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SHEAR RESISTANCE OF MRPC LIGHTWEIGHT CONCRETE BEAMS WITHOUT STIRRUPS

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Abstract: Shear behavior of (9) modified reactive powder lightweight concrete beams (MRPLWC) beams without web reinforcement under two point loading system, are studied. A number of variables are used to show their effects on the diagonal cracking load and ultimate shear load. Those variables are: volume fraction of fiber (V_f), ratio of longitudinal reinforcement (ρ) and the ratio of the shear span to the effective depth (a/d). The test results show that the shear strength increased by increasing the volume fraction and the ratio of longitudinal reinforcement, while a reduction in shear capacity is noticed by increasing the ratio of shear span to effective depth (a/d).

Keywords: *Shear Capacity, Reactive Powder Concrete, Lightweight concrete, Rectangular Beams , Diagonal Cracking Load ,Ultimate Shear Load*

مقاومة القص للعتبات الخرسانية المصنعة من خرسانة المساحيق الفعالة المعدلة الخفيفة الوزن المجردة من تسليح للقص

الخلاصة: تم دراسة سلوك القص لأُثني عشرعتبة مصنعة من خرسانة المساحيق الفعالة المعدلة بخرسانة خفيفة الوزن الغير حاوية على تسليح مستعرض للقص والمفحوصة تحت تأثير قوتين مركزتين . تم اعتماد عدة متغيرات تم اعتمادها لدراسة تأثيرها على حمل التشقق والحمل الأقصى للقص. هذه المتغيرات هي النسبة الحجمية للالياف (V_f) ، نسبة حديد التسليح الطولي (ρ) اضافة الى نسبة فضاء القص الى العمق الفعال (a/d) .اشارت نتائج الفحص الى وجود تحسن في مقاومة القص نتيجة زيادة حجم الالياف الفولاذية ونسبة حديد التسليح الطولي في حين انخفضت مقاومة القص بزيادة نسبة فضاء القص الى العمق الفعال .

1. Introduction

Reactive powder concrete is an ultrahigh strength and high ductility composite material with advanced mechanical properties which is developed in 1990’s by French company Bouygues. It is a special concrete wherein the microstructure is optimized by precise gradation of all particles in the mix to yield maximum density.

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Reactive Powder Concrete (RPC) consists of fiber-reinforced، superplasticizers, silica fume-cement mixture with very low water-cement ratio (w/c) and very fine quartz sand (0.15-0.60 mm) instead of ordinary aggregate.

In fact, it is not a concrete because there is no coarse aggregate in the cement mixture. The absence of coarse aggregate was considered by the inventors to be a key aspect for the microstructure and the performance of the RPC in order to reduce the heterogeneity between the cement based matrix and the aggregate. RPC represents a new class of Portland cement based material with compressive strength in excess of 200 MPa. By introducing fine steel fibers, RPC can achieve remarkable flexural strength up to 50 MPa. The material exhibits high ductility with typical values for energy absorption approaching those reserved for metals.

MPRC produced by replacing a fraction of quartz sand by crushed graded aggregate less than (8 mm size) to reduce the cost of RPC and to produce high strength exactly in RPC.

(Collepardi ;1997) [1] reported that replacing of fine quartz sand (0.15-0.4 mm) with the same volume of natural aggregate (less than 8 mm size) did not change the compressive strength of RPC at the same W/C . These results could not be accepted with the model suggested by (Richared and Cheyrezy ; 1995) [2]".They attributed of high compressive strength of RPC to the better homogeneity of the mixture without coarse aggregate. The main purpose of the present study was to modify RPC by replacing a fraction of quartz sand by crushed natural aggregate (porcilinete max size 8 mm) to introduce the new concrete material by reduce the cost and weight of concrete and using the advantages of RPC**.**

2. Experimental Program

In this study, nine beams were cast and tested. The beams were simply supported and subjected to two point loads. The dimensions are identical for each beam and are illustrated briefly in Fig (1) and Table (1).

