Supplement

Optimized Physics-informed Machine Learning Modeling with GAIN Data Imputation for Sustainable Pozzolanic Concrete Strength Prediction

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1 Experimental data

A total of 440 experimental samples obtained from existing literature were utilized in the present study to investigate and establish predictive models for estimating the mechanical properties of pozzolanic concrete at 28 days of curing. The corresponding dataset is presented in the following Table S1.

Table S1 List of collected experimental data for pozzolanic concrete

Ref.	Year	Num. of data	MS	SFS	ZS	MW	SFW	ZW	GC	C	W	ASP	FA	CA	DCS	LCS	WCS	DTS	LTS	WTS	CS	TS
[1]	2025	6	0.1–0.9	0	0	0–111.75	0	0	53	335.25–447	158	1.109–1.252	615	1134	150	150	150	100	200	0	36.68–47.83	2.98–3.71
[2]	2025	4	0	0.1–0.2	0	0	0–79.5	0	40	450.5–530	169	2.2	594.6–620.4	1098.2	150	300	0	–	–	–	66.26–73.34	–
[3]	2025	28	0	0	3.5	0	0	0–119.5	42.5	330.8–555.9	175.1–206	6.39–7.515	604.8–665.3	934.9–1028.4	150	150	150	–	–	–	47.2–65.1	–
[4]	2024	5	4	0	0	0–95.2	0	0	42.5	380.8–476	190	0	738	1108	100	100	100	–	–	–	45.063–53.234	–
[5]	2024	7	0–15	0	0	0–126	0	0	42.5	294–420	210	0	661	1079	100	100	100	100	300	0	22.596–29.052	2.636–3.32
[6]	2023	5	1.26	0	0	0–87	0	0	53	348–435	157.6	0.489	695	1254	100	100	100	100	300	0	39.75–62.68	4–6.35
[7]	2023	6	4	0	0	0–112.5	0	0	42.5	262.5–375	160.7	3.488–3.69	550	1100	100	100	100	100	200	0	40–49.2	4.1–5.2
[8]	2023	16	0	0	1–100	0	0	0–180	32.5–52.5	280–600	225.5–239	0	821–961.95	671.5–787.05	100	100	100	–	–	–	34.4–58.3	–
[9]	2023	5	0	0	40	0	0	0–80.8	53	323.2–404	177	0	678	1148	150	150	150	150	300	0	30.35–36.35	2.23–3.11
[10]	2022	2	0.197	0	0	0–50	0	0	42.5	450–500	190	2.25–3.375	900	650	100	100	100	100	200	0	52.5–61.5	3.2–3.74
[11]	2022	5	0–57	0	0	0–70	0	0	42.5	280–350	190–215	0	580–670	1010	150	150	150	–	–	–	33.6–42.44	–
[12]	2022	9	2.18	1.46	0	0–100	0–100	0	52.5	500	125–150	6.15–7.38	665.4–744	998.1–1116	100	100	100	150	300	0	73.251–88.065	6.621–7.533
[13]	2022	6	0	0.14	0	0	0–51.51	0	43	463.6–515.1	185.5	4.589–5.099	879.9–888.3	791.5–799	150	150	150	150	300	0	68.71–72.88	4.766–5.0847
[14]	2022	6	0	0.083	0	0	0–116.25	0	43	348.75–465	200	1.674	937.5	737	100	100	100	100	200	0	38.93–44.04	2.99–3.71
[15]	2022	9	0	8.87, 12.35	0	0	0–35.5	0	42.5	216–240	103.5–115	0.48–0.504	620	1445	100	100	100	100	100	0	16.64–72.24	2.69–4.24
[16]	2022	2	0	0.1–0.3	0	0	0–43	0	52.5	360–317	144	0–1.944	686	1209	150	150	150	150	300	0	54.2–76.8	2.7
[17]	2022	4	0	0.194	0	0	0–62.4	0	42.5	457.6–520	161.2	0.519–0.546	805	915.2	100	200	0	–	–	–	58.8–83	–

Table S1 List of collected experimental data for pozzolanic concrete (continued)

