GENERATION OF PUNCHING SHEAR STRENGTH STATISTICS OF FERROCEMENT SLABS

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Abstract

This study presents an experimental and statistical investigation on the punching shear strength of ferrocement slabs. Ferrocement, a thin composite material made of rich cement mortar reinforced with layers of wire mesh, has gained attention for its superior tensile strength, crack resistance, and ductility compared to conventional reinforced concrete. However, its behavior under punching shear—a critical failure mode in slabs and shell structures—remains inadequately explored. The research focuses on evaluating the punching shear strength of ferrocement slabs with varying mesh types, layer configurations, and thicknesses. Experimental tests were carried out on slabs subjected to concentrated loading to simulate punching shear conditions. The ultimate load-carrying capacity, failure pattern, and deflection behavior were recorded. Using the obtained results, statistical parameters such as mean, standard deviation, and coefficient of variation were derived to generate reliable strength statistics. The findings reveal that the punching shear capacity increases with higher reinforcement volume fraction and smaller mesh opening size. The results follow a normal statistical distribution, indicating consistent material performance and structural reliability. Comparisons with analytical predictions show close agreement, validating the experimental outcomes. This study contributes to the development of design data and statistical models for ferrocement slabs, supporting their wider application in lightweight and cost-effective structural systems.

Keywords: Ferrocement slabs, Punching shear strength, Statistical analysis, Wire mesh reinforcement, Structural performance, Reliability analysis

1. Introduction:

Ferrocement is a composite material constructed by cement mortar reinforced with closely spaced layers of wire mesh. The ultimate tensile resistance of ferrocement is provided solely by the reinforcement in the direction of loading. The compressive strength is equal that of the un reinforced mortar. However, in case of flexure and shear, the analysis and design of ferrocement elements are complex and are based primarily on the reinforced concrete analysis using principle of equilibrium and compatibility. Unlike studies on the behavior of ferrocement elements under flexure very limited research reports are available on the shear behavior of ferrocement elements. The reason for this may be due to the fact that the span to depth ratio of these elements is very high. But the use of ferrocement is not limited to stressed skin elements alone and it finds application in the construction of compound structural sections like I, T, C and L etc., Thus, there is a need for the understanding of this material under shear loading.

The most common type of reinforcement is steel mesh. Ferrocement is a thin cement mortar laid over wire mesh, which acts as a reinforcement. It is relatively cheap, strong and durable and is basic technique which can be easily acquired. Ferrocement is also known as ferrociment, ferrocemento, ferocimento and ferrozement. Over the past 20 years ferrocement has been used in a number of applications for the strengthening and repair of existing reinforced concrete, steel and concrete water tanks, sewers, swimming pools and the seismic retrofitting of masonry walls. Ferrocement coating are relatively lights and in most situations comparatively easy to install.

Ferrocement is a versatile construction material and confidence in the material is building up resulting in its wider application especially in developing countries such as for housing, sanitation, agriculture, fisheries, water resources, water transportation both in freshwater and marine environment, biogas structure, repair and strengthening of older structures, and others.

Considered to be an extension of reinforced concrete, ferrocement has relatively better mechanical properties and durability than ordinary reinforced concrete. Within certain loading limits, it behaves as a homogeneous elastic material and these limits are wider than for normal reinforced concrete. The uniform distribution and high surface area to volume ratio of its reinforced results in better crack arrest mechanism i.e. the propagation of cracks are arrested resulting in high tensile strength of the material.

II- LITERATURE REVIEW:

1. Historical background and foundational studies:

Ferrocement—thin cementitious elements reinforced with multiple layers of fine wire mesh—was investigated extensively from the 1970s onward for flexural and shear applications because of its high distributed reinforcement and crack-control ability. Early experimental and analytical work established ferrocement's advantages in ductility and distributed crack resistance compared with conventional RC, and set the stage for slab and panel studies. Key experimental investigations into punching/shear behaviour were reported toward the end of the 20th century; Al-Kubaisy & Jumaat's systematic experimental work on punching shear of ferrocement slabs remains one of the most frequently cited empirical studies.