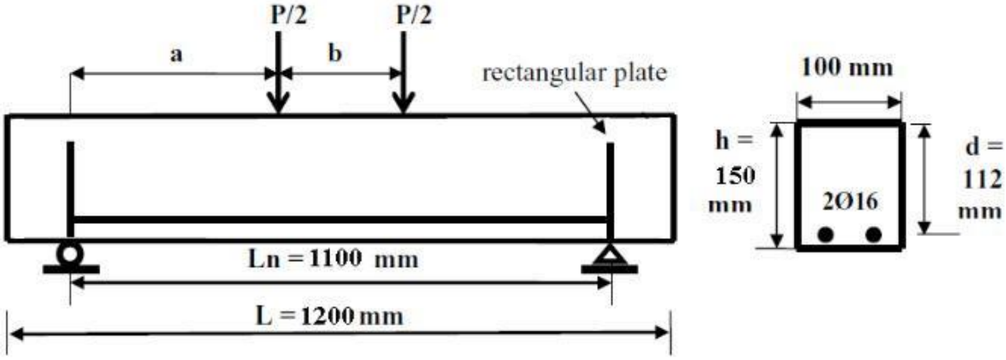


Figure1. Details of Tested Beams.

Table .(1): Characteristics of the Tested Beams.

Group	Beam No.	a (mm)	V_f	a/d	P	Reinforcement Amount
	B1	427	0.0	3.5	0.0329	2φ16
	B2	427	0.5	3.5	0.0329	2φ16
A	B3	427	1.0	3.5	0.0329	2φ16
	B4	427	2.0	3.5	0.0329	2φ16
B	B3	427	1.0	3.5	0.0329	2φ16
	B7	423	1.0	3.5	0.0427	φ16+φ20
	B8	420	1.0	3.5	0.0523	2φ20
	B9	305	1.0	2.5	0.0329	2φ16
	B3	427	1.0	3.5	0.0329	2φ16
	B10	488	1.0	4	0.0329	2φ16
C	B11	305	2.0	2.5	0.0329	2φ16
	B4	427	2.0	3.5	0.0329	2φ16
	B12	488	2.0	4	0.0329	2φ16

3. Materials

Locally produced ordinary Portland cement manufactured in Iraq was used throughout this work. The compressive strength at 3 days and 7 days are 24 MPa and 29 MPa, respectively. The blain fineness is 2650 cm^2/gm . In this work fine silica sand known as glass sand was used as fine aggregate with size (0.15-0.6) .The sulfate content is 0.35 %, specific gravity is 2.9 and absorption is 0.71%.The coarse aggregate used in this work was porecilenite which classified as lightweight aggregate in order to get modified reactive powder concrete .Porecilenite is a type of stone of white color. At first, the stone crushed by crusher machine at material laboratory in the College of Engineering at Mustansiryah University. The specific gravity is 1.46 and the absorption is 35%. Locally produced silica fume (SF) was used throughout this work. According to the manufacturer, the powder had a moisture content of 0.68% and specific surface area of 20 m^2/gm. Flocrete PC260 admixture was used as a high range water reducer conforming to ASTM C 494 (types A and G) [3]. The admixture is a Light-yellow liquid with a specific gravity of (1.1±0.02) at 25 ^oC. The steel fiber used to improve the mechanical properties , were of 0.2 mm diameter, 13 mm length, of 65 aspect ratio (L/D) and density of 7830 Kg/m^3. Also high tensile deformed steel bars (of 16 mm and 20 mm nominal diameters) were used as tension reinforcement. The bars had a yield strength of 507 MPa for 16 diameter bar mm and 496 for 20 mm diameter bar.

4. Mixes and Mixing Procedure

Four types of lightweight MRPC mixes were used in the present work as listed in Table (2). The variables of these mixes were the volume fraction of steel fiber (V_f) (where 0.0 , 0.5 , 1.0 and 2.0 %) value were considered and ratio of silica fume as additives were 10 %.

Table (2) Proportion of the used MRPLWC Mixes.

