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Durability Study of Nano Influenced Metakaolin Concrete to Acid Attack

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Abstract The two most important attributes of concrete are strength and durability. The concrete durability crisis has attracted and compelled engineers to focus on concrete performance. Considerable research and attention go into creating reinforced concrete buildings, which face challenging surroundings and are intended to last for a prolonged period of time with minimal maintenance. To accomplish this requirement, one material that has attracted a lot of attention is Nano material combined with SCM's. The researchers looked at partial cement replacement with Metakaolin levels of 10, 20, and 30% and Nano Silica levels of 1.5, 3.0, and 4.5 percent by weight of cement in this study. W/B ratios of 0.3, 0.35, and 0.4 were used with A/B ratio of 1.75. Cubes were cast for different mix proportions and immersed in 5% concentrated HCl, H_2SO_4, and $MgSO_4$ solutions for 30, 60, and 90 days. The residual compressive strength obtained after 30, 60, and 90 days of immersion in different acid solutions were compared to controlled concrete. According to ongoing research, concrete prepared with a combination of 10% Metakaolin and 3% Nano silica is the best for achieving the highest durability properties in concrete and improving its performance.

Keywords Metakaolin, Nano Silica, Durability, Residual Compressive Strength, High Performance Concrete

1. Introduction

Concrete is one of the most consumed and versatile material on the earth for building construction. As technology is at its summit, structures also need to raise the bar of high standards, high strength and design for long service life. Concrete deterioration has hampered the safety and serviceability of multi-story buildings, bridges, cooling towers, power plants, and offshore platforms. One of the most devastating forms of environmental attack is chloride ingress, which results in corrosion of the reinforcing steel and a corresponding loss of strength, serviceability, and aesthetics. This may entail early repair or replacement of the building. A common technique for preventing such deterioration is to employ slightly impermeable concrete that precludes chlorides from reaching the structure's reinforcing steel. Thus, both for design and quality control purposes, the resistance of chloride ions to penetration into concrete must be assessed, and test methodologies that enable the determination of representative values in a reasonable period of time are necessary. However, meeting these requirements and ensuring durability against the weathering impact of such reinforced concrete structures is challenging with ordinary concrete. As per Indian standards the service life of the RCC structures is designed for more than 100 years. Carbonation and the presence of chloride ions are the primary causes of steel corrosion in concrete structures. Hence, old traditional OPC with less resistance to weathering cannot meet it. The present trend in the development of infrastructure is the use of

High-performance concrete, incorporating mineral and chemical admixtures. Nano silica is one of the popular and effective options as an advanced material due to its particle size of nano metre and high pozzolanic activity. It promotes hydration of cement at early ages and enhances the properties of concrete and transform concrete completely. The experimental investigation aims to create a durable concrete that can be beneficial for modern developments and the renovation of existing structures with a remarkable rise in their life span. As a result, an experimental investigation is carried out to determine the effect of Nano-silica and Metakaolin incorporation on the concrete's durability properties.

