

Effect of Hybrid Fiber Reinforcements on the Mechanical and Ductility Performance of HPC Incorporating Micro Silica and Alccofine-1203

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Table 1: Physical properties of steel and polypropylene fibers

Fiber	Length (mm)	Diameter (mm)	Aspect ratio	Ultimate tensile strength (MPa)	Modulus of elasticity (GPa)	Density (Kg/m³)
Steel fiber	36	0.45	80	910	200	7850
Polypropylene Fiber	12	0.02	600	400	69	910

Table 2: Mix proportioning of HPC/ HPFRC/ HP-HyFRC

Mix Design	Cement	Silica fume replacement	w/b ratio	F.A	C.A	Super plasticizer (%)	Fiber content (V_f), (%)	
							Steel	Polypropylene
HPFRC-0	1	0.15 (15%) & 0.2 (20%)	0.38	1.34	2.53	1.75	0, 0.5, 1 & 1.5	0, 0.25, 0.5 & 1
HPFRC*-0	1	0.2	0.28	1.34	2.53	2.75	0, 0.5, 1 & 1.5	0, 0.25, 0.5 & 1

Table 3: 28-Day Compressive strengths and flexural strengths of HPFRC/ HP-HyFRC, and improvement in strength

Mix Designation	w/b ratio	Compressive strength, f_{cf} (MPa)	Improvement in strength (%)	Flexural strength, f_{rf} (MPa)	Improvement in strength (%)
HPFRC-0	0.38	75.05	0.00	8.12	0.00
HPFRC-S0.5	0.38	78.85	5.06	9.14	12.56
HPFRC-S1	0.38	82.50	9.93	9.80	20.68
HPFRC-S1.5	0.38	86.15	14.79	10.85	33.46
HPFRC-P0.25	0.38	75.95	1.20	8.54	5.18
HPFRC-P0.5	0.38	77.65	3.46	8.64	6.40
HPFRC-P1	0.38	78.40	4.40	8.87	9.24
HP-HyFRC(S0.5,P0.25)	0.38	79.55	5.95	9.25	13.92
HP-HyFRC(S0.5,P0.5)	0.38	79.68	6.17	9.38	15.52
HP-HyFRC(S0.5,P1)	0.38	82.54	9.98	9.69	19.33
HP-HyFRC(S1,P0.25)	0.38	83.75	11.59	10.23	25.98
HP-HyFRC(S1,P0.5)	0.38	85.50	13.92	10.96	34.98
HP-HyFRC(S1,P1)	0.38	86.45	15.18	11.29	39.03
HP-HyFRC(S1.5,P0.25)	0.38	87.05	15.98	11.76	44.82
HP-HyFRC(S1.5,P0.5)	0.38	89.25	18.92	11.95	47.16
HP-HyFRC(S1.5,P1)	0.38	90.20	20.18	12.14	49.50
HPFRC*-0	0.28	87.30	0.00	8.61	0.00
HPFRC*-S0.5	0.28	91.13	4.38	10.21	18.58
HPFRC*-S1	0.28	94.26	7.97	11.26	30.78
HPFRC*-S1.5	0.28	98.7	13.06	12.40	44.66
HPFRC*-P0.25	0.28	88.59	1.47	9.06	5.23
HPFRC*-P0.5	0.28	90.72	3.91	9.51	10.45
HPFRC*-P1	0.28	92.1	5.4	9.89	14.87
HP-HyFRC*(S0.5,P0.25)	0.28	91.15	4.41	10.68	24.04
HP-HyFRC*(S0.5,P0.5)	0.28	92.20	5.61	11.02	27.99
HP-HyFRC*(S0.5,P1)	0.28	94.70	8.44	11.48	33.33
HP-HyFRC*(S1,P0.25)	0.28	95.20	9.04	11.87	37.86
HP-HyFRC*(S1,P0.5)	0.28	98.80	13.17	12.43	44.37
HP-HyFRC*(S1,P1)	0.28	99.75	14.31	12.89	49.71
HP-HyFRC*(S1.5,P0.25)	0.28	101.80	16.32	13.34	54.94
HP-HyFRC*(S1.5,P0.5)	0.28	102.62	17.54	13.49	56.68
HP-HyFRC*(S1.5,P1)	0.28	104.30	19.47	13.95	61.44

Table 4: 28-Day Compressive strengths ratios of HPSFRC/ HPPFRC and HPC, and percentage errors

