

SHEAR STRENGTH OF PORCELINITE AGGREGATE REINFORCED CONCRETE BEAMS

Dr. Ayad A. Slaby

Dr. Kahlil I. Aziz

Ali Farhan Hadeed

Assistance Prof.

lecturer

Chief Eng.

Dep. of Civil Engeering

Dep. of Civil Engeering

Anbar Municipalities Direct.

University of Anbar

University of Anbar

Ministry of Municipalities

أخلاصه:

جرت بحوث عديدة في العراق حول تكنولوجيا المواد المتعلقة بالخرسانة الخفيفة الوزن باستعمال ركام طبيعي. البحوث التي عُملت على الخرسانة الخفيفة الوزن البورسيلينائية نُفذت في العديد من الجامعات العراقية ، وعلى الرغم من الأهمية العملية لهذا النوع من الخرسانة في تطبيقات كثيرة في مجالات الإنشاء ، إلا إن البحوث التي أجريت للتحري عن مقاومة الخرسانة الخفيفة الوزن للقص (*Shear strength*) محدودة . لذا أصبح من الضروري معرفة خواص وسلوك هذه الخرسانة.

شمل هذا البحث دراسة مقاومة العتبات المسلحة الخالية من الأطواق (*Stirrup*) لاجهادات القص (*Shear Strength*) باستعمال ركام البورسيلينيات (*Porcelinite*) وتمت مقارنة النتائج مع معادلات رياضية لباحثين سابقين وكذلك مع معادلات الأنظمة العالمية مثل نظام معهد الخرسانة الأمريكي (*ACI 318M -02*) والانكليزي (*BS-8110*) .

تمت مقارنة النتائج أيضا مع النتائج المماثلة للخرسانة العادية (*Normal weight*) من خلال نماذج أعدت لهذا الغرض في هذا العمل. الدراسة تركزت على السلوك الإنشائي للعتبات المسلحة والخالية من الأطواق وخاصة مقاومتها للقص بالإضافة إلى الانحراف والانفعال والتشققات ، بالاعتماد على متغيرين هما مقاومة الانضغاط تراوحت من (23-29.8) ميكاباسكال ونسب حديد تسليح تراوحت من (0.0174-0.0307). تمت دراسة (12) عتبة منها (9) عتبات خفيفة الوزن و (3) عتبات عادية الوزن كانت أبعادها 1800×260×135 ملم. بينت النتائج إن مقاومة العتبات الخراسانية الخفيفة ذات الركام البورسيلينائي للقص كانت أحيانا أكبر بـ 2.9 مرة من نتائج (*ACI 318M -02*) وأكبر 2.5 مرة من نتائج معادلة (*Hanson*) .

Abstract:

Research in Iraq has expanded in the field of material technology involving the properties of the light-weight concrete using natural aggregate. Research work on porcelinite concrete has been carried out in several Iraqi Universities. However , despite the great practical importance of such concrete in construction fields ,very limited amount of work has been carried out to investigate the (shear strength) of structural light-weight aggregate concrete , therefore it is important to study the properties and their structural behavior. In

this work an attempt is made to study shear strength of porcelinite reinforced concrete beams without (stirrups). The results have been compared with the results predicted by the equations of International codes, such as ACI 318M-02, BS-8110 codes and with some authors' equations as for, Hanson. The experimental results also have been compared with results obtained from normal weight concrete specimens that had been prepared for this purpose. The study mainly deals with the structural behavior of porcelinite reinforced concrete beams without stirrups, especially the shear strength, besides, the short-term deflection, strain and cracks. The variables are, compressive strength ranging between (23.0-29.8) MPa and reinforcement percentages ranging between (0.0174-0.0307). A total of 12 beams are tested; (9) are light weight concrete beams without stirrups and (3) are normal weight concrete beams, also without stirrups. The dimensions of all those beams are 135 * 260 * 1800 mm. The structural results more often, give values 2.9 times more than that of (ACI-02)

Notations	
A	Shear span of the beam (mm)
a/d	Shear span-depth ratio
A_s	Area of tension reinforcement, mm ²
A_v	Area of shear reinforcement, mm ²
B or b_w	Width of beam, mm
D	Effective depth of the beam (mm)
E_s	Modulus of elasticity of reinforcement, MPa
f'_c	Compressive strength of concrete (cylinder), MPa
f_r	Modulus of rupture, MPa
f_t	Splitting tensile strength, MPa
f_u	Ultimate steel strength, MPa
f_y	Specified yield strength of reinforcement, MPa
M_u	Designed moment at given section, m-kN
p_{fer}	First flexural crack load, kN
ρ or ρ_w	Ratio of tension reinforcement (A _s /bd)
ρ_b	Reinforcement ratio producing balanced strain condition
ρ_c	Density of concrete, kg/m ³
R²	Coefficient of Determination
V	Nominal shear force, kN
V_a	Nominal shear force carried by aggregate interlock, kN
V_c	Nominal shear force provided by concrete, kN
V_{cal}	Estimated shear force, kN
V_{cr}	Measured shear force at cracking, kN
V_d	Nominal shear force carried by dowel action, kN
V_r	Factored shear force of beam at ultimate state, kN
V_u	Designed shear force at given section, kN
V_{ucr}	Measured shear force at ultimate state, kN
Δ_{cr}	Deflection of first shear crack at beam mid span, mm
Δ_{fer}	Deflection of first flexural crack at beam mid span, mm
Δ_u	Deflection of ultimate shear crack at beam mid span, mm

<u>Abbreviations</u>	
AVG	Average
C	Cement
CA	Coarse aggregate
COV	Coefficient of variation
FA	Fine aggregate
HRWA	High range water Reducing Admixture
HSC	High strength of (LWC)
LWA	Light weight aggregate
LWAC	Light weight aggregate concrete
LWC	Light weight concrete
LSC	Low strength of (LWC)
MSC	Medium strength of (LWC)
NWC	Normal weight concrete
NWCB	Normal weight concrete beam
SD	Standard deviation
SLWA	Structural light weight aggregate
SLWAC	Structural light weight Aggregate concrete
SLWC	Structural light weight concrete
SLWACB	Structural light weight aggregate concrete beams
SP	Superplasticiser
w/c	Water-cement ratio

code and 2.5 times more than that of Hanson's equation.

1. Introduction:

All structural concrete elements, beams, columns, walls and slabs depend on concrete to resist part of the shear force applied to them. Since a shear failure is rather sudden and non-ductile, it is imperative that the designer be able to accurately predict the concrete contribution to the shear strength. It is essential to study the shear strength of LWAC structural members to provide engineers with a safe proven design method.

The use of the porcelinite aggregate in the production of structural light concrete (SLWC) has a wide objective and requires a lot of research to become suitable for practical application.

1.1 Light Weight Concrete

One of the disadvantages of conventional or Normal Weight Concrete (NWC) is the high self weight of concrete. Density of the normal concrete (NWC) is in the order at 2200 to 2600 kg/m³. This heavy self weight may make it an economical structural material. Attempts have been made in the past to reduce the self weight of concrete to increase the efficiency of concrete as a structural material. The light weight concrete (LWC) is a concrete whose density varies from 300 to 1850 kg/m³ ⁽¹⁾. With the introduction of reinforced concrete members employing (LWA), the density limit has had to be revised ⁽²⁾.

The draft international standard model code for concrete construction classifies light weight concrete (LWC) as having densities between 1200 and 2000 kg/m³ (cited by Ref. 2).

The most obvious characteristic of (LWC) is of course its density which is always considerably less than that of (NWC).

1.2 Porcelinite Light Weight Aggregate Concrete in Iraq

Recent research ^(3, 4, 5, 6, 7,8) has shown that there is an abundant supply of light weight rock that may be used to produce concrete of lower density than the present practice in this country⁽⁹⁾. The aggregate which is used, is quarried from rocks discovered in the Iraqi Western Desert. It is called porcelinite⁽¹⁰⁾.