2. Experimental findings influential parameters:

A consistent finding across experimental investigations is that punching shear capacity of ferrocement slabs is strongly governed by a small set of parameters: reinforcement volume fraction (number of mesh layers and wire diameter), mesh opening/type (welded square vs. chicken mesh), slab overall thickness, and mortar matrix strength. Studies show finer mesh and higher mesh volume fractions increase ultimate punching capacity and delay crack localization; increasing slab thickness and mortar strength also raise capacity but with diminishing returns compared to reinforcement details. Several laboratory programs (including self-compacting ferrocement slab tests) explicitly varied volume fraction, thickness and bearing-plate size to quantify these effects.

3. Statistical and predictive approaches:

Because ferrocement production and mesh placement introduce variability, several researchers have moved beyond single-value reporting to statistical and data-driven prediction of punching strength. Desayi & Nandakumar proposed semi-empirical prediction for ferrocement shear, while later work used larger experimental databases to train computational models. Notably, back-propagation neural networks (BPNN) have been applied to predict punching shear strength using multi-parameter datasets and have outperformed some empirical formulae in fitted cases, indicating the value of data-driven modeling for capturing interactions among variables. These approaches underpin the rationale for producing formal statistical descriptions (mean, SD, COV) rather than single deterministic values.

4. Strengthening and hybrid material trends (recent years):

Recent research trends (post-2015, accelerating in 2020–2025) focus on hybrid matrices and strengthening strategies: using ECC/UHPC overlays, fiber additions (synthetic or PET), or bonded ferrocement strips to enhance punching behaviour and post-punching robustness. Experimental and numerical studies on using ferrocement strips or advanced cementitious overlays show substantial gains in punching capacity and residual load-carrying after initial punching—highlighting practical retrofit/strengthening applications as well as material development directions. These modern interventions show that slab punching performance can be significantly improved without large increases in thickness when combined materials or bonded strips are used.

5. Gaps in literature and need for rigorous statistics:

Despite the valuable body of experiments, two important gaps appear repeatedly: (a) many studies use relatively small test sets (single labs, limited parametric range), limiting confidence in generalizing empirical models; (b) few published works present full probabilistic descriptions (pdfs, confidence intervals) of punching strength suitable for reliability-based design. Where statistical measures are reported, coefficients of variation tend to be moderate, but a systematic, multi-source statistical synthesis is rare. This gap motivates studies that both expand experimental datasets and quantify variability (mean, SD, COV, distributional fit) so designers can adopt reliability-based partial factors or probabilistic safety assessments.

III. MATERIALS:

The Materials used in this dissertation are cement, sand, water, superplasticizer, wire meshes ad skeletal steel.

1) Cement:

Ordinary Portland cement (OPC-43 grade) of Grasim industries Ltd. from a single batch was used throughout the course of the investigation.

2) Sand:

Well graded locally available river sand from Shahpur taluka of 2.36 mm size was used, lumps of clay were separated out from the sand. The sand having finesses modules between 4-4.6 is suitable for ferrocement slab construction.

The grading of sand for mortar mixes becomes very important to get workable cement mortar with low w/c ratio. The analysis of the sand used is carried out to find the FM of the sand. The results of the given analysis are tabulated in (Table -4.1).

3. Water

Water used for both mixing and curing should be free from injurious amounts of deleterious materials. Potable water is generally considered satisfactory for mixing and curing of concrete. In the present work potable tap water is used.

4. Superplasticizer

High range water-reducing admixture (HRWA) from Fosroc Chemicals India Limited, Bangalore of type Conplast SP-430 has been used.

IV. EXPERIMENTAL INVESTIGATIONS:

Table 4.2: Details of Test Specimens

Slab Designation	Parameters to be investigated	Thickness h (mm)	No. of wire mesh	No. of skeletal steel	Volume fraction Of Reinforcement V_f (%)	W/C Ratio	Mortar Strength (N/mm^2)	Loading area mm^2
A1		30	2	10	1.45	0.34	43	10000
A2		30	2	8	1.24	0.34	42.85	10000

A3	V_f	30	1	8	1.03	0.34	40.408	10000
A4		30	3	8	1.45	0.34	39.796	10000
A5		30	2	-	0.42	0.34	39.184	10000
B1	h	20	1	10	1.85	0.34	37.143	10000
B2		25	2	8	1.5	0.34	35.714	10000
B3		35	2	6	0.89	0.34	33.673	10000
C1	f_{cu}	30	2	6	1.04	0.35	30.408	10000
C2		30	2	6	1.04	0.4	22.05	10000
C3		30	2	6	1.04	0.45	12.5	10000