Mix Designation	Compressive strength, f_{cf} (MPa)		f_{cf} / f_c		Predicted Compressive strength, f_{cf} by the model (MPa)		Predicted error (%)	
	Cube	Cylinder	Cube	Cylinder	Cube	Cylinder	Cube	Cylinder
HPFRC-0	75.05	60.79	1.00	1.00	75.05	60.79	0.00	0.00
HPFRC-S0.5	78.85	63.28	1.05	1.04	79.22	64.16	-0.44	-1.40
HPFRC-S1	82.5	67.24	1.10	1.11	83.38	67.54	-0.65	-0.44
HPFRC-S1.5	86.65	73.14	1.15	1.20	87.55	70.91	-1.42	3.05
HPFRC-P0.25	75.95	61.76	1.01	1.02	76.01	61.57	-0.07	0.13
HPFRC-P0.5	77.65	62.9	1.03	1.03	76.96	62.34	0.53	0.89
HPFRC-P1	78.4	65.11	1.04	1.07	78.88	63.89	-0.60	1.87
HPFRC*-0	87.3	70.71	1.00	1.00	87.30	70.71	0.00	0.00
HPFRC*-S0.5	90.13	74.8	1.03	1.06	92.15	74.63	-1.32	0.22
HPFRC*-S1	94.26	76.42	1.08	1.08	96.99	78.56	-1.15	-2.80
HPFRC*-S1.5	98.7	80.44	1.13	1.14	99.84	82.48	-0.67	-2.54
HPFRC*-P0.25	88.59	72.07	1.01	1.02	88.41	71.61	0.20	0.64
HPFRC*-P0.5	90.72	73.25	1.04	1.04	89.53	72.51	0.44	1.01
HPFRC*-P1	92.1	75.52	1.05	1.07	91.75	74.32	0.39	0.09

Table 5: 28-Day Flexural strength ratios of HPSFRC/HPPFRC and HPC, and percentage errors

Mix Designation	Flexural strength, f_{rf} (MPa)	f_{rf}/f_r	Predicted flexural strength, f_{rf} by the model (MPa)	Predicted error (%)
HPFRC-0	8.12	1.00	8.12	0.00
HPFRC-S0.5	9.14	1.13	9.15	-0.09
HPFRC-S1	9.8	1.21	10.18	-3.84
HPFRC-S1.5	10.85	1.34	11.20	-3.26
HPFRC-P0.25	8.54	1.05	8.36	2.09
HPFRC-P0.5	8.64	1.06	8.60	0.43
HPFRC-P1	8.87	1.10	9.09	-2.43
HPFRC*-0	8.61	1.00	8.61	0.00
HPFRC*-S0.5	10.21	1.19	9.70	4.99
HPFRC*-S1	11.26	1.31	10.79	4.17
HPFRC*-S1.5	12.4	1.44	11.88	4.19
HPFRC*-P0.25	9.06	1.05	8.87	2.14
HPFRC*-P0.5	9.51	1.09	9.12	4.08
HPFRC*-P1	9.89	1.15	9.63	2.59

Table 6: Elastic modulus of HPFRC and HP-HyFRC

Mix Designation	Peak stress f'_{cf} (MPa)	Elastic modulus E_c (GPa)	Predicted values by the model (GPa)	Predicted error (%)
HPFRC-0	60.79	33.72	33.14	1.72
HPFRC-S0.5	63.28	34.95	34.37	1.65
HPFRC-S1	67.24	35.76	36.33	-1.58
HPFRC-S1.5	73.14	38.92	39.22	-0.76
HPFRC-P0.25	61.76	34.06	33.62	1.29
HPFRC-P0.5	62.9	34.53	34.19	1.00
HPFRC-P1	65.11	35.12	35.28	-0.45
HP-HyFRC(S1,P0.5)	70.68	36.91	37.02	-0.30
HP-HyFRC(S1,P1)	72.26	38.06	38.79	-1.91
HP-HyFRC(S1.5,P0.5)	76.57	41.24	40.89	0.86
HP-HyFRC(S1.5,P1)	77.06	41.69	41.12	1.36
HPFRC*-0	70.71	37.38	38.03	-1.73
HPFRC*-S0.5	74.8	39.68	40.02	-0.87
HPFRC*-S1	76.42	40.79	40.81	-0.06
HPFRC*-S1.5	80.44	44.26	42.76	3.38
HPFRC*-P0.25	72.07	37.94	37.69	0.66
HPFRC*-P0.5	73.25	39.12	39.27	-0.38
HPFRC*-P1	75.52	40.28	40.38	-0.24
HP-HyFRC*(S1,P0.5)	77.44	42.03	42.31	-0.67
HP-HyFRC*(S1,P1)	78.47	42.61	41.95	1.55
HP-HyFRC*(S1.5,P0.5)	81.04	44.98	44.03	2.11
HP-HyFRC*(S1.5,P1)	82.12	45.21	44.89	0.71