2. Literature Rreview:

2.1 Factors Affecting the Shear Strength of Reinforced Concrete Beams.

In the first decades of the last century, it was demonstrated that the nominal shear strength depends not only on the quality of the material (its strength), but also on the amount of longitudinal tensile reinforcement and the length of the beam and the depth or stiffness of the beam^(11,12). Around 1950-1960 the research results clearly showed that the shear strength of the reinforced concrete beams was a complex phenomenon including more than one variable. It is now strongly apparent that the main variables which influence the shear strength of concrete member without shear reinforcement are the concrete compressive strength ($f'c$), the shear span to depth ratio (a/d), and the tensile reinforcement ratio (ρ_w)^(11,13).

3. Experimental Work:

The experimental program had consisted of casting and testing nine reinforced light-weight porcelinite aggregate concrete beams, and three normal weight reinforced concrete beams. The tests were done under simply supported condition with two point load. All beams have 1800 mm span length and (260*135) mm cross-section. The variables which were adopted, for (LWAC) beams are:

(a) *The compressive strength of concrete range ($20 \leq f'c \leq 30$) MPa, and (b) Longitudinal reinforcement steel ratio ρ_w (0.0174, 0.024 and 0.0307).*

3.1 Coarse Aggregate

3.1.1 Porcelinite Aggregate

Local natural (LWA) of porcelinite stone was used as coarse aggregates. It was received in medium lumps from the State Company of Geological Survey and Mining. The quarry of this stone is located in Trefawi area in Rutba at the Western desert in Al-Anbar governorate. The jaw of machine crusher was set up to give a finished product of about 12.5mm maximum aggregate size. The physical and chemical tests were done by the State Company of Geological Survey and Mining (SCGSM) Table (1) and (2) list those properties respectively. Table (3) represents mineral analysis of the porcelinite aggregate. The grading of

coarse porcelinite aggregates conformed to ASTM C330-87⁽¹⁴⁾ as shown in Table (4).

3.2 Concrete Mixes

Mix design methods applying to (NWC) are generally difficult to use with (LWAC). The lack of accurate value of absorption, specific gravity and the free moisture content in the aggregates make it difficult to apply the water/cement ratio accurately for mix proportioning⁽¹⁾. Light weight concrete mix design is usually established by trial mixes⁽¹⁾. Concrete mixes containing porcelinite aggregates as (LWA) should have an oven-dry density $< 2000 \text{ kg/m}^3$, and a compressive strength $> 15 \text{ MPa}$, in order to meet the class (I) of the RILEM classification⁽¹⁵⁾ which is adopted by CEB-FIP manual. Different trial mixes were made to conform to these specifications. Table (5) shows the details of the mixes. (NWC) mixes carried out according to ACI.211⁽¹⁶⁾.

3.3 Beam Specimens Details

As mentioned the dimensions of the beams for both kinds are (135mm*260mm) cross section, (1800mm) overall span length, with 1600mm clear span center to center. All these beams were provided with tension steel bars only without stirrups. Three percentages of tension reinforcement (ρ_w) are adopted in these tests, which were (0.0174, 0.024 and 0.0307). These steel percentages were greater than those generally encountered in service structures, to avoid flexural failures⁽¹⁷⁾. The minimum clear cover was taken to be 40mm for both sides and bottom according to ACI 318M-02 requirements section (7.7)⁽¹⁷⁾. The beams were numbered, B1, B2 ... to the B12. The beams of B1 to B9 were of (LWAC), while B10 to B12 were of (NWC). Table (6) shows the properties and details of these beams. Fig. (1) Shows the loading and the beam specimens' details. The shear span-depth ratio ($a/d = 2.5$) had been selected for short beam⁽¹⁸⁾ to ensure the beam exhibits shear failure.

3.4 Measurements and Instrumentation of Beams

3.4.1 Load Measurements

A loading machine with 3000kN hydraulic jack was used. The load was applied by using a steel I-beam divided into equal two points loads 635mm spacing over simply supported span of 1600mm as shown in Fig. (1). Plate (1) shows the setting up of machine for testing the beams. The test was carried out in the structural laboratory of Civil Engineering Department of Al-Mustansirya University.

3.4.2 Deflection Measurements

The deflections were measured at mid-span using a mechanical dial gauge having an accuracy of 0.01mm.

3.4.3 Concrete Strain Measurements

A mechanical method was used for measuring the strain distribution across the middle section of beams. The column of four rows of demec strain gauges were distributed along the depth on one face of the beam as shown in Fig. (2). the accuracy of strain reading was 0.002mm.

4. Test Results

Nine (LWAC) beams were tested, seven of them have a constant steel ratio ($\rho_w=0.0307$) with various compressive strengths ranging from 23 MPa to 29.8 MPa, in order to investigate the influence of compressive strength on the shear strength for the beams. The two remaining beams have constant compressive strength (25.5MPa) with various steel ratios ($\rho_w=0.0174$ and $\rho_w=0.024$), to investigate the influence of steel percentage on the shear strength for these beams. For (NWC) beams, three beams were tested, two beams with constant steel ratio ($\rho_w=0.0307$) and with compressive strengths (25.14MPa and 25.7MPa). The other was tested with steel ratio ($\rho_w=0.024$) and compressive strength of (27.2MPa). Table (6) shows the properties and results of tested beams.

4.1 Deflection

Deflection of reinforced (LWAC) beams is an important design consideration because of the relatively low modulus of elasticity of this material⁽¹⁹⁾. If the deflections of light weight and normal weight beams of the same compressive strength are compared, the deflection of the light weight beams are from 15 to 35 percent greater than those of the normal weight beams⁽¹⁹⁾.

4.1.1 Load-Deflection Behavior

The applied load (twice the shear) versus the span center deflections of the nine (LWAC) beams and of the three (NWC) beams are shown in Figs. (3) to (5). Fig. (3) shows the total relationships of load-deflection of seven (LWAC) beams of constant steel percentage ($\rho_w=0.0307$) with different compressive strengths (23.0 to 29.8) MPa. Fig. (4) shows the total relationships of load-deflection of three (LWAC) beams having a constant compressive strength (25.5)MPa and different percentages (0.0174, 0.024 and 0.0307). Fig.(5) presents the comparisons of load-deflection behaviors for the (LWAC) and (NWC) beams. From Figs(3) and (4), it is observed that, in the pre cracking of flexural stage, up to (about 40% of the ultimate load) the deflection increases essentially linearly with loading. This is expected since the strains in the steel and concrete are relatively small and both materials are in the elastic portion of their respective responses.

4.1. 2 Effect of Concrete Compressive Strength

Fig. (3) Shows the comparison of the load-deflection curves for the seven (LWAC) beams. Those beams are of the same reinforcement amounts but different concrete strength values. The beam, which has higher (f'_c) value, suffers less deflection than the beam with lower (f'_c) value at the same load. This is understandable because higher strength concrete beams are (at least initially) stiffer than lower strength ones due to the increase in the modulus of elasticity with the increase in concrete strength. The beams presented in Fig.(3), are (B3 to B9) having (f'_c) from (23.0MPa to 29.8MPa) with constant ($\rho_w=0.0307$).

4.1.3 Effect of Reinforcement Content

Fig. (4) Shows the load-deflection relationship for the (LWAC) beams of constant f'_c (25.5MPa) and different ρ_w (0.0174 , 0.0241 and 0.0307). The beam with higher steel ratio (ρ_w), has a stiffer response in terms of load-deflection behavior. This is primarily due to the larger effective moment of inertia due to the larger amount of tensile reinforcement. The beams (B1, B2 and B3) are represented in the above figure. Beam (B1) of low steel percentage exhibits more ductility as shown in Fig. (4).

