Journal of Engineering and Sustainable Development
Vol. 22, No.05, September 2018
ISSN 2520-0917
https://doi.org/10.31272/jeasd.2018.5.9

EFFECT OF STEEL FIBERS RATIO ON THE STRUCTURAL BEHAVIOR OF DOMES

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Abstract: The main objective of the current paper is to investigate the effects of the ratio of steel fibers on structural behavior of reinforced concrete hemispherical domes. Three reinforced concrete domes were experimentally implemented, two of them made fully of reactive powder concrete and the last one made of ferrocement concrete. All specimens have 800 mm diameter, 400 mm height and 20 mm thickness, and they reinforced with welded wire meshes. The experimental program included casting and testing the domes, by applied a single point load at the center of dome, until the failure is happened. The first cracking load, ultimate load, load deflection curves, and crack pattern for all tested domes were included in this study. In general, the effects of concrete type and the ratio of steel fiber are obviously important on the behavior and ultimate strength of the domes.

Keywords: *Hemispherical Dome, Ferrocement Concrete, Reactive Powder Concrete, Steel Fiber ratio.*

تأثير نسبة الألياف الفولاذية على السلوك الهيكلي للقباب

الخلاصة: الهدف الرئيسي من البحث الحالي هو معرفة الآثار المترتبة من تغيير نسبة الألياف الحديدية على السلوك الهيكلي للقباب النصف كروية. تضمنت الدراسة سلوك ثلاثة قباب من الخرسانة المسلحة، اثنان منها صبت من خرسانة المساحيق الفعالة، والاخيرة مصنوعة من الفيروسمنت. جميع النماذج صبت بقطر 800 ملم و ارتفاع 400 ملم و سمك 20 ملم ، وسلحت بمشبك من الأسلاك الملحومة. تضمن البرنامج العملي صب وفحص القباب، بتسليط حمل مركز في نقطة في اعلى القبة، لحين حدوث الفشل. كما تضمن البحث تسجيل قراءات قيم حمل التشقق الاول، الحمل الاقصى ، منحنيات الحمل-الانحراف وشكل الفشل. اظهرت الدراسة بشكل واضح تاثير كل من نوع الخرسانة و نسبة الالياف الحديدية على تصرف و مقاومة القباب.

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1. Introduction

The ACI code defines a thin shell as a three-dimensional spatial structure made up of one or more curved slabs or folded plates whose thicknesses are small compared to their other dimensions. Thin shells are characterized by their three-dimensional load carrying behavior, which is determined by the geometry of their forms, by the manner in which they are supported, and by the nature of the applied load [1].

Shell structures have played an important role in structural design throughout the centuries. Besides being visually appealing they possess interesting technical properties. From an engineering perspective, shell structures may be called the prima donnas of structures. Their behavior is difficult to analyze and can be somewhat unpredictable in that apparently small changes of geometry or support conditions may result in totally different responses [2].

Reactive Powder Concrete (RPC) is a developing composite material that will allow the concrete industry to optimize material use, generate economic benefits, and build structures that are strong, durable, and sensitive to environment. It consists of a special concrete where the microstructure is optimized by precise gradation of all particles in the mix to yield maximum density. It uses extensively the pozzolanic properties of highly refined silica fume and optimization of the Portland cement chemistry to produce the highest strength hydrates. Fibrous articles of different variety that consisted in RPC have a significant role in increasing its strength and cohesion. Through adding fibers, not just the strength, the structural perfection, and the post-crack status will be improved [3]. Steel fibers is a primary and secondary reinforcing medium and is most suited to thin sections and plates where stresses are highly variable [4].

This study aims at:

1. Evaluate the structural behavior of thin shell (dome) made with reactive powder concrete.
2. Investigate the influence of volume fraction of steel fiber on the structural behavior of dome.

2. Research Review

Silvia et al (2003) [5] indicate that the RPC mixes produced with brass plated fibers gave compressive and flexural strength higher than RPC containing the other types of fibers.

Ivana (2012) [6] presented that varying the thickness of the shell, with the largest thickness at the supports, leads to the most effective design in terms of reduced tensile Stresses, reduced deflections, and most efficient use of material.

