tests, as shown in Figure (1), were conducted in this research according to EN 12350-1, 2 requirements.

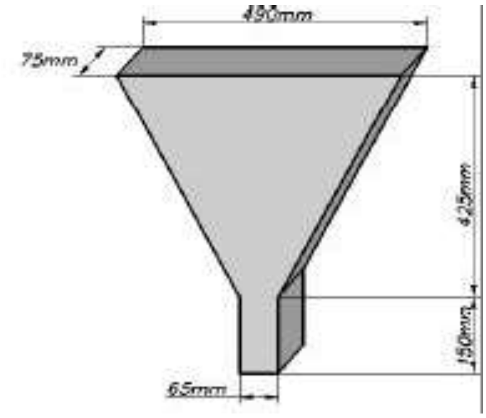




a.

Slump-flow and T50. b. U-box test.





c. L-box test.

d. V-funnel test.

Figure (1): Fresh concrete tests.

2. Hardened Tests

2.1 Compressive Strength

Compressive strength was carried out and tested according to BS 1881: part 116:1983. A total number of 36 cubes of 100 mm were tested by using a hydraulic compression machine of 2000 KN. All specimens were cured in water until testing age to investigate the effect of water to powder ratio on mechanical properties of SCC. Each result of compressive strength obtained is the average for three specimens.

2.2 Splitting Tensile Strength

The splitting tensile strength was determined according to the procedure outlined in BS 1881: part 117: 1983. A total number of 24 cylinders (100*200) mm were tested. Cylinders were cast, demolded and cured in a similar way as the cubes. Each splitting tensile strength result was the average of strength for two specimens. The splitting tensile strength is calculated from the equation:

$$\sigma = \frac{2P}{\pi L D} ---------- (1)$$

Where:

σ =tensile strength (N/mm^2). P=the applied compressive load (N).

L=the cylinder length (mm). D=the cylinder diameter (mm).

2.3 Flexural Strength

Concrete prisms of dimensions (100*100*400) mm were cast according to BS 5328:4:1990 procedure. Modulus of rupture test according to BS1881:118:83 was performed using two-point load test and calculated from the simple beam bending formula:

$$R = \frac{pl}{bd^2} ---------(2)$$

Where:

p=maximum applied load (N). , l=span length (mm).
b=specimen width (mm). , d=specimen depth (mm).

2.4 Static Modulus of Elasticity

The static modulus of elasticity was determined according to BS 1881:121:1983 specifications. A total number of eight cylinders (150*300) mm were tested. All specimens were cast, demolded and cured as for the compressive strength cubes. A hydraulic compression machine of 2000 kN is used to apply a compression load until 40 % of the ultimate load. The proving rings used which have a gauge length of 200 mm and gauge with an accuracy of 0.01 mm, is made according to BS 1881:121:1983. The recorded results were the average of readings for two cylinders. The modulus of elasticity may be calculated as follows:

$$E_c = \frac{S_2 - S_1}{\varepsilon_2 - \varepsilon_1} -------(3)$$

Where:
E_c=modulus of elasticity GPa.
S_2=stress corresponding to 40 % of ultimate load MPa.
S_1=stress corresponding to the longitudinal strain of $50*10^{-6}$ MPa.
ε_2=longitudinal strain produced by S_2.
ε_1 $=50*10^{-6}$

2.5 Schmidt *Rebound Hammer Test*

Schmidt hammer was used to estimate the surface hardness of concrete specimens by recording the rebound number, which could be used as a measure of the concrete strength and percentage of voids. The test method is prescribed by BS 1881:202:1986 specifications.

2.6 *Ultra-Sonic Pulse Velocity*

This test is carried out according to BS 1881: part 203:1986, using the portable ultra-sonic non-destructive digital indicating tester (PUNDIT) with frequency of 36 kHz to determine wave velocity in concrete specimens. The transit time is recorded in microseconds. Pulse velocity, V, in Km/sec is calculated as follows:

$$V = \frac{L}{T} ------------(3)$$

Where:
V=ultra-sonic pulse velocity, Km/sec.
L=path length, mm. T=transit time, μ sec.