Mix Type	Cement Kg/m^3	Sand Kg/m^3	Coarse Aggregate (Porcelnite)****	SF %*	Flocrete** PC 260	W/C	Fiber Content***
M0-10	900	900	50%	10	5%	0.2	0.0
M0.5-10	900	900	50%	10	5%	0.2	0.5
M1-10	900	900	50%	10	5%	0.2	1.0
M2-10	900	900	50%	10	5%	0.2	2.0

* Percentage of cement weight.
** Percentage of binder (cement + silica fume) weight.
*** Percentage of mix volume.
**** Percentage of fine aggregate

The mixes were mixed using a rotary mixer of 0.15 m^3 capacity at the material laboratory in the college of engineering at Mustansiriyah University.

Plate (1) Testing Set up .

5. Shear Strength of MRPLWC beams

5.1 Effect of Volume Fraction of Steel Fiber (V_f)

Figure (2) shows the relation between fiber volume fraction of steel fiber on both the ultimate shear load and the diagonal shear load. It was found that the diagonal shear load increased by (45.45 , 59.1 and 81.82 %) and the ultimate shear load increased by (15.6 , 20.3 and 146.87%) by using fiber volume fraction of (0,0.5,1 and 2%) respectively by compared with the control non fibrous lightweight MRPC beam B1. Increases in the cracking and ultimate load capacities associated with the steel fibers enhance the performance of both shear transfer mechanisms by friction or interface shear along the diagonal crack surface and shear stresses of the uncracked compression zone and the orientation of fibers through restricting propagation flexural cracks restricted .The orientation of fibers across the initiating flexural cracks restricted its propagation and transmitted the tensile stresses uniformly to the concrete media surrounding the crack instead of being concentrated at its tip. This would result in reduced stress intensity at the crack tip so that the beam could accommodate an additional load before the initiating flexural crack being transformed into diagonal crack.

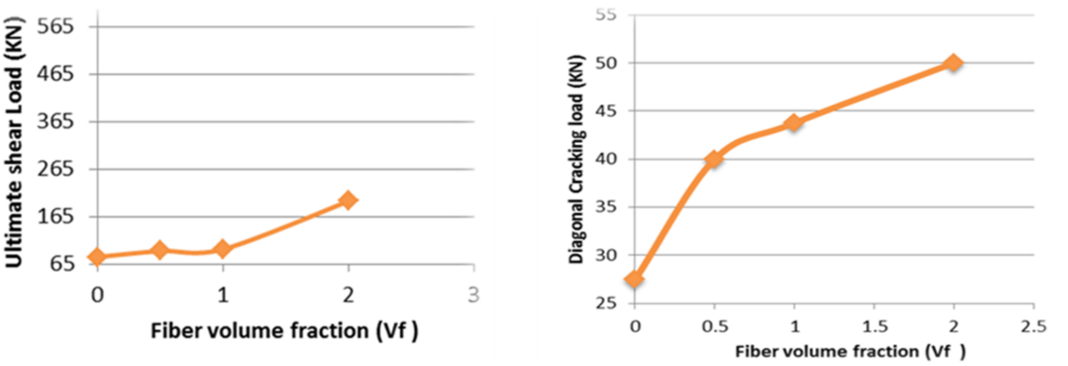


Figure2. Effect of Volume Fraction of Fiber on Shear Strengths of the MRPC beams.

5.2 Effect of Longitudinal Reinforcement Ratio (ρ)

Figure (3) shows the relation between the shear load and the longitudinal steel ratio of MRPC beams (B8, B7, and B3) which have different value of the longitudinal steel ratios which were (ρ) 0.0523, 0.0426 and 0.0329 respectively. In these beams the volume fraction of fibers , silica fume content and other parameters were kept constant (SF=10 % , V_f=1.0 % , a/d=3.5 , respectively).