4.1.4 Load-Deflection Behavior of (LWAC) and (NWC) Beam

Fig. (5) Presents the deflection behavior of (LWAC) beams (B2 , B3) against the deflection behavior of (NWC) beams (B10 , B11 , B12) due to the same load intensity. For comparison , it has been found that beam (B11) and beam (B12) , are stiffer than beam (B3) , in spite of having , approximately the similar compressive strength and the same tensile reinforcement. This situation may be attributed to the high modulus of elasticity of (NWC) which is more than that of (LWAC). Normal weight beams have the linear behavior of term load-deflection up to (about 40% of ultimate load), as for beams (B11) and (B12). Light weight concrete beams, as mentioned previously, exhibit linear behavior of term load-deflection, approximately up to (about 40% of ultimate load). In general, the trends of load-deflection behaviors for (NWC) and (LWAC) beams in this study are the same. The differences are in the magnitudes or values of the stiff nesses for the tested beams. From Fig. (5), it is clear that the deflection of (LWAC) beams of with an average value equal to 75% more than that of (NWC) beams having approximately the same compressive strength.

4.2 Shear (Diagonal) Cracking and Ultimate Loads:

Table (7) presents the measured test results (neglecting the beams weight) for (LWAC) beams (B1 to B9). Four design methods of calculating the shear capacity expressed in terms of shear force (V_{cal}) are employed by ACI 318M-02⁽¹⁷⁾, Hanson's formula (Hanson,1961)⁽²⁰⁾ , BS 8110⁽²¹⁾ and Mu'tas formula⁽²²⁾. Table (7) also presents the measured test results of (NWC) beams (B10 to B12), and evaluated these results with Eq. (5-11) of ACI 318M-02⁽¹⁷⁾ for (NWC). Eq. (A-3) by Hanson, gives a large underestimated values of ultimate shear force (V_{ucr}) for porcelinite concrete beams, the percent differences range from (149% to 171%). Eq.(A-2) by BS-8110 , gives underestimated values of ultimate shear force , with percent differences ranging from (35% to 63%). Eq.(A-1) by ACI 318M-02 code , also gives much under estimated values of ultimate shear force , where percent differences ranging from (162% to 197%). Eq.(A-4) by Mu'taz , gives slightly overestimated values of ultimate shear force , the percent differences range from (1% to 12%). It is seen that the porcelinite concrete beams exhibit shear capacity more than that of predicted equations by Hanson, ACI 318M-02, and BS-8110. This indicates that the porcelinite light weight aggregate concrete beams give good results of shear strength, compared with other light weight aggregate beams. Light weight

concrete beams exhibit shear strength (V_{ucr}) less than that of normal weight concrete (with same compressive strength and reinforcement).

The formulas, (A-1), (A-2), (A-3), (A-4) and (A-5) are listed in the Appendix (A).

4.2.1 Effect of Compressive Strength on Shear Strength of the Tested Beams

Fig. (6) Shows the effect of compressive strength on shear strength of the porcelinite concrete beams. There is an increase in the shear cracking and ultimate loads due to the increase in the compressive strength. Fig.(7) shows the comparison between measured and predicted shear forces at ultimate state for the porcelinite concrete beams having the same steel amount with different compressive strengths. It seems that the experimental values of ultimate shear forces are more than the predicted values by Hanson, BS-8110, and ACI-02, equations. From Table (7) and Fig. (6) it is observed that the beams of (NWC) exhibit shear strength more than that of beams of (LWAC), for the same compressive strength and steel amount. It is found that beam (B11) exhibits shear strength more than that of beam (B3) by about (23%). Also (B10) gives shear strength about (13%) more than that of (B2).

4.2.2 Effect of Longitudinal Reinforcement on Diagonal Cracking and Ultimate Loads:

The longitudinal reinforcement ratio has pronounced effect on the basic shear transfer mechanisms. A factor that affects the rate at which a flexural crack develops into an inclined crack is the magnitude of the shear stresses near the tip of that crack. The intensity of principal stresses above the flexural crack will depend upon the depth of penetration of the flexural crack. The greater the penetration of the flexural cracks, the greater the principal stress for a given applied shear. The greater the value of ρ_w , the less the penetration of the flexural crack. Consequently, the greater the value ρ_w , the greater must be the shear to cause the principal shear which will result in diagonal tension cracking (Elzanaty et al., 1985)⁽²³⁾.

4.2.2.1 Beams of Constant Compressive Strength (25.5)MPa with Various (ρ_w):

The effect of longitudinal steel ratio on the shear strength for the tested beams, those having constant compressive strength (25.5MPa) and the steel percentages (0.0174, 0.024 and 0.0307) is shown in Table (7) and Fig. (8).

Tested beams exhibit the increase on shear strength due to the increase of (ρ_w), at both shear cracking and ultimate stages. The increase of (ρ_w) from 0.0174 to 0.0307 (76%) leads to increasing the ultimate shear force from 43 to 52 kN (21%). The explanation of this situation is as mentioned in the above section (4.4.2). Fig. (8) and Table (7) shows that the shear strength at ultimate stage of (NWC) beams is more than that of (LWAC) beams at the same compressive strength and the same tensile reinforcement. That is due to the tensile strength of (NWC) being more than that of (LWAC) by about 25% in this study. Fig. (9) explains the comparison between measured and predicted values of shear

strength of porcelinite beams, those that have the similar compressive strength, but having various steel percent. It is clear that the experimental measured values are greater than that predicted by Hanson, BS 8110 and ACI-02 code equations. So, the porcelinite aggregate concrete beams give good results for shear strength. From Table (7), it is found that the ratio V_{ucr} / V_{cal} which is considered as a factor of safety against the shear failure, is 2.833 (average value), for the ACI-02 equation (A-1), and it is 0.915 (average value), for the Mu'taz equation (A-5). These average values of the ratio V_{ucr} / V_{cal} , which is calculated from the equations, (A-1) and (A-4), are for all nine tested (LWAC) beams. From that the following relations can be obtained:

$$V_{cal} - ACI = 0.35 V_{ucr} \quad \text{----- (1)}$$

$$V_{cal} - Mu'taz = 1.1 V_{ucr} \quad \text{----- (2)}$$

For porcelinite reinforced concrete beams, investigated in this study, the ACI-02 equation gives the reduction factor about 65%. Mu'taz equation is not suitable for predicting the shear strength for this investigation. It gives values about 10% more than measured values (V_{ucr}).

4.3 Crack Pattern Development and General Behavior

The general cracking performance was similar to all the (LWAC) beams which were considered as short beams ($a/d \leq 2.5$)⁽¹⁸⁾. (NWC) beams exhibited the same behavior. All beams tested in this study failed in shear. The modes of failure were similar for all beams (shear compression-tension failure) except that (B7) failed by shear tension failure.

Plate (2) shows the crack patterns for some beams.

5. Proposed equation

5.1 Basic Shear Transfer Mechanisms

Depending on shear transfer mechanism as shown in Fig.(10). So the total shear force which can be resisted:

$$V = V_c + V_a + V_d \quad \text{----- (3)}$$

5.2 Development of Shear Equation

Depending on reference (22) which has studied the behavior of strength of porcelinite reinforced beams, the shear resistance of uncracked concrete in the compression zone can be expressed as:

$$V_c = C_1 (f'_c)^{0.173} \cdot \rho_w^{0.346} \cdot bd \quad \text{----- (4)}$$

In which C_1 is constant.

The shear force carried by the aggregate interlock is

$$V_a = C_2 (f'_c \cdot \rho_w \cdot d/a)^{1/3} \cdot bd \quad \text{----- (5)}$$

In which C_2 is constant.