RESULTS AND DISCUSSION

The results of the experimental work of this research are listed in Table (8), and figures (2) to (7). The properties of fresh concrete are presented in Table (8). These results show that the SCC used is complying with the requirements of SCC and is found to have a good consistency and workability at fresh state compared to reference normally vibrated mix.

From the results of compressive strength shown in Figure (2) it can be seen that the decrease in water to powder ratio leads to increase the compressive strength due to the use of super-plasticizers. Moreover, a decrease in the water to powder ratio from (0.62 to 0.51), (0.62 to 0.4) and (0.62 to 0.3) leads to increase the compressive strength by (5-14) %, (10-23) % and (27-40) % at 28 days respectively. This is due to the lower initial volume of voids that is needed to be filled by the hydration products and the better dispersion of the powders in the mix. Thus, the SCC used has doubled the compressive strength with respect to that of reference normal vibrated concrete and lies under high strength concrete [9].

From the results in Figure (3) it can be seen that increasing the water to powder ratio from (0.4 to 0.51) and (0.4 to 0.62) decreases the splitting tensile strength by (1-3) %, (1-20) %, (1-8) %, (7-17) %, (2-9) % and (14-18) % at 7, 28 and 90 days respectively. This is due to the high initial volume of capillary voids in the mix which increases when increasing the water content.

From the results in Figure (4), it can be seen that S_{40} shows higher flexural strength than those of S_{51} and S_{62}. Furthermore, increasing the water to powder ratio from (0.4 to 0.51) and (0.4 to 0.62) results in a decrease in the flexural strength by (17-46) %, (11-36) % and (15-34) % at 7, 28 and 90 days respectively. This is due to the weakly transition zone between matrix and aggregate when using high water content in the mix. This observation was noticed by Victor [(10)] and Malhotra [(11)].

From the results shown in Figure (5) it can be seen that increasing the W/P ratio from (0.4 to 0.51) and (0.4 to 0.62) leads to a reduction in the pulse velocity by (2-6) %, (5-10) %, (1-8) %, (2-13) %, (2-7) % and (4-10) % at 7, 28 and 90 days respectively. This reduction in U.P.V. with the increase in W/P ratio is due to the large early volume of voids in concrete body, which obstruct the pulse transition and prolong the transit time.

From Figure (6) it can be seen that increasing the water to powder ratio from (0.4 to 0.51) and (0.4 to 0.62) results in a reduction in the rebound number by (5-8) %, (7-10) %, (2-7) % and (4-7) % at 28 and 90 days respectively. This behavior can be explained by increasing the volume of voids in the concrete structure and to the use of ultra-fine particles in the mix. The estimated compressive strength from rebound number is less than that measured on cubes by (10-30) %, and the surface hardness test is not applicable at early ages due to using high amount of fine materials and decreasing the size and amount of coarse aggregate used in the mix. This is why the surface hardness tests are not favorable to this kind of concrete, "Self-Compacting Concrete"

From the shown results in Figure (7), it can be seen that the 28-days modulus of elasticity for concrete cylinders ranges between (30.71-35.65) GPa for all the SCC specimens. However, increasing the water to powder ratio from (0.3 to 0.4) and (0.3 to 0.51) leads to a reduction in the static modulus by (2-7) % and (5-9) %. This behavior is due to the large early volume of voids in concrete in higher W/P ratios. On the other hand, the densifying effects of fillers reduce the pore size in low water to powder ratio. The inclusion of filler powders in the voids among and between cement particles makes strong, homogenous and dense interface zone between matrix and aggregate.

Table (8): Fresh concrete results.