Table 4.3: Slab-A1

SI. No	Hydraulic jack reading load (KN)	Dial gauge reading	Deflection = (Dial gauge readingx100x 0.01)(mm)	Remarks
1.	2	1-30	1.3	
2.	4	1-60	1.6	Initial cracks
3.	6	2-10	2.10	
4.	8	2-70	2.7	
5.	10	4-10	4.10	
6.	12	4-95	4.95	
7.	14	6-40	6.40	
8.	16	8-60	8.60	
9.	17	12-95	12.95	Ultimate load

Table 4.8: Slab-B1

SI. No	Hydraulic jack reading load (KN)	Dial gauge reading	Deflection = (Dial gauge readingx100x 0.01)(mm)	Remarks
1.	2	3-70	3.70	Initial cracks
2.	4	10-20	10.20	
3.	6	17-60	17.60	Ultimate load

Table 4.11: Slab-C1

SI. No	Hydraulic jack reading load (KN)	Dial gauge reading	Deflection = (Dial gauge readingx100x 0.01)(mm)	Remarks
1.	2	2-60	2.60	
2.	4	3-60	3.60	
3.	6	4-20	4.20	Initial cracks
4.	8	4-90	4.90	
5.	10	5-20	5.20	
6.	12	6-30	6.30	
7.	14	7-10	7.10	
8.	16	7-90	7.90	
9.	17	9-30	9.30	Ultimate load

Table 4.14: Test results and location of critical perimeter

Sl. No.	Slab designation	Average thickness h(mm)	compressive strength of cubes (f_{cu})	Average radius of truncated failure cone		coefficient K
				Top face r_t (mm)	Bottom face r_b (mm)	
1	A1	30		48	214	1.763
2	A2	30		56	178	1.396

3	A3	30	41.05	60	204	1.789
4	A4	30		72	180	1.632
5	A5	30		74	200	1.920
6	B1	20	35.51	57	171	1.976
7	B2	25		61	182	1.817
8	B3	35		60	244	1.9823
9	C1	30	21.65	78	152	1.344
10	C2	30		80	192	1.894
11	C3	30		86	212	2.234
Average value of K=						1.80

Table 4.15: Test Results on cracking and punching shear strength

Sl. No	Slab designation	length of critical perimeter U_0(mm)	cracking load P_{cr} (KN)	Test Ultimate Load P_u (KN)	Test Ultimate shear stress V_u (N/mm^2)
1.	A1	832	4	17	0.681
2.	A2	832	6	19	0.761
3.	A3	832	2	8	0.32
4.	A4	832	4	15	0.6
5.	A5	832	2	9	0.36
6.	B1	688	2	6	0.436
7.	B2	760	4	13	0.684
8.	B3	904	5	18	0.569
9.	C1	832	5	17	0.681
10.	C2	832	4	15	0.60

11.	C3	832	5	16	0.641

Table 4.16: Compressive strength of cubes: (f_{cu}) (11 cubes for 11 slabs)

SI. No	Slab designation	Water cement ratio	Load (KN)	Compressive strength in N/(mm^2)
1.	A1	0.34	214	43.0
2.	A2	0.34	213	42.85
3.	A3	0.34	201	40.408
4.	A4	0.34	198	39.796
5.	A5	0.34	195	39.184
6.	B1	0.34	185	37.143
7.	B2	0.34	178	35.714
8.	B3	0.34	169	33.673
9.	C1	0.35	152	30.408
10.	C2	0.40	110	22.05
11.	C3	0.45	62	12.5

Table 4.17: Test Result

Sl. No	Slab designation	cracking load P_{cr} (KN)	observed Ultimate load P_u (KN)	Deflection at ultimate load (mm)	critical perimeter U_0 (mm)	observed Shear stress V_u (N/mm^2)	$\frac{V_u}{\sqrt{fcu}}$
1.	A1	4	17	12.95	832	0.681	0.104
2.	A2	6	19	9.9	832	0.761	0.116
3.	A3	2	8	8.15	832	0.32	0.05
4.	A4	4	15	10.90	832	0.60	0.096
5.	A5	2	9	14.95	832	0.36	0.057