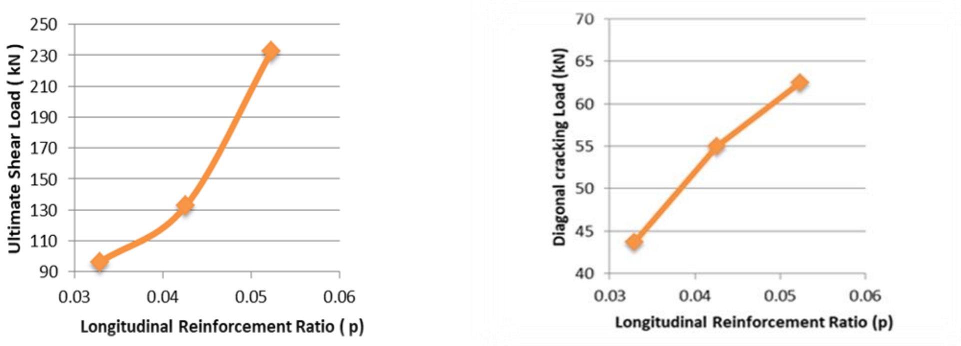


Figure 3. Effect of Longitudinal Reinforcement ρ on the Shear strength of MRPC beams .

It is noticed that increasing the steel rebars ratio ρ from 0.0329 to 0.0426 and 0.0523 increased the diagonal cracking load V_{cr} by about (25.7 and 42.86 %), respectively. Meanwhile, the ultimate shear load V_u increased by about (37.66 and 141.56%), respectively as shown Fig.(3). The longitudinal reinforcement ratio has a pronounced effect on the basic shear transfer mechanism. An important factor that affects the rate at which a flexural crack develops into an inclined one is the magnitude of shear stresses near the crack tip. The greater value of ρ reduce the width of the flexural crack. Increasing ρ also increases the dowel capacity of the member by increasing the dowel area and therefore, decreasing the tensile stresses in beams. Also with low ρ values the presence of steel fibers was significant in improving the splitting strength between the bars and concrete.

5.3 Effect of Shear Span to Effective Depth Ratio (a/d)

Figures (4) and (5) show the relationship between (a/d) ratio with shear load and diagonal cracking load respectively. The test result show that the shear load is more influenced with the effect of a/d ratio. In specimens with V_f =2.0 % , SF=10 % , ρ =0.0329 it was noticed that the shear load decreased by about (9.19 and 34.48%) when the (a/d) ratio increased from 2.5 to (3.5 and 4) . While this reduction was about (9.09 and 18.18%) , respectively in diagonal cracking load .In the other hand , in specimens with V_f=1.0, SF=10, *p*=0.0329 ,the reduction in shear load was about (53.614 and 56.63%, respectively and the diagonal cracking load was about (10.26 and36.25%) . For the same applied load level any intended increase in a/d ratio means higher bending moment in the shear span. This would result in an increase in flexural stress, the tensile stress , the shear stress and the principal tensile stress and hence decreases the diagonal cracking load. Therefore, by increasing the a/d ratio the flexural stresses close to the crack tip will increase ,

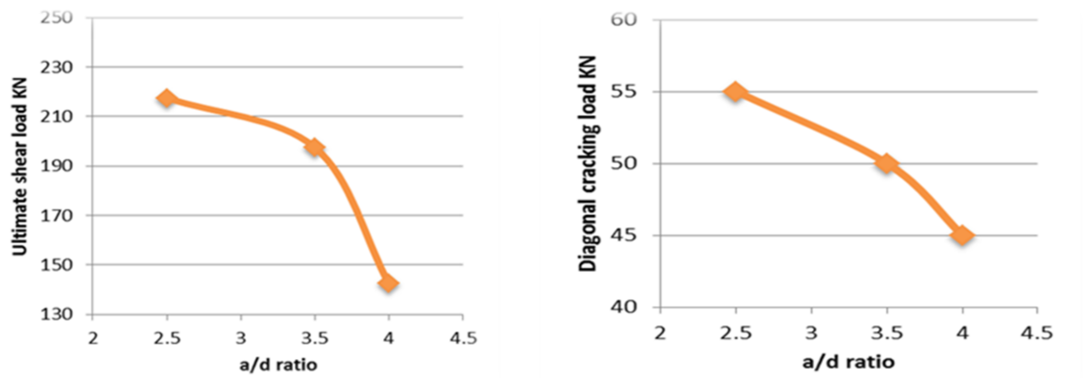


Figure 4. The Effect of Shear Span to Depth Ratio on the Shear Strength of MRPC Beams When V_f is Equal to 2.0%.