Ref.	Year	Num. of data	MS	SFS	ZS	MW	SFW	ZW	GC	C	W	ASP	FA	CA	DCS	LCS	WCS	DTS	LTS	WTS	CS	TS
[18]	2022	4	0	0	13.6	0	0	0–132	42.5	308–440	155	0.54–0.909	722	1083	150	150	150	–	–	–	42–54.29	–
[19]	2021	5	1	0	0	1–156	0	0	43	234–390	144.3	3.276	872	1082	150	150	150	–	–	–	56.14–69.88	–
[20]	2021	3	3	0	0	0–60	0	0	42.5	340–400	160	1.44–1.71	854	1086	100	100	100	100	100	400	50.8–62.26	4.8–6.37
[21]	2021	8	0	0.152	0	0	0–69.54	0	43	285.6–463.5	185.4–186	0	530.27–834	1114	150	150	150	150	300	0	33.41–55.21	–
[22]	2021	36	0	0.1–0.15	0	0	0–58.5	0	43	97.5–390	140	3.861	856–994	1038–1153	150	150	150	–	–	–	48.32–79.4	–
[23]	2021	6	0	0	3.9–5	0	0	0–190	43	213–473	160	0.799–1.064	606–646	1255–1177	150	150	150	150	300	0	26.66–59.55	2.07–3.78
[24]	2020	20	3.2	0	0	0–156.7	0	0	42.5	297.9–663.7	146–234.8	5.445–8.955	634	951	150	150	150	–	–	–	22.8–54.2	–
[25]	2020	4	0	0.15	0	0	0–76.8	0	42.5	435–512	163	1.024	673	1174	150	150	150	150	300	0	60.78–66.5	3.31–4.22
[26]	2020	4	0	0.125–0.143	0	0	0–96	0	53	540–635	190	3.15–4.995	610	955	150	150	150	150	300	0	68.44–75.56	5.73–6.3
[27]	2020	3	0	0.1–0.2	0	0	0–36.8	0	53	427.5–475	166.3	1.071–1.408	650	1079	100	100	100	100	200	0	54.09–58.054	3.055–3.324
[28]	2020	25	0	0.1–0.15	0	0	7.02–35.2	0	43	195–383	140	1.931–3.792	856–930	1038–1122	150	150	150	150	300	0	55.35–79.4	3.86–5.17
[29]	2019	5	1.8	0	0	0–84	0	0	43	336–420	181	0	668	1232	150	150	150	150	300	0	40.43–45.36	3.16–3.43
[30]	2019	12	0	0.15	0	0	0–60	0	42.5	270–600	212	0–1.082	472–716	1020	100	100	100	–	–	–	27–58	–
[31]	2018	8	0.89	0	0	0–80	0	0	42.5	240–400	180–240	3.015–5.175	1046–1206	563.12–649.3	150	150	150	–	–	–	29.46–52.72	–
[32]	2018	6	1.3	0.8	0	0–55	0–55	0	42.5	490–589	161–190	2.637–4.509	904–924	790–808	100	200	0	60	150	0	88.1–115.3	6.8–7.1
[33]	2018	7	7	5.8	0	0–75	0–75	0	42.5	425–500	190	2.88–4.275	118	908	100	100	100	–	–	–	63–90	–
[34]	2018	5	0	0.12	0	0	0–96	0	42.5	384–480	172.8	3.24	896.1	800	150	150	150	–	–	–	66.08–95.3	–

Table S1 List of collected experimental data for pozzolanic concrete (continued)