Mix notation	Slump-flow (mm)	T50 Sec.	R_1-R_2 (cm)	H_2/H_1 (%)	V-time Sec.
Limitations	600-800	2-5	0-3	80-100	5-15
S_{62}	738	2.9	0	90	6
S_{51}	710	3.8	0	88	7.5
S_{40}	695	4.3	0.4	85	9
S_{30}	655	5.1	0.7	82	11
Ref. mix	150	---	---	---	---

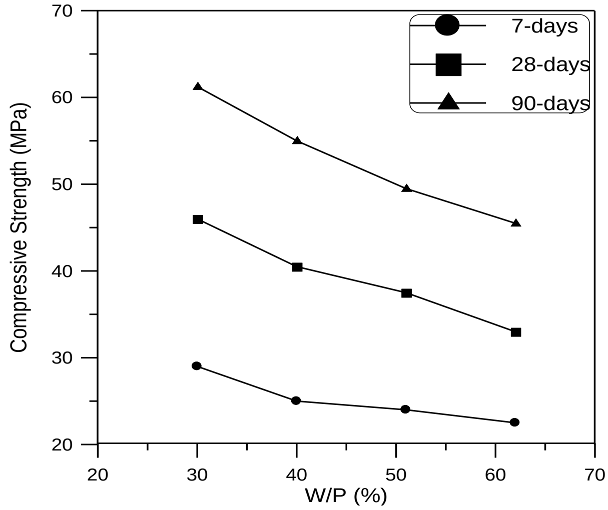


Figure (2): Relationship between compressive strength and W/P ratio.

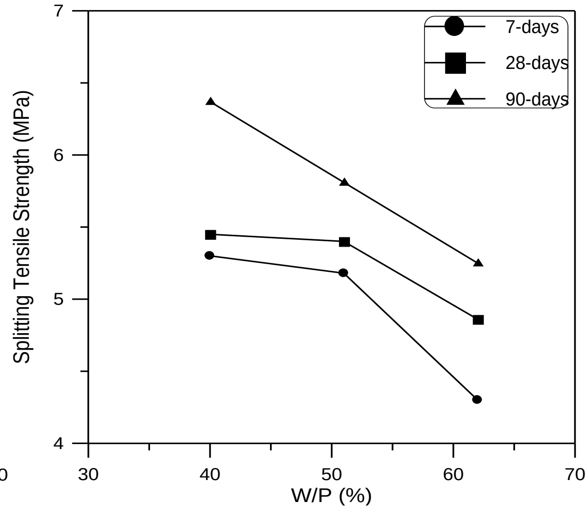


Figure (3): Relationship between splitting tensile strength and W/P ratio.

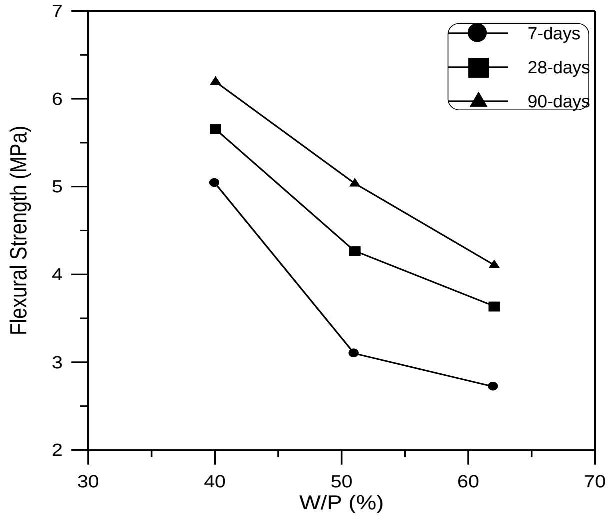


Figure (4): Relationship between flexural strength and W/P ratio.