The performance of HPC decreased in compressive strength percent rapidly from 0% to 10% metakaolin replacement for Hydrochloric acid attack. Optimum results obtained were at 10% replacement. Percentage weight loss is least for HPC mixes containing 10% replacement [1]. Mineral admixtures improved the durability qualities of the mix when compared to the control mix [2]. The percentage loss of weight is least for the mix containing 5% GGBS, 5% Metakaolin and 20% copper slag. Similarly, in hydrochloric acid immersion the compressive strength of concrete is 2.24% higher than the concrete with 28days water curing. The reason is the combined effect of GGBS, Metakaolin and copper slag [3]. Nano silica incorporated concrete exhibited 45.48% increase in resistance to acid attack, a 5% increase in resistance to alkali attack and 58.3% decrease in water absorption than conventional concrete. But Nano silica incorporated concrete showed much more resistance to chloride ion penetration than Conventional concrete [4]. Nano silica has an exceptional property of high pozzolanic action with the particle size of nano meter [5]. The review presents the influence of Nano silica in concrete, its pore filling effect and its pozzolanic activity with cement towards the improvement of mechanical properties and durability aspects [6]. More calcium hydroxide (CH) consumption forms secondary C-S-H due to highly reactive Nanosilica as a pozzolona [7,8]. Du et al. [9] and Quercia et al. [10] reported that the chloride diffusion coefficient of concrete was reduced by NS addition. For w/b=0.65 and0.55, the chloride diffusion coefficient of concrete decreased with the addition of 0.5 percent NS. When compared to the reference, NS clearly refined the porosity microstructure of w/b=0.55 and 1 percent NS addition [11]. Strength, durability, shrinkage, and steel-bonding qualities are all impacted by nano-sized particles or voids [12]. The pozzolanic reaction with calcium hydroxide increases the quantity of C–S–H, resulting in greater matrix densification and better material strength and durability [13]. The inclusion of nano-silica enhanced the amount of C–S–H and C–A–H in the paste [14]. Its high reactivity and very large specific area leads to high degree of pozzolanic activity. Nano-silica has found widespread use in this field. Nano-silica promotes the dissolution of C3S and production of C–S–H by providing nucleation sites for C–S–H and its activity is inversely related to its size [15]. Nano-scale silica serves as both a filler and an activator, promoting pozzolanic reaction based on the rate of heat evolution [16]. The addition of nano-silica changed the porosity of the cement paste and lengthened the average chain length of silicate chains [17]. The addition of nano-silica to concrete increased its resistance to chloride penetration [18].

Not much has been explored for a blend of admixture containing Metakaolin and Nano silica to enhance the durability performance for acid attack. Hence, a void still exists in research and also Indian standard code is voiceless to designing the concrete mix for High Performance concrete. The outcome from the study may be an effort to develop mix design charts which is the need of the hour. The main focus is to see how partial cement substitution with Nano Silica and Metakaolin affects high-performance concrete performance when exposed to Hydrochloric acid, Sulphuric acid, and Magnesium Sulphate attack.

2. Materials and Their Properties

Ordinary Portland cement of Grade 53 and having specific gravity of 3.10 is adopted. Coarse aggregate sizes larger than 4.75 mm from the local stone quarry with 40% passing 12.5mm sieve and retained on 10mm and 60% passing through 20mm sieve and retained on 12.5mm sieve was used and of specific gravity 2.75. Fine aggregates form the portion below 4.75 mm, from local river conforming to zone II with a specific gravity of 2.67. Metakaolin appearance was off white powder with a specific surface area 12.7m^2/gm and specific gravity of 2.6. Nano silica is white fine powder with surface area of 200-220 m^2/gm and specific gravity of 2.3. Concrete was mixed with potable fresh water that was devoid of organic and acid compounds. Fosroc's chloride-free Superplasticizer (SP) was employed, with a specific gravity of 1.18. In the investigation, 5% concentration solutions of hydrochloric acid (HCl), magnesium sulphate ($MgSO_4$), and sulfuric acid (H_2SO_4) were used.

Table 1. Mix Nomenclature.