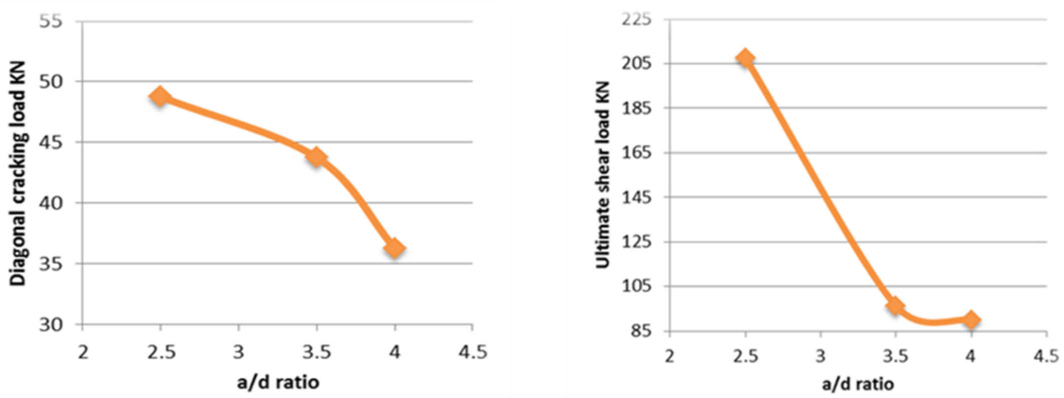


Figure5. The Effect of Shear Span to Depth Ratio on the Shear Strength of MRPC Beams when V_f Equal to 1.0% .

6. Load-Deflection Behavior

6.1 Effect of Volume Fraction of Steel Fibers (V_f)

Figure (6) shows the effect of volume fraction of steel fibers V_f on mid span deflection of lightweight MRPC beams B1 (V_f=0.0) and B2 (V_f = 0.5) , B3 (V_f = 1.0) and B4 (V_f = 2.0).From Fig.(6) it is clear that at early stage of loading the mid span deflection decrease as the volume fraction of steel fiber increased. This behavior may be attributed to the improved stiffness of light MRPC beam and improved the mechanical properties of MRPC concrete such as compressive strength, tensile strength and modulus of elasticity" .

It is clear from Fig.(6) that the midspan deflection at ultimate load is considerably increased by the presence of steel fiber . The addition of steel fibers to lightweight MRPC beams at volume fraction of (0.5 ,1.0 ,2 %) resulted in an increase in the value of midspan deflection by (11.9 , 42.86 and 80.95 %) respectively compared to the nonfibrous beam. Also, the ductility ratio increased by about (8 , 32.33 and 81 %) due to the use of steel fibers by (0.5 ,1.0 and 2%) respectively .

6.2 Effect of Longitudinal Reinforcement Ratio (ρ)

It observed from Fig.(7) that the midspan deflection at same load decrease with increase of longitudinal reinforcement (ρ) .This behavior is due to the fact that any increase in ρ leads to reduce the width of flexural cracks and hence decreases the deflection of the lightweight MRPC beams at the same load level by comparing the deflection response of MRPC beams B8 (ρ =5.23 %) , B7 (ρ = 4.26) and B3 (ρ =3.29 %) a steady decrease in value of midspan deflection with raising ρ value is indicated .It also observed from Figure (7) the midspan deflection at the ultimate load increases by 108.33 % and 33.33 %, respectively for B8 and B7 when compared with, B3 and that ductility ratio increased with increasing ρ . Finally the ductility ratio increased by 11.84 % for B7 and 65.74 % for B8 when compared with B3.

6.3 Effect of Shear Span to Effective Depth Ratio (a/d)

The load-deflection curve for the lightweight MRPC that beam Figs.(8) and (9) show that for a given load level at early stage of loading the deflection increases with increasing a/d ratio. Concerning the results of MRPC beams with V_f =2.0 the increase in a/d ratio from 2.5 for B11 to 3.5 for B4 and 4 for B12 increased the midspan deflection at ultimate load by about 13.87 % for B11 and 10.95 % for B4. Also the ductility ratio increased by 77.1 % for B11 and 11.04% for B4 compared with B12 For V_f =1.0 the increase in a/d ratio from 2.5 for B9 to 3.5 for B3 and 4 for B10 caused increased in value of the midspan deflection at ultimate load by about 211.11 % for B9 and 33.33 % for B3. Also ductility ratio increased by 149.22 % for B9 and 23.68 % for B3 compared with B10.