Yousry, Boshra and Amany (2014) [7] found that the dome reinforced with fiberglass mesh has the highest service load and ultimate load and the dome reinforced with welded wire meshes achieved highest ductility ratio and energy absorption.

3. Experimental Program

3.1 *Materials*

3.1.1 Cement

Iraqi Ordinary Portland cement (Mass) (type I) is used in this study. The cement was stored in closed plastic containers throughout the experimental work to keep the cement in good conditions and to minimize the effect of humidity. Physical and chemical composition and properties of the used cement are given in Tables (1 and 2), respectively. The properties are conformed to the Iraqi Specifications limits [8] for ordinary Portland cement.

Table (1): Chemical Analysis and Compound Composition of the Used Cement*

Chemical Properties			
Chemical Component		By The Weight %	IQS 5/1984 Limitations
Name	Symbol		
Loss on Ignition	L.O.I	1.64	Not More than 4%
Silicon Dioxide	SiO_2	23.8	
Aluminum Oxide	Al_2O_3	5.08	
Iron Oxide	Fe_2O_3	4.63	
Calcium Oxide	CaO	59.34	
Magnesium Oxide	MgO	2.1	Not more than 5%
Sulphur Trioxide	SO_3	2.41	Not more than 2.8%when C3A more than 5%
Insoluble Residue	I.R	1.0	Not more than 1.5%
Tricalcium Aluminates	C_3A	5.64	
Lime Saturation Factor	L.S.F	0.76	0.66-1.02

*The Test was carried out by the Specialized Institute for Engineering Industrial.

Table (2): Physical Properties of the Used Cement*

Physical Properties			
Physical Property		Value	IOS 5/1984 Limitations
Name	Unit		
Specific Surface Area	cm^2/g	3100	Not Less Than 2300
Initial Setting Time	min	175	Not Less Than45
Final Setting Time	Hours	3.8	Not more than 10
Compressive Strength at3 days	MPa	25	Not Less Than 15
Compressive Strength at7 days	MPa	31	Not Less Than 23
Soundness by Autoclave Method	%	0.35	Not more than 0.8

*The Test was Carried Out by the Buildings Materials Laboratory of Engineering College-Mustansiriyah University

3.1.2 Extra fine sand

Extra fine sand, anti-slip aggregate #4, with size (300-400) µm is used for RPC mix. This type is from Don Construction products and its grading in accordance with the fine grading of the IQS No.45/1984 [9]. Table (3) shows the sieve analysis of this type of sand and Table (4) shows the physical properties of this extra fine sand satisfy the requirements of the IQS No.45/1984[9].

Table (3): Grading of the extra fine sand for RPC Compared with the Requirements of IOS NO.45/1984[9]

Sieve size (mm)	% Passing by weight	Limits of the IQS No.45/1984 (zone 3)
10	100	100
4.75	100	95-100
2.36	100	95-100
1.18	100	90-100
0.60	100	80-100
0.30	42	15-50
0.15	8	0-15

Table (4): physical properties of extra find sand for RPC

Physical properties	Test Results	Limits of the IQS No.45/1984
Specific gravity	2.70	-
Sulfate content	0.09%	≤ 0.50%

3.1.3. Water

Ordinary tap water was used for all the specimens.

3.1.4 Silica Fume

A grey densified grade 920 D silica fume (which is a byproduct from the manufacture of silicon or Ferro-silicon metal) was used, which was imported from the Elkem Company in UAE. Silica fume is an extremely fine powder, its particles are hundreds of times smaller than cement particles, always used in 15 to 25% by of cement[10], as partial replacement of cement or as an additive (as used in the present work) to enhance concrete properties. Chemical composition of silica fume used in this investigation is shown in Table (5). The used silica fume conforms to the chemical and physical requirements of ASTM C1240-04[11] as shown in Tables (6).

3.1.5 High Range Water Reducing Admixture (HRWRA)

The HRWRA used in this work is a third generation super-plasticizer for concrete and mortar which is known commercially as (Glenium 51). Glenium 51 has been primarily developed for applications where the highest durability and performance are required. Glenium 51 is free from chlorides and complies with ASTM C494-99type G and F.