Mix Name	Metakaolin	Nano Silica	Aggregate Binder Ratio	Water Binder Ratio	Super Plasticizer	Mix Name	Metakaolin	Nano Silica	Aggregate Binder Ratio	Water Binder Ratio	Super Plasticizer
	MK (%)	NS(%)	A/B	W/B	(%)		MK (%)	NS(%)	A/B	W/B	(%)
MK0NS0A	0	0	1.75	0.3	1	MK0NS0D	0	0	1.75	0.375	1
MK0NS1A	0	1.5	1.75	0.3	1	MK0NS1D	0	1.5	1.75	0.375	1
MK0NS2A	0	3	1.75	0.3	1	MK0NS2D	0	3	1.75	0.375	1
MK0 NS3A	0	4.5	1.75	0.3	1	MK0 NS3D	0	4.5	1.75	0.375	1
MK10NS0A	10	0	1.75	0.3	1	MK10NS0D	10	0	1.75	0.375	1
MK10NS1A	10	1.5	1.75	0.3	1	MK10NS1D	10	1.5	1.75	0.375	1
MK10NS2A	10	3	1.75	0.3	1	MK10NS2D	10	3	1.75	0.375	1
MK10NS3A	10	4.5	1.75	0.3	1	MK10NS3D	10	4.5	1.75	0.375	1
MK20NS0A	20	0	1.75	0.3	1	MK20NS0D	20	0	1.75	0.375	1
MK20NS1A	20	1.5	1.75	0.3	1	MK20NS1D	20	1.5	1.75	0.375	1
MK20NS2A	20	3	1.75	0.3	1	MK20NS2D	20	3	1.75	0.375	1
MK20NS3A	20	4.5	1.75	0.3	1	MK20NS3D	20	4.5	1.75	0.375	1
MK30NS0A	30	0	1.75	0.3	1	MK30NS0D	30	0	1.75	0.375	1
MK30NS1A	30	1.5	1.75	0.3	1	MK30NS1D	30	1.5	1.75	0.375	1
MK30NS2A	30	3	1.75	0.3	1	MK30NS2D	30	3	1.75	0.375	1
MK30NS3A	30	4.5	1.75	0.3	1	MK30NS3D	30	4.5	1.75	0.375	1
MK0NS0B	0	0	1.75	0.325	1	MK0NS0E	0	0	1.75	0.4	1
MK0NS1B	0	1.5	1.75	0.325	1	MK0NS1E	0	1.5	1.75	0.4	1
MK0NS2B	0	3	1.75	0.325	1	MK0NS2E	0	3	1.75	0.4	1
MK0 NS3B	0	4.5	1.75	0.325	1	MK0 NS3E	0	4.5	1.75	0.4	1
MK10NS0B	10	0	1.75	0.325	1	MK10NS0E	10	0	1.75	0.4	1
MK10NS1B	10	1.5	1.75	0.325	1	MK10NS1E	10	1.5	1.75	0.4	1

Table 1. Continued

MK10NS2B	10	3	1.75	0.325	1	MK10NS2E	10	3	1.75	0.4	1
MK10NS3B	10	4.5	1.75	0.325	1	MK10NS3E	10	4.5	1.75	0.4	1
MK20NS0B	20	0	1.75	0.325	1	MK20NS0E	20	0	1.75	0.4	1
MK20NS1B	20	1.5	1.75	0.325	1	MK20NS1E	20	1.5	1.75	0.4	1
MK20NS2B	20	3	1.75	0.325	1	MK20NS2E	20	3	1.75	0.4	1
MK20NS3B	20	4.5	1.75	0.325	1	MK20NS3E	20	4.5	1.75	0.4	1
MK30NS0B	30	0	1.75	0.325	1	MK30NS0E	30	0	1.75	0.4	1
MK30NS1B	30	1.5	1.75	0.325	1	MK30NS1E	30	1.5	1.75	0.4	1
MK30NS2B	30	3	1.75	0.325	1	MK30NS2E	30	3	1.75	0.4	1
MK30NS3B	30	4.5	1.75	0.325	1	MK30NS3E	30	4.5	1.75	0.4	1
MK0NS0C	0	0	1.75	0.35	1	MK0NS0F	0	0	1.75	0.425	1
MK0NS1C	0	1.5	1.75	0.35	1	MK0NS1F	0	1.5	1.75	0.425	1
MK0NS2C	0	3	1.75	0.35	1	MK0NS2F	0	3	1.75	0.425	1
MK0 NS3C	0	4.5	1.75	0.35	1	MK0 NS3F	0	4.5	1.75	0.425	1
MK10NS0C	10	0	1.75	0.35	1	MK10NS0F	10	0	1.75	0.425	1
MK10NS1C	10	1.5	1.75	0.35	1	MK10NS1F	10	1.5	1.75	0.425	1
MK10NS2C	10	3	1.75	0.35	1	MK10NS2F	10	3	1.75	0.425	1
MK10NS3C	10	4.5	1.75	0.35	1	MK10NS3F	10	4.5	1.75	0.425	1
MK20NS0C	20	0	1.75	0.35	1	MK20NS0F	20	0	1.75	0.425	1
MK20NS1C	20	1.5	1.75	0.35	1	MK20NS1F	20	1.5	1.75	0.425	1
MK20NS2C	20	3	1.75	0.35	1	MK20NS2F	20	3	1.75	0.425	1
MK20NS3C	20	4.5	1.75	0.35	1	MK20NS3F	20	4.5	1.75	0.425	1
MK30NS0C	30	0	1.75	0.35	1	MK30NS0F	30	0	1.75	0.425	1
MK30NS1C	30	1.5	1.75	0.35	1	MK30NS1F	30	1.5	1.75	0.425	1
MK30NS2C	30	3	1.75	0.35	1	MK30NS2F	30	3	1.75	0.425	1
MK30NS3C	30	4.5	1.75	0.35	1	MK30NS3F	30	4.5	1.75	0.425	1