6.	B1	2	6	17.60	688	0.436	0.071
7.	B2	4	13	10.60	760	0.684	0.114
8.	B3	6	18	5.80	904	0.569	0.098
9.	C1	6	17	9.30	832	0.681	0.123
10.	C2	4	15	7.20	832	0.60	0.127
11.	C3	4	16	8.80	832	0.641	0.181

Table 4.18: Comparison of test ultimate load (P_u) with design codes

Sl. No.	Slab Designation	Test ultimate load (P_u) (KN)	Ultimate load KN		$\frac{\text{Column(3)}}{\text{Column(4)}}$	$\frac{\text{Column(3)}}{\text{Column(5)}}$
			ACI 318-95 (KN)	BS 8110-1997 (KN)		
Column (1)	Column (2)	Column (3)	Column (4)	Column (5)	Column (6)	Column (7)
1.	A1	17	27.169	26.98	0.626	0.630
2.	A2	19	27.122	26.94	0.700	0.705
3.	A3	8	26.338	26.42	0.304	0.303
4.	A4	15	26.138	26.292	0.574	0.570
5.	A5	9	25.936	26.156	0.347	0.340
6.	B1	6	13.921	17.00	0.431	0.353
7.	B2	13	18.848	20.974	0.689	0.619
8.	B3	18	30.47	29.364	0.590	0.613
9.	C1	17	22.848	24.036	0.744	0.707
10.	C2	15	19.456	21.594	0.771	0.674
11.	C3	16	14.648	17.872	1.092	0.895
Mean					0.624	0.583
S.D					0.21	0.173

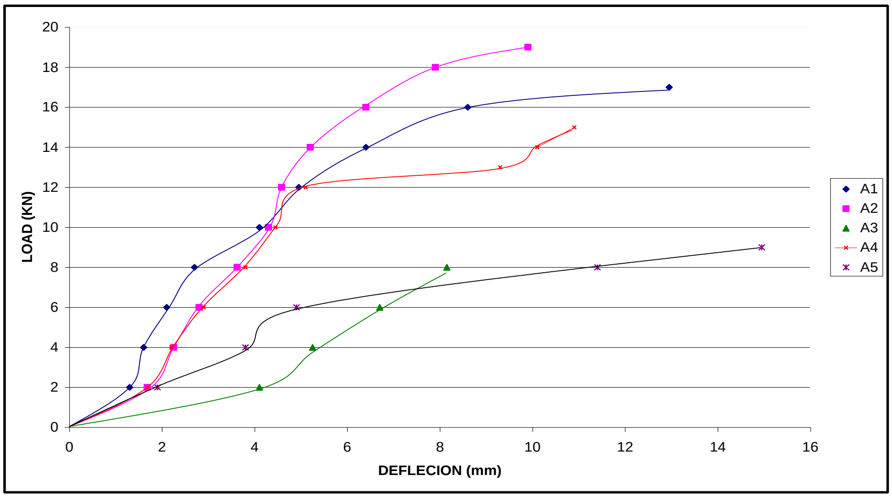

Fig 4.5: Group-5 for slabs (C1, C2 &C3)