Ref.	Year	Num. of data	MS	SFS	ZS	MW	SFW	ZW	GC	C	W	ASP	FA	CA	DCS	LCS	WCS	DTS	LTS	WTS	CS	TS
[35]	2018	3	0	0.128	0	0	0–40	0	42.5	360–400	180	0	937–944	865–871	100	100	100	150	300	0	31–40	2.33–3.17
[36]	2018	5	0	0	12.04	0	0	0–90	40	360–450	185	0.72	823.2–840.3	952.7–972.5	100	200	0	150	300	0	41.36–45.85	3.8–4.5
[37]	2017	5	0.2	0	0	0–100	0	0	42.5	400–500	100	4.95–6.048	779.02–787.27	1159.64–1171.95	100	100	100	150	150	150	79.316–85.116	5.33–5.67
[38]	2017	7	2.4	0	0	114	0	0	43	266–380	171	0.342	656	1169	100	100	100	–	–	–	39.4–49.4	–
[39]	2017	6	1–2	0	0	0–76	0	0	53	304–380	163	1.869	881	1135	150	150	150	–	–	–	43.17–47.01	–
[40]	2017	6	0	0.14	0	0	0–46.8	0	43	421.2–468	168.48	4.633	911.23–918.76	871.65–878.86	150	150	150	150	300	0	53.26–55.91	3.52–3.6
[41]	2017	4	0	0–1	0	0	0–57.14	0	53	323.77–380.9	171.41	0	817.34	1012.03	150	150	150	150	300	0	25.89–34.76	2.56–2.98
[42]	2017	4	0	0.229	0	0	0–62.4	0	42.5	457.6–520	161.2	1.31–1.419	804.9–805.1	914.3	100	200	0	100	200	0	58.8–83	5.68–7.3
[43]	2017	3	0	0.195	0	0	0–65	0	53	570–635	135–140	5.143	708–717	1103–1158	150	150	150	–	–	–	92.2–102.93	–
[44]	2016	8	0.152–0.182	0	0	0–88	0	0	42.5	264–440	198–200	0	600–710	1240	150	150	150	–	–	–	23.9–48	–
[45]	2016	5	3	0	0	0–57.48	0	0	43	421.52–479	192	0	522	1185	150	150	150	100	200	0	37.15–38.44	3.82–4.02
[46]	2016	5	2.67–3.43	0	0	0–100	0	0	53	410–510	162	1.35–1.80	806	972	150	150	150	150	300	0	61.9–72.7	3.4–4.1
[47]	2016	12	1.3	0	0	0–140	0	0	42.5	310–589	161–192	2.637–6.75	904–993	790–868	100	200	0	100	200	0	83.7–117.4	5.2–7.4
[48]	2016	3	0	4.2	0	0	0–100	0	42.5	300–400	180	0.315–0.653	925–944	854–871	100	100	100	–	–	–	31.18–39.95	–
[49]	2016	5	0	0	11.82	0	0	0–37.1	42.5	333.9–371	130	0.835	1158	811	100	100	100	–	–	–	70.1–79.4	–
[50]	2015	4	1.5–2.5	0	0	0–75	0	0	53	425–500	190	1.35	900	650	150	150	150	150	300	0	43.05–71.3	3.48–5.74
[51]	2015	5	5.1, 7.5	0	0	0	0	0–70	52.5	280–350	175	0.089–0.63	720	1200	100	200	0	–	–	–	55.8–79.9	–
[52]	2015	5	0	0.1	0	0	0–75.77	0	43	303.08–378.85	197	0	718.48	1224.97	150	150	150	150	300	0	21.03–29.18	2.26–3.25

Table S1 List of collected experimental data for pozzolanic concrete (continued)

Ref.	Year	Num. of data	MS	SFS	ZS	MW	SFW	ZW	GC	C	W	ASP	FA	CA	DCS	LCS	WCS	DTS	LTS	WTS	CS	TS
[53]	2013	5	2	0	0	0–87.56	0	0	53	350.22–437.78	197	0	643.68	1104.36	150	150	150	150	300	0	37.04–51.56	2.79–3.04
[54]	2013	4	0.16	0	0	0–80	0	0	53	453.33–533.33	160	0.958–1.917	645–677	1144–1201	100	100	100	100	200	0	91.04–98.81	4.69–5.19
[55]	2013	10	0	0.119	0	0	0–90	0	43	360–450	180	0.945–4.914	630.75	1097.23	150	150	150	–	–	–	49.48–71.33	–
[56]	2013	10	0	0.119	0	0	0–90	0	43	360–450	225	0–2.214	599.29	1050.08	150	150	150	–	–	–	45.35–58	–
[57]	2012	4	0–10	0	0	0–90	0	0	52.5	510–600	150	2.07–4.32	650	1050	100	100	100	–	–	–	84.74–101.83	–
[58]	2012	10	0.2	0.12	0	0–82.5	0–82.5	0	42.5	399.5–550	137.5–164.5	0.837–4.32	745.4–757.4	976.9–993.9	150	150	150	150	300	0	61.52–85.93	3.52–5.926
[59]	2012	5	0	0.1	0	0	0–102.8	0	53	411.2–514	185.6	1.369	456.932	1391.642	150	150	150	150	300	0	38.3–47.3	3.98–4.95
[60]	2008	6	0–2	0	0	0–90	0	0	42.5	280–450	158–193	1.435–5.084	948–960	844–854	100	100	100	100	200	0	45.34–78.32	2.35–3.091
[61]	2004	5	0–7.5	0	0	0–70	0	0	55	280–350	175	0.081–0.574	720	1200	150	150	150	0	0	0	55.8–79.96	–

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