The dowel force is represented as:

$$V_d = C_3 (f'_c)^{0.5} \cdot (\rho_w)^r \cdot bd \quad \text{----- (6)}$$

In which C_3 is some constant and r , varying from 0.3 to 0.5 in a practical range, is a parameter that is dependent on spacing of the reinforcement. Substituting Eq.(5.2), (5.3) and (5.4) in Eq.(5.1), with some simplifications, gets this shape of the formula

$$v = \frac{V}{bd} = C_4 (f'_c)^s \cdot r_w^l \cdot \left(\frac{d}{a}\right)^w \quad \text{-----}(7)$$

Depending on the general shape of the above formula and using the experimental data of this study (compressive strength, steel percentages, and a/d, values), is obtain suitable parameters for new proposed equation, which must be acceptable for this work.

By using the statistical program (statistica Version 5.5), for several trials we get the final form of proposed equation for reinforced (LWAC) beams of a/d equal to 2.5 as follow:

$$v = \frac{V}{bd} = 0.6 \cdot f'_c \cdot (r_w)^{\frac{1}{3}} \cdot \frac{d}{a} \quad \text{-----} (8)$$

For ($20 \leq f'_c \leq 30$) and ($1745 \leq \rho_c \leq 1855$) at age 28 days⁽²⁴⁾.

6. Conclusions

The results indicated that the structural light-weight aggregate concrete produced from local porcelinite aggregate conforms to requirements of class 1 according to RILEM classification, it can produce structural light weight concrete of compressive strength varies from (23.0 to 29.8) MPa with the density ranges from (1745 to 1855) kg/m³, by using cement content about (550 and 650) kg/m³. Such concrete exhibited good mechanical properties. It gave the values of splitting tensile strength, modulus of rupture and modulus of elasticity, 75%, 90% and 60% from those of normal weight concrete respectively having the same compressive strength and meeting the requirement of ACI-213. The structural results indicate that the strength of reinforced light weight concrete beams on shear is acceptable. More often, the experimental results give values more than that of the predicted equation. The results are 2.9 times more than that of (ACI-02) code and 2.5 times more than that of Hanson equation. It has been found that the diagonal and ultimate tensile strength of porcelinite light weight aggregate reinforced beams are affected by the same variables as those influencing normal weight concrete. The difference between the two types of materials is in the magnitude of diagonal and ultimate tensile resistance and is not a fundamental difference in behavior. The beams which have a compressive strength and steel percentage similar to those of normal weight concrete beams gave shear strength 20% less than that of normal weight concrete beams at ultimate failure.

The results showed that the compressive strength had the significant influence on the shear strength of the porcelinite reinforced concrete beams. When the compressive strength increased from (23 to 29.8) MPa, the ultimate shear strength increased from (50-57.50) MPa. In the last part of the study, it is found that the proposed equation gives more suitable values than those of well-known equations and the authors which are used in this study through the comparison

$$v = \frac{V}{bd} = 0.6 \cdot f'_c \cdot (r_w)^{\frac{1}{3}} \cdot \frac{d}{a}$$

with experimental results related with the porcelinite reinforced concrete beams. The proposed equation as follow:

Table (1) Physical properties of porcelinite aggregate

Property	Specification	Results
Specific gravity	ASTM C127-84 ⁽²⁵⁾	1.6
Absorption %	ASTM C127-84	37.2
Dry loose unit weight (kg/m ³)	ASTM C29-87 ⁽²⁶⁾	802*
Dry rodded unit weight, (kg/m ³)	ASTM C29-87 ⁽²⁶⁾	838
Aggregate crushing value%	BS812-part110-1990 ⁽²⁷⁾	17

*Within the limit of ASTM C330 (880 Kg/ m³)

Table (2) Chemical analysis of porcelinite aggregate

Oxides	% By weight
SiO ₂	69.77
Fe ₂ O ₃	1.48
Al ₂ O ₃	2.78
TiO ₂	0.14
CaO	6.52
MgO	5.7
SO ₃	0.15
L.O.I	11.45

#Tests were carried out by the stat company of geological survey and mining (SCGSM).

Table (3) Mineral analysis of porcelinite aggregate

Compound	% By weight
Opal-Ct	56
Quartz	3
Dolomite	11
Apatite	4
Clay	25

#Tests were carried out by the SCGSM.

Table (4) Grading of coarse porcelinite aggregate

Sieve size (mm)	% Passing ASTM C330-87 ⁽¹⁴⁾	Coarse aggregate % passing
12.5	100	100
9.5	80-100	84.3

4.75	5-40	33.5
2.36	0-20	10.7
1.18	0-10	0.72

Table (5) Mix proportions for (LWAC)⁽²⁴⁾

No.	Quantities kg/m ³			w/c	Sp. % wt. of cements	Density kg/m ³	f'c (MPa) at 28day s	Slump (mm)	
	Cement	Natural Sand	Crushed porcelinite						
LWAC	1	550	500	520	0.40	2	1755	23.8	110
	2	550	500	520	0.36	2	1760	24.3	90
	3	550	500	520	0.32	2	1820	26.5	80
	4	550	500	520	0.44	2	1745	20.9	130
	5	550	500	520	0.42	2	1747	23.3	125
	6	600	600	500	0.30	2	1810	28.3	65
	7	650	600	440	0.30	2	1815	29.03	60
NWC	8	350	865	960	0.40	-	2314	25.6	150
	9	400	840	960	0.50	-	2338	25.0	115

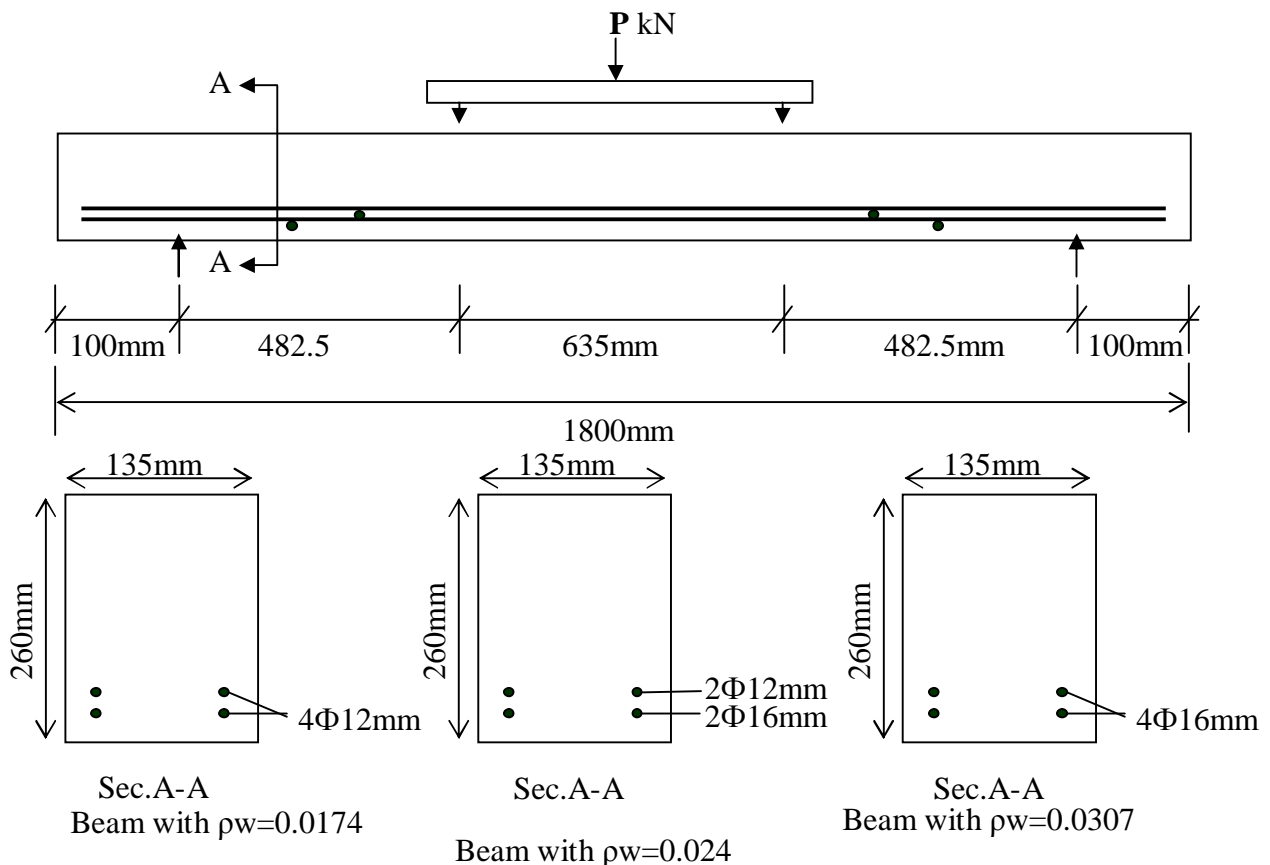
Table (6) Properties and details of beams⁽²⁴⁾