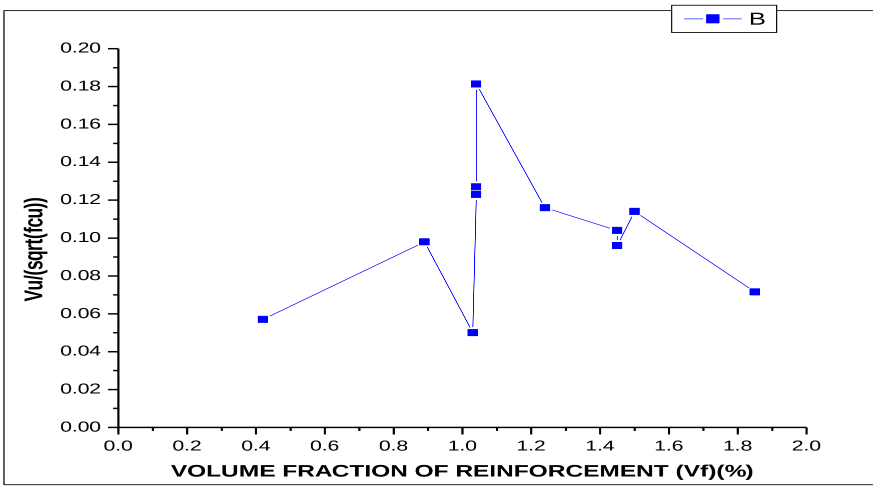

Fig 4.6: Volume fraction of reinforcement (V_f) V/S $\frac{V_u}{\sqrt{f_{cu}}}$

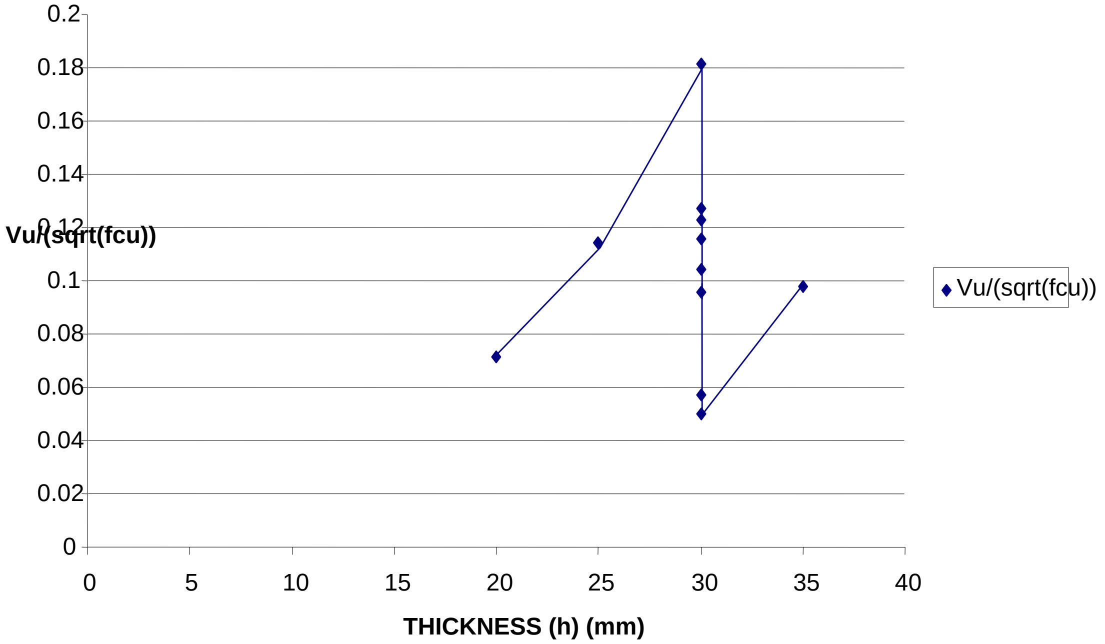

Fig 4.7: Thickness (h) V/S. $\frac{V_u}{\sqrt{f_{cu}}}$