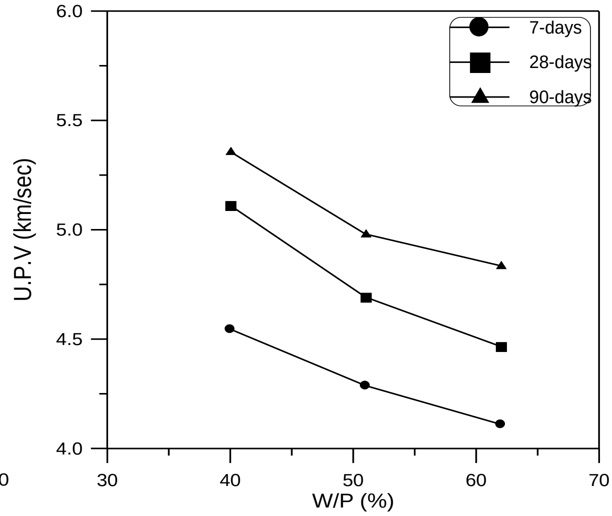


Figure (5): Relationship between U.P.V and W/P ratio.

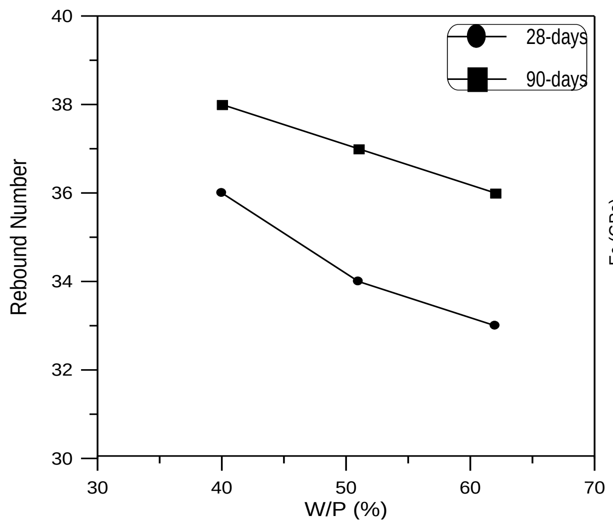


Figure (6): Relationship between rebound number and W/P ratio.

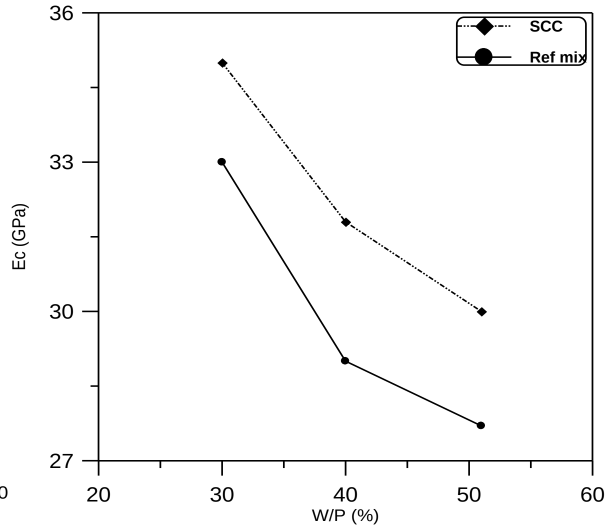


Figure (7): Relationship between Ec and W/P ratio for SCC and NVC.

CONCLUSIONS

Based on the tests results of the present study the following conclusions can be drawn:-

1.Increasing the W/P ratio from (0.4 to 0.62) results to decrease the compressive strength by (11, 23 and 27) % at 7, 28 and 90 days respectively.

2.Specimens in flexure and splitting show similar behavior to those in compressive.

3.The 28-days Ec ranges between (30.71-35.65) GPa for SCC and ranges between (27.3-33) GPa for reference mix. Increasing the W/P ratio from (0.3 to 0.4) decreases the Ec by (2-7) %, while from (0.3 to 0.51) decreases the Ec by (5-9) %.

4.When the W/P ratio increases from (0.4-0.62) the U.P.V decreases by (2-10) %, (1-13) % and (2-10) % at 7, 28 and 90 days respectively.

5.The estimated compressive strength from rebound number is less than that measured on cubes by (10-30) %; this is why this kind of tests is not favorable for SCC.

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