	B9	135	260	1800	1600	482.5	193	2.5	0.0307	7
NWC Beam No.	B10	135	260	1800	1600	482.5	193	2.5	0.024	Mix. 8
	B11	135	260	1800	1600	482.5	193	2.5	0.0307	used 8
	B12	135	260	1800	1600	482.5	193	2.5	0.0307	tab. 9 (3.12)
LWAC	B1	135	260	1800	1600	482.5	193	2.5	0.0174	1
	B2	135	260	1800	1600	482.5	193	2.5	0.024	1
	B3	135	260	1800	1600	482.5	193	2.5	0.0307	1
	B4	135	260	1800	1600	482.5	193	2.5	0.0307	2
	B5	135	260	1800	1600	482.5	193	2.5	0.0307	3
	B6	135	260	1800	1600	482.5	193	2.5	0.0307	4
	B7	135	260	1800	1600	482.5	193	2.5	0.0307	5
	B8	135	260	1800	1600	482.5	193	2.5	0.0307	6

Table(7) Summary of the results of LWAC and(NWC)beams and comparative equations ⁽²⁴⁾

Beams	a/d	ρ_w	f'_c MPa	V_{er} kN	V_{ucr} kN	Hanson Eq. or (A-3)		BS-8110 Eq. (A-2)		ACI318M-02 Eq. (A-1)		Mu'taz Eq. (A-4)		ACI318M-02 Eq. (A-5)		Failure mode	
						V_{cal}	V_{ucr}/V_{cal}	V_{cal}	V_{ucr}/V_{cal}	V_{cal}	V_{ucr}/V_{cal}	V_{cal}	V_{ucr}/V_{cal}	V_{cal}	V_{ucr}/V_{cal}		
LWAC	B1	2.5	0.0174	25.5	40	43	16.65	2.58	27.72	1.55	16.43	2.62	48.26	0.89	-	-	Tension-compression
	B2	2.5	0.024	25.5	38	46	18.44	2.49	30.58	1.49	17.31	2.66	52.3	0.88	-	-	Tension-compression
	B3	2.5	0.0307	25.5	45	52	20.25	2.57	33.48	1.55	18.21	2.86	55.62	0.94	-	-	Tension-compression
	B4	2.5	0.0307	26.7	46	52.5	20.53	2.55	34.0	1.54	18.54	2.83	58.23	0.90	-	-	Tension-compression
	B5	2.5	0.0307	27.2	46.5	55.5	20.64	2.69	34.21	1.62	18.67	2.97	59.33	0.94	-	-	Tension-compression
	B6	2.5	0.0307	23.0	44	50	19.65	2.54	32.35	1.55	17.5	2.86	50.17	0.99	-	-	Tension-compression
	B7	2.5	0.0307	24.3	44	51	19.97	2.55	32.95	1.55	17.87	2.85	53.0	0.96	-	-	Diagonal Tension
	B8	2.5	0.0307	28.3	47	56	20.89	2.68	34.67	1.62	18.96	2.95	61.73	0.91	-	-	Tension-compression
	B9	2.5	0.0307	29.8	48	57.5	21.22	2.71	35.27	1.63	19.35	2.97	65.0	0.88	-	-	Tension-compression
NWC	B10	2.5	0.024	27.2	35	52	-	-	-	-	-	-	-	-	23.7	2.19	Tension-compression
	B11	2.5	0.0307	25.7	56	66	-	-	-	-	-	-	-	-	24.35	2.71	Tension-compression
	B12	2.5	0.0307	25.14	48	64	-	-	-	-	-	-	-	-	24.15	2.65	Tension-compression