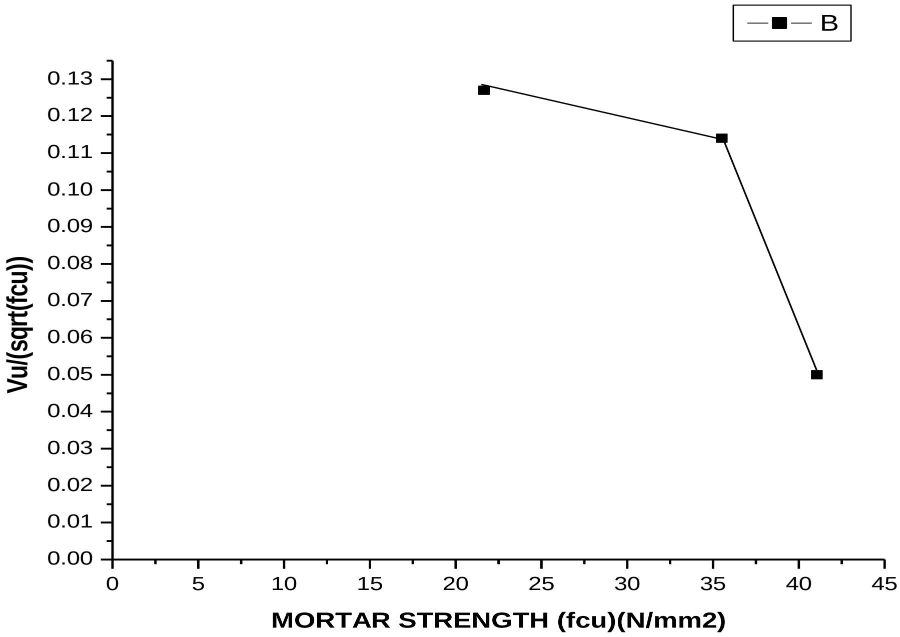

Fig 4.8: Mortar strength (f_{cu}) V/S. V_u/ $\frac{V_u}{\sqrt{f_{cu}}}$

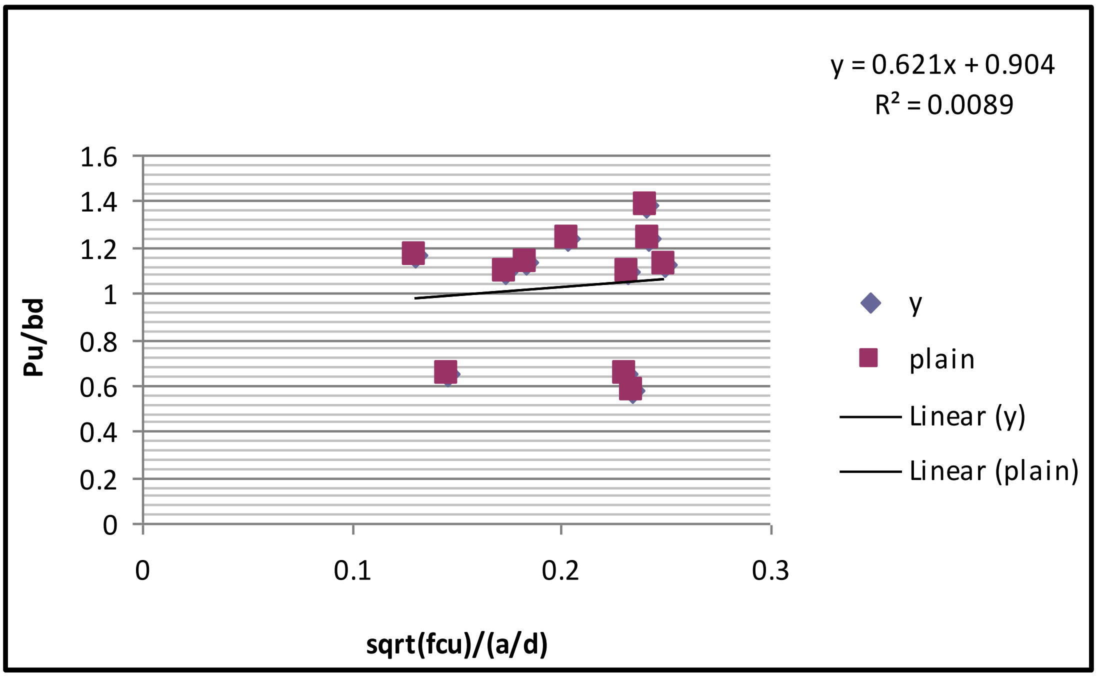

Fig 4.9: Regression between the parameters P_u/bd and $\frac{\sqrt{f_{cu}}}{a/d}$