Table 7: Ductility of HPFRC and HP-HyFRC

Mix Designation	Ductility in compression (Energy absorption)	Ductility ratio
HPFRC-0	0.14	1
HPFRC-S0.5	0.25	1.78
HPFRC-S1	0.36	2.57
HPFRC- P0.5	0.17	1.21
HPFRC-P1	0.21	1.5
HP-HyFRC(S1,P0.5)	0.55	3.93

Table 8: 28-day Compressive strength of HPC (Silica fume/ Silica fume + Alccofine)

Mix Designation	w/b ratio	SF (%)	28-day Compressive strength, f_{cf} (MPa)			
			AF = 0%	AF = 5%	AF = 8%	AF = 10%
HPFRC-0	0.38	20	75.05	77.02	77.18	76.4
HPFRC*-0	0.28	20	87.3	89.25	90.21	88.63

Table 9: 28-day Flexural strength of HPC (Silica fume/ Silica fume + Alccofine)

Mix Designation	w/b ratio	SF (%)	28-day flexural strength, f_{rf} (MPa)			
			AF = 0%	AF = 5%	AF = 8%	AF = 10%
HPFRC-0	0.38	20	8.12	8.28	8.57	8.19
HPFRC*-0	0.28	20	8.61	8.74	8.03	8.67

Table 10: 28-day compressive strength and predicted values of HP-HyFRC by MLRM and their corresponding absolute variations

MIX Designation	w/b	28-day compressive strength, MPa		Absolute error (%)
		Experimental	Predicted	
HPFRC-0	0.38	75.05	74.89	0.21
HPFRC-S0.5	0.38	78.85	78.77	0.10
HPFRC-S1	0.38	82.5	82.66	0.19
HPFRC-S1.5	0.38	86.65	86.58	0.08
HPFRC-P0.25	0.38	75.95	76.03	0.1
HPFRC-P0.5	0.38	77.65	76.77	1.14
HPFRC-P1	0.38	78.4	78.64	0.31
HP-HyFRC(S0.5,P0.25)	0.38	79.55	79.91	0.45
HP-HyFRC(S0.5,P0.5)	0.38	79.68	80.65	1.22
HP-HyFRC(S0.5,P1)	0.38	82.54	82.53	0.02
HP-HyFRC(S1,P0.25)	0.38	83.75	83.79	0.05
HP-HyFRC(S1,P0.5)	0.38	85.5	84.53	1.13
HP-HyFRC(S1,P1)	0.38	86.45	86.41	0.05
HP-HyFRC(S1.5,P0.25)	0.38	87.05	87.72	0.77
HP-HyFRC(S1.5,P0.5)	0.38	89.25	88.46	0.89
HP-HyFRC(S1.5,P1)	0.38	90.2	90.33	0.15
HPFRC*-0	0.28	87.3	86.77	0.61
HPFRC*-S0.5	0.28	91.13	90.88	0.27
HPFRC*-S1	0.28	94.26	94.99	0.19
HPFRC*-S1.5	0.28	98.7	99.15	0.45
HPFRC*-P0.25	0.28	88.59	88.27	0.36
HPFRC*-P0.5	0.28	90.72	89.26	0.35
HPFRC*-P1	0.28	92.1	91.75	0.39
HP-HyFRC*(S0.5,P0.25)	0.28	91.15	92.38	1.35
HP-HyFRC*(S0.5,P0.5)	0.28	92.2	93.37	1.27
HP-HyFRC*(S0.5,P1)	0.28	94.7	95.85	1.22
HP-HyFRC*(S1,P0.25)	0.28	95.2	96.49	1.36
HP-HyFRC*(S1,P0.5)	0.28	98.8	97.48	1.34
HP-HyFRC*(S1,P1)	0.28	99.75	99.96	0.21
HP-HyFRC*(S1.5,P0.25)	0.28	101.8	100.65	1.13
HP-HyFRC*(S1.5,P0.5)	0.28	102.62	101.63	0.96
HP-HyFRC*(S1.5,P1)	0.28	104.3	104.12	0.17