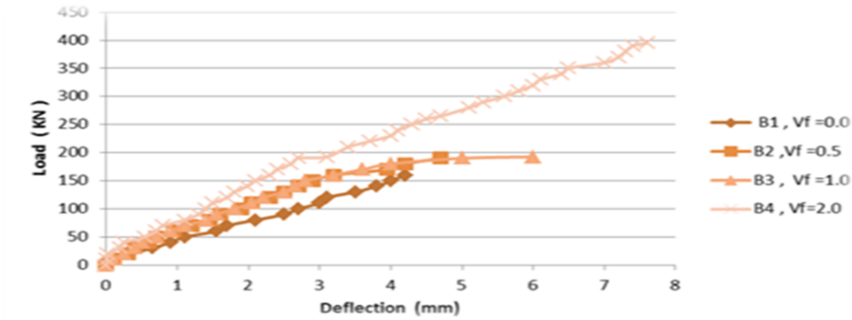


Figure 6. Effect of fiber content on the Load-Mid span Deflection Curves of MRPC Beams

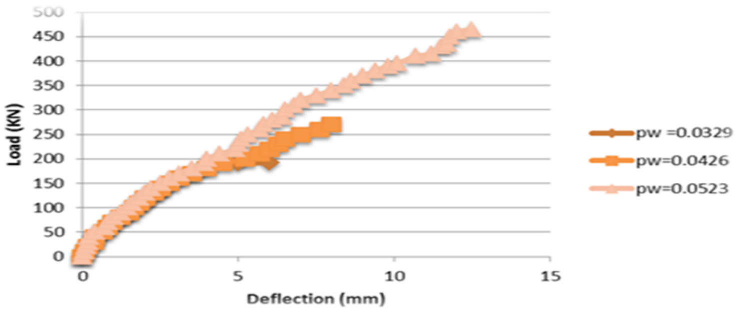


Figure 7. Effect of Steel Ratio ρ on the Load Mid-span Deflection Curves of MRPC Beams

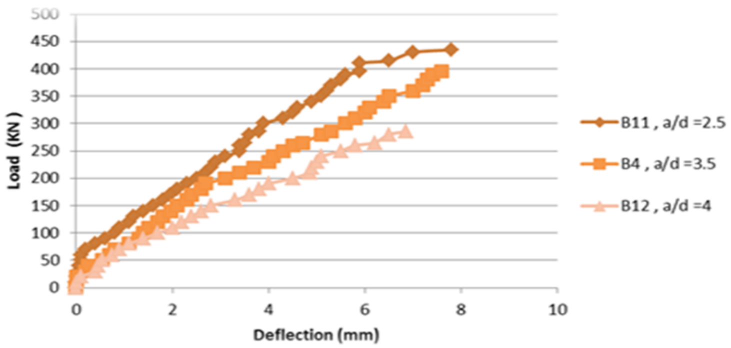


Figure 8. Effect of a/d Ratio on the Load-Mid-Span Deflection Curves of MRPC beams when V_F=2.0

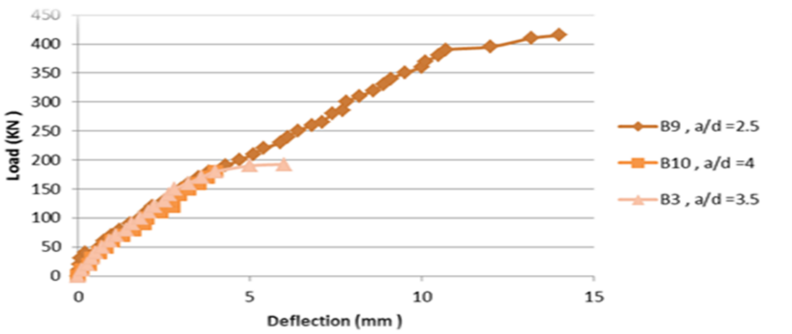


Figure9. Effect of a/d Ratio on the Load-Mid –span Deflection Curves of MRPC beams when V_f=1.0 .