Table 2. Mix proportion of Metakaolin and Nanosilica based HPC mixes (MKNSHPC) for Aggregate binder ratio 1.75.

SL. No.	Mix	Cement (Kg)	Meta Kaolin (Kg)	Nano Silica (Kg)	Water (Litres)	Coarse Aggregate (Kg)	Fine Aggregate (Kg)	SL. No.	Mix	Cement (Kg)	Meta Kaolin (Kg)	Nano Silica (Kg)	Water (Litres)	Coarse Aggregate (Kg)	Fine Aggregate (Kg)
1	MK0NS0A	789.5	0	0	236.86	829.01	552.673	49	MK0NS0D	749.39	0	0	279.5	782.66	521.78
2	MK0NS1A	776.7	0	11.827	236.55	827.91	551.94	50	MK0NS1D	733.29	0	11.17	279.2	781.68	521.12
3	MK0NS2A	763.8	0	23.623	236.23	826.81	551.21	51	MK0NS2D	721.22	0	22.31	278.8	780.71	520.47
4	MK0NS3A	751	0	35.39	235.92	825.72	550.48	52	MK0NS3D	709.18	0	33.42	278.5	779.73	519.82
5	MK10NS0A	707.1	78.57	0	235.71	824.97	549.98	53	MK10NS0D	667.77	74.2	0	278.2	779.06	519.37
6	MK10NS1A	694.4	78.46	11.77	235.39	823.88	549.25	54	MK10NS1D	655.82	74.1	11.12	277.9	778.09	518.73
7	MK10NS2A	681.7	78.36	23.51	235.08	822.79	548.53	55	MK10NS2D	643.9	74.01	22.2	277.5	777.12	518.08
8	MK10NS3A	669.1	78.26	35.22	234.77	821.71	547.81	56	MK10NS3D	632.01	73.92	33.26	277.2	776.15	517.44
9	MK20NS0A	625.5	156.37	0	234.56	820.97	547.31	57	MK20NS0D	590.85	147.71	0	277	775.49	517
10	MK20NS1A	613	156.17	11.71	234.25	819.89	546.59	58	MK20NS1D	579.05	147.53	11.06	276.6	774.53	516.35
11	MK20NS2A	600.5	155.96	23.39	233.95	818.81	545.88	59	MK20NS2D	567.28	147.35	22.1	276.3	773.57	515.71
12	MK20NS3A	588	155.76	35.05	233.64	817.74	545.16	60	MK20NS3D	555.54	147.16	33.11	275.9	772.61	515.07
13	MK30NS0A	544.7	233.43	0	233.43	817.01	544.67	61	MK30NS0D	514.64	220.56	0	275.7	771.96	514.64
14	MK30NS1A	532.3	233.12	11.66	233.12	815.94	543.96	62	MK30NS1D	502.99	220.29	11.01	275.4	771	514
15	MK30NS2A	520	232.82	23.28	232.82	814.87	543.25	63	MK30NS2D	491.37	220.01	22	275	770.05	513.37
16	MK30NS3A	507.7	232.52	34.88	232.52	813.81	542.54	64	MK30NS3D	479.77	219.74	32.96	274.7	769.1	512.73
17	MK0NS0B	774.3	0	0	251.63	821.96	541.98	65	MK0NS0E	731.76	0	0	292.7	768.35	512.23
18	MK0NS1B	761.6	0	11.599	251.3	811.91	541.27	66	MK0NS1E	719.9	0	10.96	292.3	767.4	511.6
19	MK0NS2B	749.1	0	23.167	250.98	810.85	540.57	67	MK0NS2E	708.06	0	21.9	292	766.46	510.97
20	MK0NS3B	736.5	0	34.71	250.65	809.8	539.87	68	MK0NS3E	696.26	0	32.81	291.6	765.52	510.35
21	MK10NS0B	693.5	77.05	0	250.43	809.08	539.38	69	MK10NS0E	655.61	72.85	0	291.4	764.87	509.92
22	MK10NS1B	681.1	76.96	11.54	250.1	808.03	538.69	70	MK10NS1E	643.89	72.76	10.91	291	763.94	509.29
23	MK10NS2B	668.6	76.96	23.06	249.78	806.98	537.99	71	MK10NS2E	632.2	72.67	21.8	290.7	763	508.67
24	MK10NS3B	656.3	76.96	34.54	249.46	805.94	537.29	72	MK10NS3E	620.54	72.58	32.66	290.3	762.07	508.05