V_{cal} = Estimated value of shear force, kN



Note: Effective depth for all Beams taken 193mm

Fig.(1) Loading and Specimen details ⁽²⁴⁾

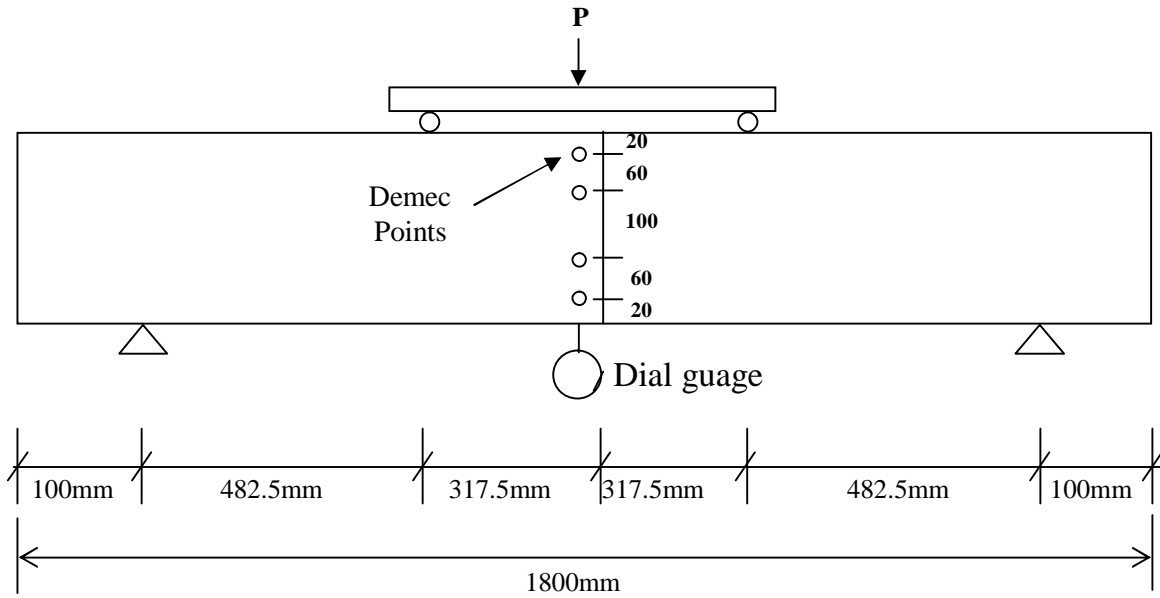


Fig. (2) Dial gauge and demec points locations ⁽²⁴⁾

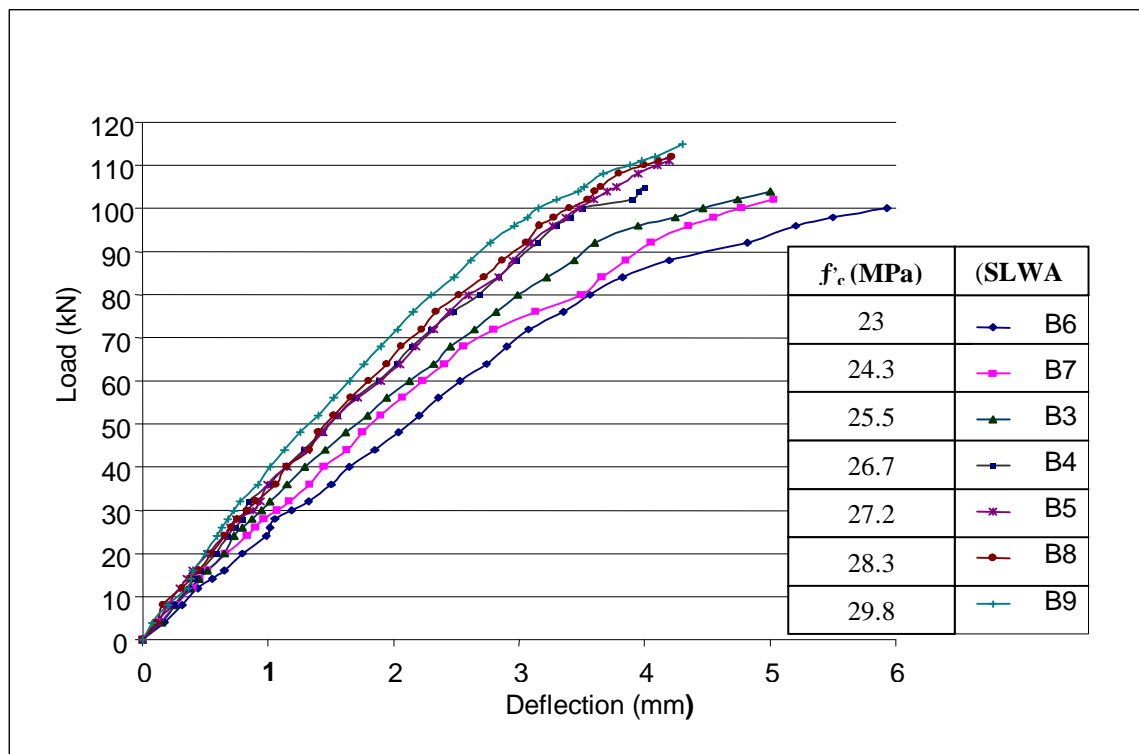


Fig.(3) Effect of compressive strength of concrete on Load-Deflection relation ships at mid span of (SLWACB) ⁽²⁴⁾

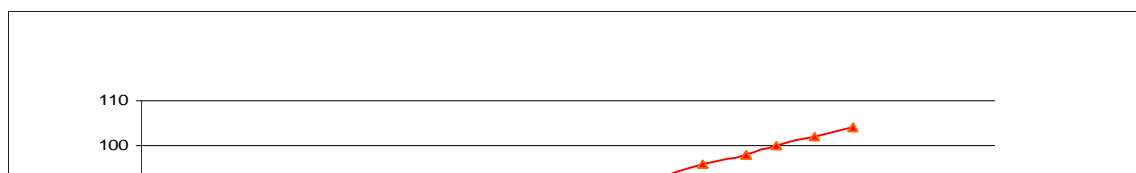


Fig. (4) Effect of longitudinal steel on Load-Deflection relationships at mid-span of (SLWACB)⁽²⁴⁾

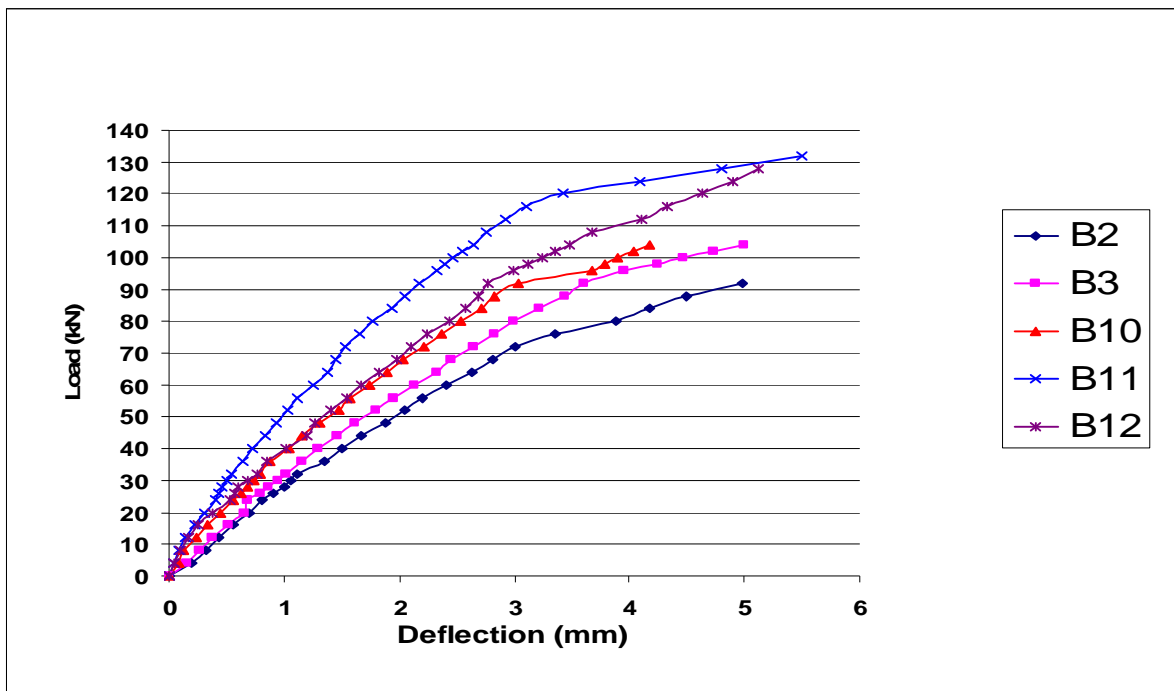


Fig. (5) Load-Deflection curves for (SLWAC) and (NWC) beams at mid-span⁽²⁴⁾

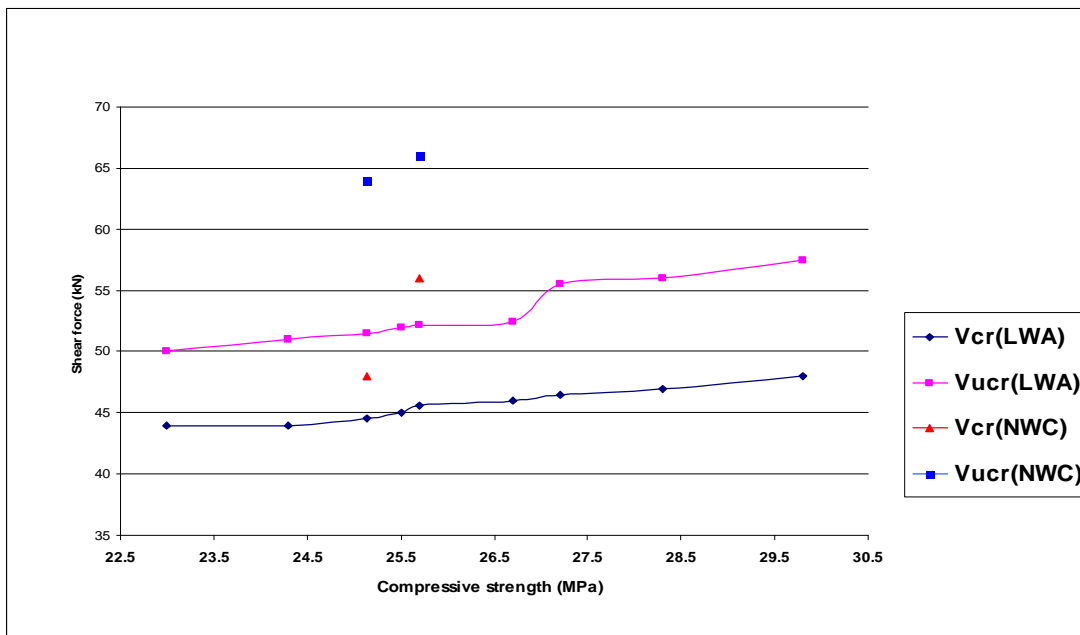


Fig. (6) Effect of compressive strength on shear strength for (SLWAC) and (NWC) Beams with constant ($\rho_w = 0.0307$)⁽²⁴⁾