7. Crack Patterns and Failure Mechanisms

The fibers volume fraction has a significant effect on the width and rate of growth of cracks. It was noticed that the beams without fibers failed suddenly with shear failure occurred after the formation of diagonal cracks. However, after initial in fibrous lightweight MRPC beams multiple cracks were observed to form soon and the rate of crack grows with increasing the fiber volumetric content .It is observed that in specimens with lower quantity of steel fiber, the cracks propagated by faster rate . However the ultimate load was higher than that in beam with higher percentage of steel fibers.

From above it was concluded that the failure mechanism depended on:

- Shear span to depth ratio a/d
- Volume fraction fiber V_f.
- Manner of loading.

All the beams tested in this study failed in shear .The mode of failure depends on (a/d) ratio. It was found that the specimens with (a/d) of 2.5 failed in shear, while the specimens with a/d of (3.5 and 4) failed in diagonal tension with the exception of B10 and B4 which was failed in shear-flexural failure. However the ultimate loads were higher than the inclined cracking loads by about 190.9 to 272 % for all beams with a/d ratio ranging from 2.5 to 4 and longitudinal reinforcement ratio varying from 3.29 percent to 5.23 percent and V_f varied from 0.0 % to 2 %.

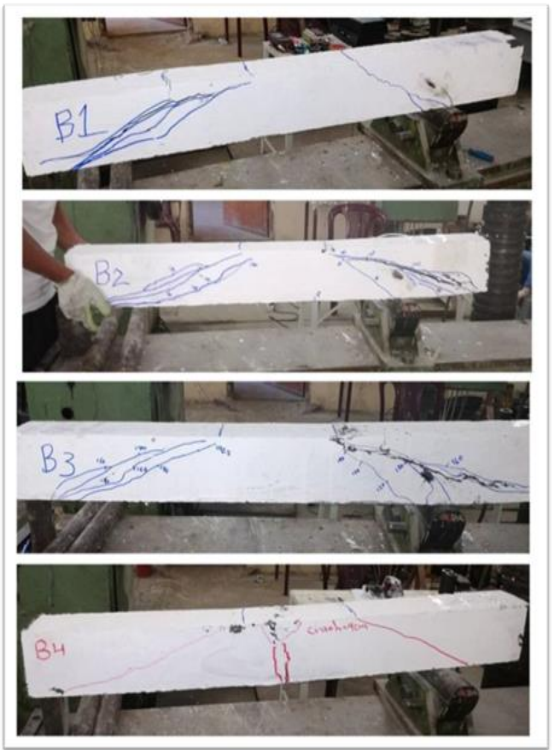
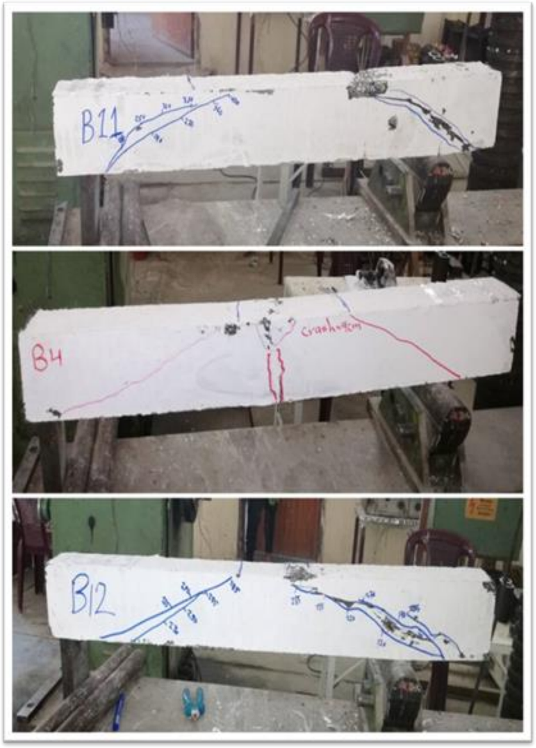