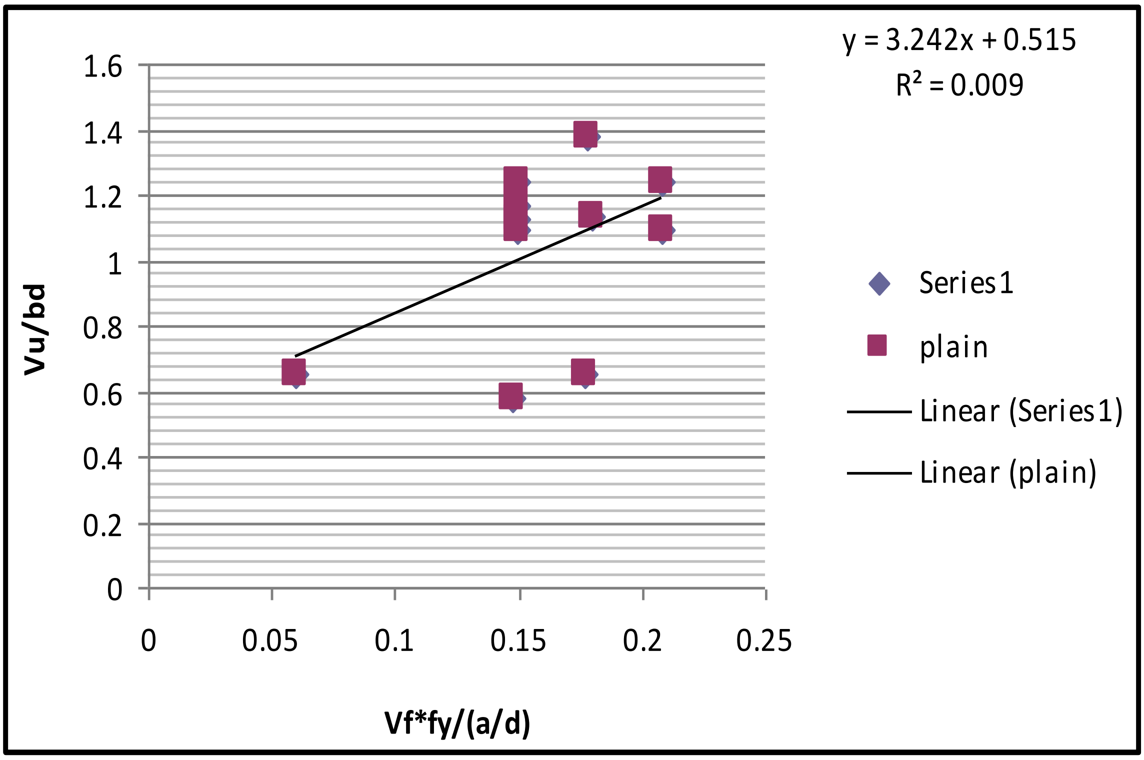

Fig 4.10: Regression between the parameters (P_u)/bd and $V_f \times \frac{f_y}{a/d}$

IV. CONCLUSION:

1. The ferrocement slabs have undergone punching shear failure instead of flexure.
2. The ferrocement slabs exhibit twin peaks in the load-deflection history. The first peak corresponds to the punching shear failure, while the second peak is due to the development of tensile membrane action at large deformation. The second peak tends to be higher than the first one for slabs with high volume fraction of reinforcement or larger loaded area.
3. The critical punching shear perimeter may be assumed at a distance equal to 1.8 times the slab thickness from the face of the bearing plate, the shape being an enlarged reflection of the bearing plate.
4. Within the scope of the present tests, both cracking and punching shear strengths, in terms of load, increase with an independent increase in V_f, f_{cu} and h, but decrease as the effective span is increased.
5. The load-deflection curves for ferrocement slabs under punching shear exhibit ductile behavior. The inclined shear plane usually forms at the periphery of the loaded area on the top surface, with fewer cracks at the top surface than at the bottom.
6. Upto 1.04% of volume fraction of reinforcement (V_f) the punching shear strength has improved. Further increase in (V_f) has resulted in a drop in the punching shear strength.
7. An increase in the slab thickness (h) has resulted in an increase in the punching shear strength.
8. An increase in the Mortar strength (f_{cu}) has resulted in an increase in the punching shear strength.
9. The number and extends of cracks appearing at the compression side are unaffected by the study parameters.
10. Shear behavior of ferrocement elements is almost similar to the shear behavior of reinforced concrete elements.
11. The code equations are not suitable for predicting the punching shear strength of ferrocement slabs.
12. The proposed empirical expression by M.A. Mansur, I.Ahmed & Paramasivam is used to estimate the shear strength of ferrocement elements and is compared with the observed and predicted values.
13. The predicted values are compared with the design codes.
14. The observed, proposed and predicted values are compared with each other.
15. Good agreement is found between observed, proposed and the predicted values.

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