Table (5): Chemical Analysis of Silica Fume *

Oxide composition	Oxide content %
SiO_2	86.46
Al2O3	1.6
Fe2O3	1.11
Na2O	0.3
K2O	1.9
CaO	1.8
MgO	1.9
SO3	0.25
L.O.I.	4.02

*Tests were carried out at the General Company of Geological Surveying and Mining

Table (6): Chemical and Physical Requirements of Silica Fume [11]

Requirement	Analysis %	ASTM C 1240 specification
SiO_2	86.46*	>85.0
Moisture content	0.68**	<3.0
L.O.I	4.02*	<6.0
Percent Retained on 45-µm (No.325) Sieve, Max.	7	<10
Accelerated Pozzolanic Strength Activity Index with Portland Cement at 7 days, Min. Percent of Control	128.6	>105
Specific Surface, Min, m^2/g	21	>15

*Tests were carried out at the General Company of Geological Surveying and Mining
**According to its certificate of conformity

3.1.6 Ultra-Fine Steel Fibers (UFSF)

Ultra-fine steel fibers are used throughout the experimental program. Shown in Figure (1). This type of ultra-fine steel fibers is manufactured by the Ganzhou Day Metallic Fibers Co, Ltd, China. The properties of the used steel fibers are presented in Table (7). Micro steel fiber is the material of Reactive Powder Concrete (RPC) and Slurry Infiltrated Concrete (SIFCON).

Figure. (1) Sample of Steel Fibers

Table (7): Characteristics of Used Steel Fibers *

Type of steel fiber	Density (kg/m^3)	Length of fiber (mm)	Diameter of Fiber (mm)	Tensile strength (MPa)	Modulus of Elasticity (GPa)
Straight	7800	15	0.2	2850	210

*Manufacturer properties.

3.1.6 Welded Wire Mesh

Square welded wire meshes as shown in Figure (2), their main properties are shown in Table (8).

Table (8): Properties of the Welded Wire Mesh mesh*

Property	Specifications
Yield strength (Fy)	302 MPa
Relative density	7860 kg /m^3
Modulus of Elasticity (Es)	67000 MPa
Average diameter	0.7 mm
Opening size of mesh	(13*13) mm

*According to manufacturer list

Figure. (2) Welded Wire Mesh.

3.2. Mix Proportions

Two types of concrete mixes were used in this investigation Ferrocement, RPC. The details of these two concrete mixes are shown in Table (9).

Table (9): Mix Proportions

Type of concrete		Cement (kg/m^3)	Fine Sand (kg/m^3)	Silica Fume (kg/m^3)	Volume of Fiber V_f%	w/c %	sp %
RPC	DR1	933	1030	234	1%	0.18	4%
	DR2	933	1030	234	2%	0.18	4%
Ferrocement Concrete	DF1	650	1310	65**	-	0.35	1% *

*1% percent by weight (cement + silica fume)
** 65= 10% replacement of cement content

3.3. Test Specimens

Three domes specimens with (thickness= 20mm, diameter= 800mm, height= 400mm) dimensions were tested. The variables are concrete type and the value V_f in RPC mix. All domes were simply supported along the four edges. Single point load applied at the center of dome. Table (10) shows the domes designation. Welded wire mesh of (0.7mm) diameter used as flexural reinforcement placed in the center of concrete. Each welded wire mesh have an average yield strength (fy) of (320 N/mm^2) determined from tensile test. The welded wire mesh is uniformly spaced and placed in two perpendicular directions.

One copper mold was used to cast the domes, first of mold was cleaned, assembled and oiled. The welded wire mesh was placed at their position on the mold .

For the domes with two types of concrete, the two domes were RPC with different percentage of micro steel fiber and one the dome was Ferrocement. The hardened domes were removed from the molds and cured in hot water containers at temperature of 60 c^o until testing at age of 28 days. The tested domes were placed on the testing machine and the load applied until failure. Figure (3) shows the molds, the welded wire mesh and the tested domes before and after casting.