Plate (2) Crack Pattern in Group (A)

Plate (3) Crack Pattern in Group (B)



Plate(5) Crack Pattern in Group (C)when V_f=2

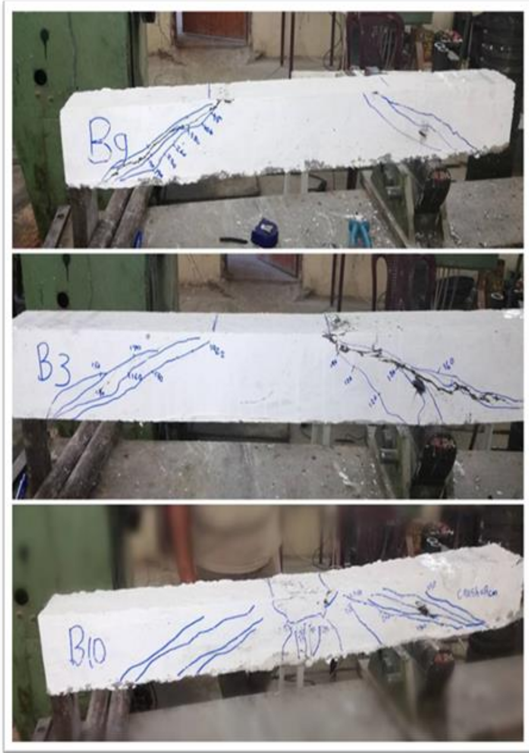


Plate (6)Crack Pattern in Group C when V_f =1.0 %

8. Conclusions

1. The inclusion of steel fibers in lightweight MRPC mixture affect the magnitude of the initial diagonal cracking load and ultimate load which are increased by increasing the volume fraction of fibers
2. Increasing the longitudinal reinforcement ratio ρ from 3.29 % , 4.26 % and 5.23 % in lightweight MRPC beams increased both the diagonal cracking load by 25.7 % and 42.86% respectively and ultimate load by 37.66 % and 41.56% respectively .
3. Increasing the shear span to effective depth ratio from 2.5 to 3.5 and 4 in lightweight MRPC beams having V_f = 2.0 % decreased the diagonal cracking load by 9.09% and 18.18 % respectively and the ultimate load decreased by 9.19 % and 34.48 % respectively.
4. The mode of failure is affected by the a/d ratio, and the volume fraction of steel fiber when the a/d ratio is increased from 3.5 to 4.0 and V_f increased from1.0 to 2.0 the mode of failure change from diagonal tension failure to shear–flexural failure.

9. Notation

MRPLWC	Modified Reactive Powder Lightweight Concrete
V_f	Volume Fraction of Steel Fiber
SF	Silica Fume Content
P	Longitudinal Reinforcement Ratio
a/d	Shear Span to Effective Depth Ratio

10. References

1. Collepardi, S., Coppola, L., Troli, R. and Collepardi, M.,(1997) *"Mechanical Properties of Modified Reactive Powder Concrete* " , In: V-M. Malhotra Ed. Proceeding Fifth CANMET/ACI International conference on Superplasticizers and the Chemical Admixture in Concrete , Rome , Italy, and Farmington Hills, MI: ACI Publication SP-173, pp. 1-21.
2. Richard, P., and Cheyrezy, M.,(1995) "*Composition of Reactive Powder Concretes"* ,Cement and Concrete Research, Vol. 25, No. 7, 1995, pp. 1501-1511
3. ASTM C 494/C 494M – 1999a, (1999) *"Standard Specification for Chemical Admixtures for Concrete",* Vol. 04.02, pp. 1-9.
4. Richard, P. And Cheyrezy, M. H."(1994*) Reactive powder concretes with high ductility and 200–800 MPa compressive strength*. "Concrete Technology : Past Present , and Future . Proceedings of the V. Mohan Malhotra Symposium , ACI , SP – 144 , S. Francisco . 4 ,pp. 507 – 518.
5. T. Sujatha, D. Basanthi (2014) , *Modified Reactive Powder Concrete* , International Journal of Education and applied research , Vol. 4, Issue Spl-2.