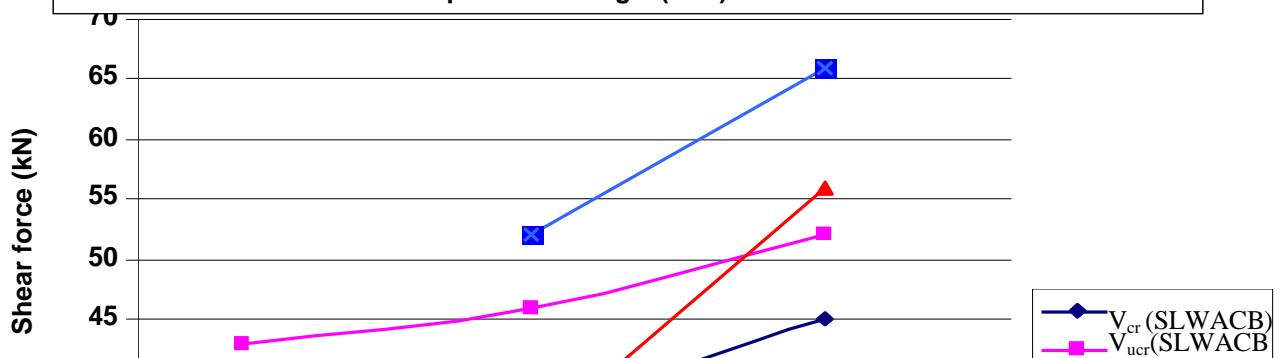
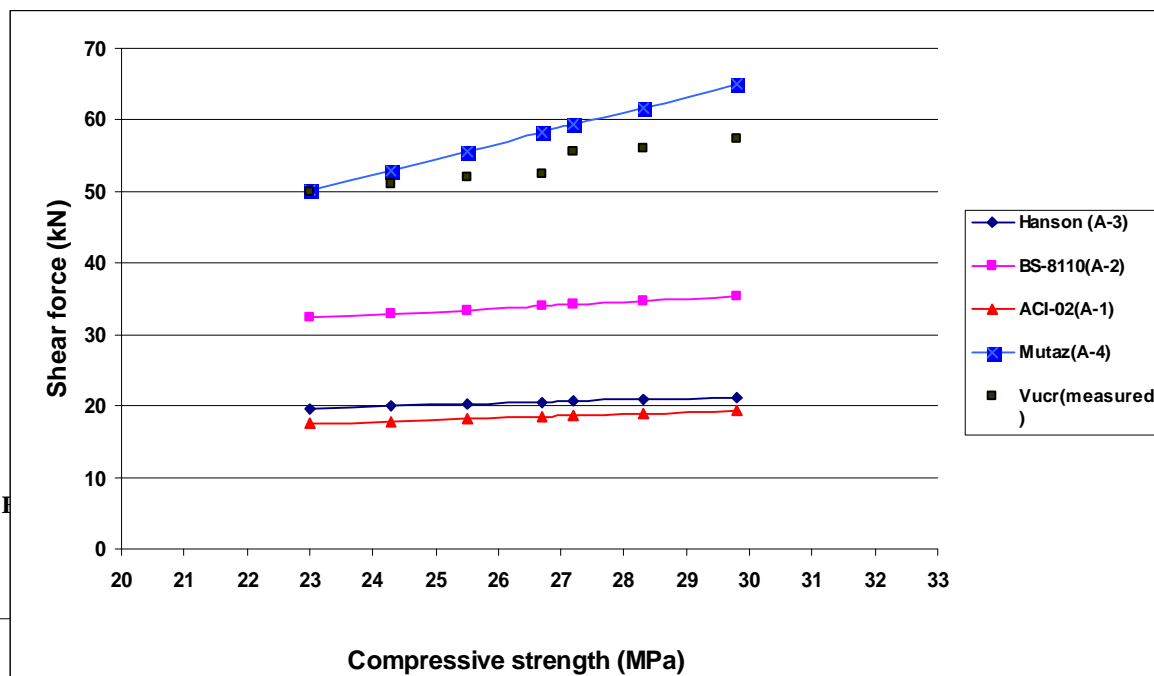
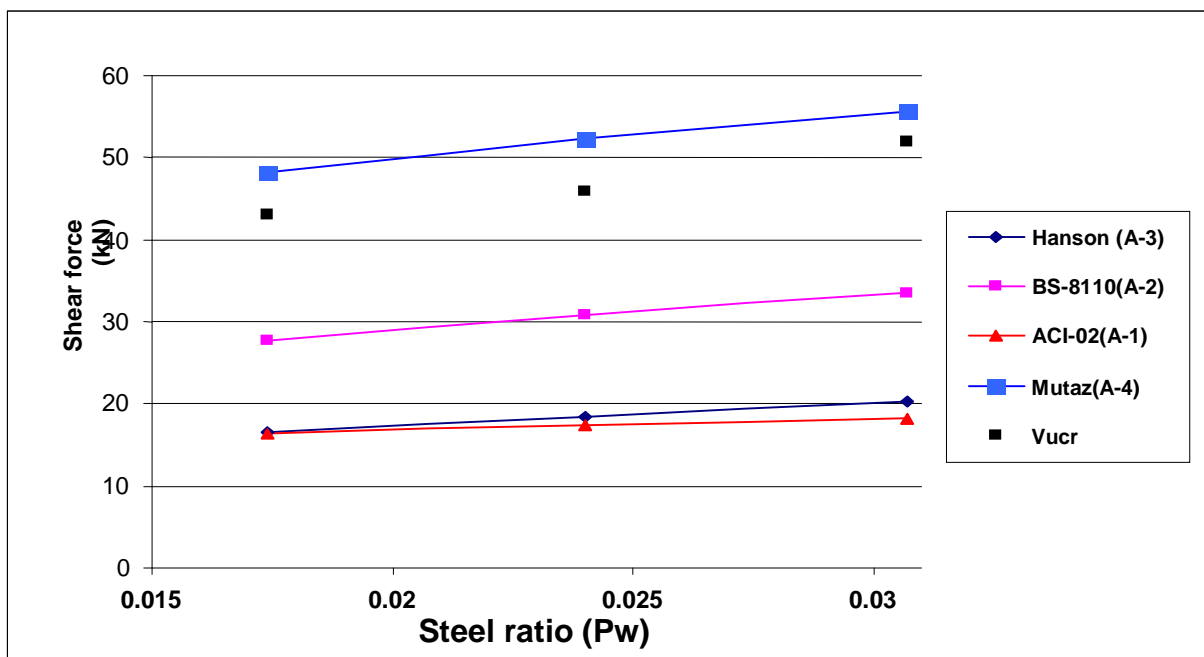


Fig. (8) Effect of steel ratio on shear strength of (SLWAC) Beams with constant compressive strength (25.5MPa)⁽²⁴⁾



(Constant compressive strength 25.5MPa)⁽²⁴⁾

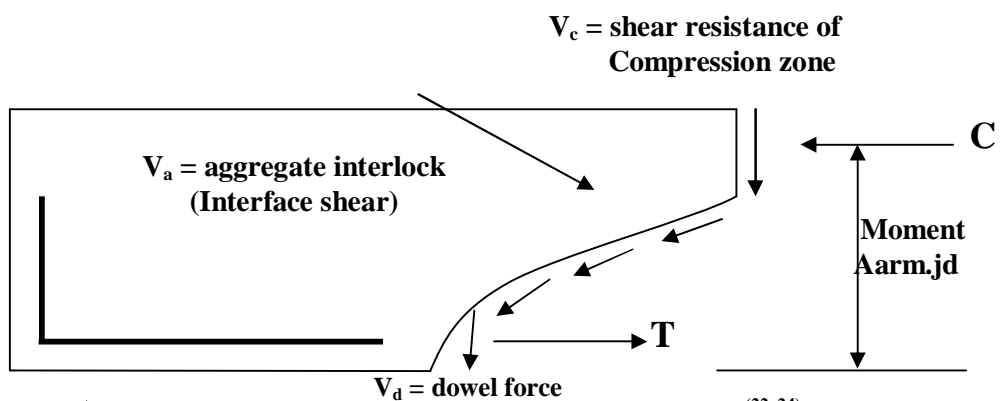


Fig. (10) Shear transfer mechanism of slender beams^(22, 24)