Table (10): Designations and Dimensions Slabs Designation

Concrete Type	Dome Designation	Dimension(mm)		Thickness (mm)	Volume of Fiber (V_f %)
		H	D		
Ferrocement Concrete (FC)	DF	400	800	20	-
Reactive Powder Concrete (RPC)	DR1	400	800	20	1 %
	DR2	400	800	20	2 %

4. Results and Discussion

Type of concrete	Cubic strength (f cu) MPa	(Fsp) MPa	(fr) MPa	(Ec) GPa
Ferrocement concrete	40	4.68	4.95	34.62
RPC (vf= 1%)	130	7.17	11.3	50.44
RPC (vf=2%)	195	10.83	12.55	57.93

Photos in Figure (4) show the cracks patterns for the domes (DF, DR1 and DR2). It can be seen that all domes were failed due to punching shear and the cracks are observed the corner area. The nature of failure and distance between the face of the dome and the cracks are not same and differ from dome to another. The failure area in DF was narrower than DR1 and DR2. Whilst the cracks is much obvious in DR2 than in DR1 and Ferrocement. This can be attributed to the development of strength, the structural integrity and increase of volume of fiber (V_f = 2%) in DR2. The nature of failure of DR1 and DR2 confirm this explanation. Higher value of V_f in DR2 lead to improve the properties of RPC matrix and make it more capable to carry significant stresses over a relatively large strain capacity in the post-cracking stage, while the DF matrix will become the weakest substance and will fail before any crack can be noticed in RPC matrix.

Figure. (3) Molds and Tested Domes

DF

DR2

DR1

Figure. (4) Cracks Patterns and Failure Mode for the Tested domes.

Table (11): Cracking Loads of Tested domes.

Dome	DF	DR1	DR2
Cracking load(kN)	3.75	8.75	10
Failure load(kN)	13.75	45.75	56.25
(Pcr/Pu)*100%	27.27	19.1	17.8

It is noticed from Table (11) that, the cracking loads are about (27.27 %) of the ultimate loads for domes with Ferrocement and about (17.8 – 19.1) % for domes with RPC, from all above, it can be concluded that:

1. In general, domes with RPC have higher percent of cracking loads and this may be the reason for the more ductile failure mode that occurs for ultra-high strength concrete domes.

This may be illustrated that, the composition of RPC gives tensile strength higher than of Ferrocement. In addition, the used micro steel fibers improve the concrete tension, strength of splitting and rupture.

2. The cracking loads increase with the increase in compressive strength of concrete.

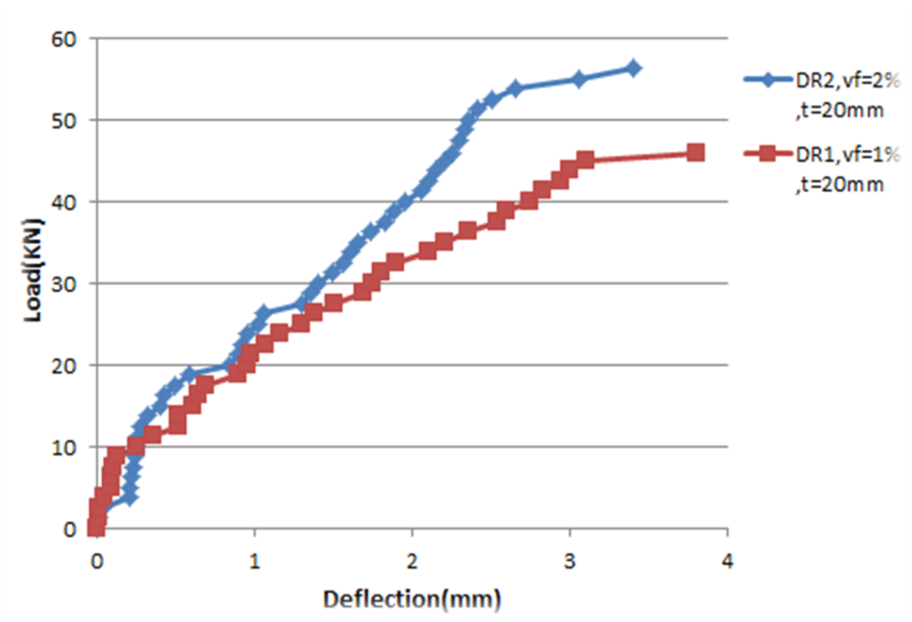

Figure. (5) Effect of Volume of Fiber on Load-deflection Behavior for RPC.

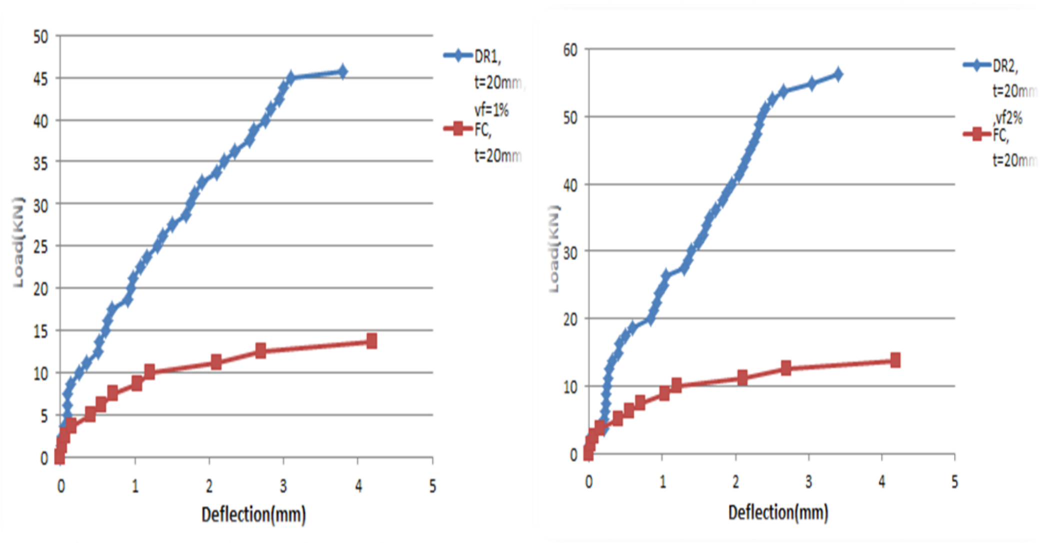

Figure. (6) Effect of Concrete Type on Load-deflection

Figure (5) shows that, the vertical deflection decrease with the increase of percentage of volume of fiber under loading. A maximum deflection of 3.8mm is obtained for the dome DR1 with ultimate load 45.75 kN. The maximum deflection for the dome DR2 is 3.4mm at 56.25 kN. It means that, the addition of volume of fiber increase the ductile behavior of RPC domes under in plan loading.

And Figure (6) it is noticed that, the difference in vertical deflections between Ferrocement and RPC for the same load is clear and considerable. This means that, the dome of RPC will behave in more ductile behavior of failure. It is also obvious from Figures (5) that, the curves for domes DF and DR1, also between DF and DR2 become close to each at the beginning of the curve.

5. Conclusions

1. The ultimate strength capacity of concrete domes is affected by volume of fiber. In general, the ultimate strength capacity of the dome increases with the increase in volume of fiber. For an increase in volume of fiber from V_f= 1% to V_f= 2% for RPC specimens, the increase in ultimate load when t= 20 mm is about 22.95 %.
2. The ultimate strength capacity of concrete domes is affected by concrete strength. The ultimate strength capacity of the dome increase with the increase in concrete strength. For an increase in concrete strength from (40 to 130) MPa for RPC specimens, the increase in ultimate load when t= 20 mm, V_f= 1% is about 232.72 %. The increase in ultimate load for RPC is about 309.1 %, for an increase in concrete strength from (40 to 195) MPa for domes when V_f= 2%, t= 20 mm.
3. The structural behavior and the vertical deflections of RPC domes depend on volume of fiber. The increase in volume of fiber of the domes from V_f (1% to 2%), leads to a decrease in the vertical deflection of the domes for RPC. The presence of volume of fibers for RPC specimens has an obvious effect on stiffening the domes, which reduces the vertical deflection.
4. The structural behavior and the vertical deflections of RPC domes depend on concrete strength. As concrete strength of the dome increase from (40 to 130,195) MPa, the vertical deflection decreases and the structural behavior of the domes tends towards more ductile failure. RPC domes exhibit less vertical deflection than Ferrocement.
5. The failure mode of the concrete domes is affected by concrete strength. The concrete strength has a minor effect on the failure mode of the concrete domes when the concrete type is changed from Ferrocement to RPC (concrete strength approximately from 40 MPa to 130, 195 MPa). The Ferrocement Concrete dames fail in a ductile manner; whereas, the RPC domes result in explosive more ductile type of failures.

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