Plate (1) Beam test machine⁽²⁴⁾

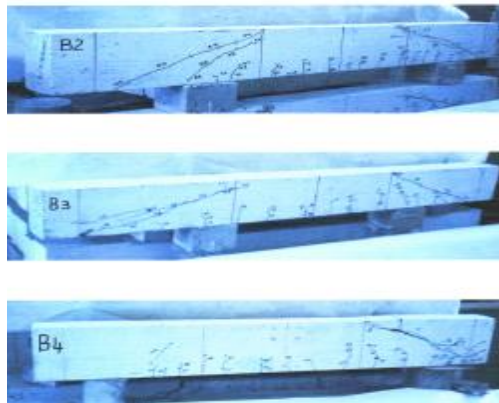


Plate (2) Crack pattern⁽²⁴⁾

References:

- 1-Shetty, M.S. "Concrete Technology", S. Chand and Company (PVT) Ltd, New Delhi, 3rd edition (reprinted), 1989, pp.502-517.
- 2-Short, A., and Kinniburgh, W., "Light Weight Concrete", CR Books Ltd. 3rd Edition, 1978, 442 pp.
- 3-Al-Dhaher, B.A.A., "The Use of Local Porcelinite for the Production of Light Weight Concrete Units", MSc. Thesis, University of Technology, April 2001, 113 pp.

- 4- الراوي ، قصي شرقي عبد العزيز "خواص الخرسانة خفيفة الوزن المصنعة من ركام البورسيلينايت" رسالة ماجستير ، كلية الهندسة/ القسم المدني - جامعة بغداد ، نيسان 1995 ، ص 117.
- 5-Al-Haddad, M.Y., "Durability of Porcelinite Light Weight Concrete against Chloride and Sulfate Solutions", M.Sc. Thesis University of Technology, Aug.2000, 145 pp.
- 6-Al-Ani, M.K.M., "Corrosion of Steel Reinforcement in Structural High Performance Light Weight Concrete", M.Sc. Thesis, university of Technology, April 2002, 104 pp.
- 7-Al-Kadhi, A.G.T., "Engineering Properties of High Performance Fiber Reinforced Porcelinite Light Weight Aggregate Concrete for Structural Purposes", M.Sc. Thesis, University of Technology, May 2002, 139 pp.
- 8- Al-Wahab, M.A., "Fire Resistance Properties of Porcelinite Light Weight Concrete", M.Sc. Thesis, university of Technology, July 2003, 133 pp
- 9-Al-Musawi, J.M., "Flexure Behavior of Porcelinite Reinforced Concrete Beams", Doctor Philosophy Thesis, University of Technology, November 2004, 189 pp.
- 10-Al-Jabbory, W.M., "Mining Geology of Porcelinite Deposits in - Jandali-Western Desert, Iraq", M.Sc. Thesis, University of Baghdad, October 1999, 100 pp.
- 11- Al-Sahlani, M.H., "Behavior of Repaired Reinforced Normal, High and Light Weight Concrete Beams Failed in Shear", M.Sc. Thesis, University of Al-Mustansiriya, September 2005, 96 pp.
- 12-Rebeiz, K.S., Fente, J. and Frabizzio, M.A., "Effect of Variables on Shear Strength of Concrete Beams ", Journal of Materials in Civil Engineering, ASCE, V.13, No.6 , Nov - Dec. 2001, Pp. 467- 470.
- 13-Kim, J.K. and Park, Y.D., "Prediction of Shear Strength of Reinforced Concrete Beams Without Web Reinforcement", ACI Journal, V.93, No.3, Mar.1996, pp. 213-221.
- 14- ASTM C330-87, "Standard Specification for Light Weight Aggregates for Structural Concrete", Annual Book of ASTM Standards, Vol. 04-02, 1988, pp. 187-189.

References:

- 15-RILEM (1978) Functional Classification of Light Weight Concrete Recommendation LC2., 2nd Edition.
- 16-ACI Committee 211, Recommended Practice for Selecting Proportions for normal and heavy Weight Concrete (ACI 211, 1-77), *j. Amer. C0ncr.*

- Inst.*,66,No.8, pp.612-29(1969); 70, No. 4, pp.577-8 (1974); 74, No. 2 pp. 59-60 (1977).
- 17- ACI Committee 318, “Building Code Requirements for Structural Concrete (318M-02) and Commentary (318RM-02)” American Concrete Institute, 2002, 443 pp.
- 18- ACI-ASCE Committee 426,“The Shear Strength of Reinforced Concrete Members”, ACI Manual of Concrete Practice, Part 4 , 1985, 111 pp.
- 19-Hanson, J.A. (1958), “Shear Strength of Light Weight Reinforced Concrete Beams”, ACI J., 30(3), pp. 387-403.
- 20-Hanson, J.A., “Tensile Strength and Diagonal Tension Resistance of Structural Light Weight Concrete”, American Concrete Institute Journal, Proc. Vol.58, July, 1961, pp. 1-39.
- 21-BS 8110 (1997), “Code of Practice for Design and Construction”, 2nd Edition, BSI, London.
- 22- Al-Dhalimi, M.K., “Shear Behavior of Porcelinite Aggregate R.C. Beams”, Ph.D Thesis, University of Technology, April 2005, 134 pp.
- 23-Elzanaty, A.H., Nilson A.H. and Slate, F.O. (1985), "Shear-Critical High- Strength Concrete Beams", Department of structural Eng. , School of Civil and Environmental Eng., Cornell University, Report 85-1.
- 24-Al-Mohamady Ali F.,”Shear Strength of Porcelinite Aggregate Reinforced Concrete Beams” MSc. Thesis, Engineering College, University of Anbar, Febreuary 2007,106 pp.
- 25-ASTM C29-87, “Standard Test Method for Unit Weight and Voids in Aggregate”, Annual Book of ASTM Standards, Vol.04-02, 1988, pp. 1-3.
- 26-ASTM C127-84, “Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate”, Annual Book of ASTM Standards, Vol.04-02, 1988, pp. 64-68.
- 27-BS 812, Part 110, 1990, “Method for Determination of Aggregate Crushing Value (ACV)”, British Standards Institution, 8 pp.

Appendix A

1-For LWAC:*ACI 318M-02*

Eq. (11-5):

$$V_c = 0.85 \sqrt{f'_c + 120 \rho_w v_u d / M_u} bd / 7 \quad \text{----- (A-1)}$$

British standards institution, BS-8110-1997

$$V_c = 0.85 \sqrt{1.25 (100 \rho_w)^{1/3} (400/d)^{1/4} (\sqrt{f'_c} / 25)^{1/3}} bd \quad \text{----(A-2)}$$

Hanson's Equation:

$$V_c = (\sqrt{f'_c + 285 \rho_w v_u d / M_u}) bd / 11 \quad \text{----- (A-3)}$$

Mu'taz Equation:

$$V_c = (0.5 f'_c \rho_w^{1/4} d / a) bd \quad \text{----- (A-4)}$$

2-For NWC*ACI 318M-02*

Eq. (11-5)

$$V_c = (\sqrt{f'_c + 120 \rho_w v_u d / M_u}) bd / 7 \quad \text{----- (A-5)}$$

*Where:** *Modification for sand- light weight concrete.*