Table 2. Continued

25	MK20NS0B	613.5	153.38	0	249.24	805.23	536.82	73	MK20NS0E	580.14	145.03	0	290.1	761.43	507.62
26	MK20NS1B	601.2	153.18	11.49	248.92	804.19	536.13	74	MK20NS1E	568.57	144.86	10.86	289.7	760.51	507
27	MK20NS2B	589	152.98	22.95	248.6	803.16	535.44	75	MK20NS2E	557.02	144.68	21.7	289.4	759.58	506.39
28	MK20NS3B	576.8	152.79	34.38	248.28	802.12	534.75	76	MK20NS3E	545.51	144.51	32.51	289	758.66	505.77
29	MK30NS0B	534.3	228.98	0	248.06	801.42	534.28	77	MK30NS0E	505.35	216.58	0	288.8	758.02	505.35
30	MK30NS1B	522.2	228.68	11.43	247.74	800.39	533.59	78	MK30NS1E	493.92	216.32	10.82	218.4	757.1	504.74
31	MK30NS2B	510.1	228.39	22.84	247.42	799.36	532.91	79	MK30NS2E	482.52	216.05	21.61	288.1	756.19	504.12
32	MK30NS3B	498	228.1	34.21	247.1	798.34	532.23	80	MK30NS3E	471.14	215.79	32.37	287.7	755.27	503.51
33	MK0NS0C	759.5	0	0	265.84	797.53	531.68	81	MK0NS0F	718.61	0	0	305.4	754.54	503.03
34	MK0NS1C	747.2	0	11.379	265.5	796.51	531.01	82	MK0NS1F	706.98	0	10.77	305	753.63	502.42
35	MK0NS2C	734.9	0	22.728	265.16	795.49	530.33	83	MK0NS2F	695.37	0	21.51	304.7	752.72	501.81
36	MK0NS3C	722.6	0	34.05	264.83	794.48	529.65	84	MK0NS3F	683.79	0	32.22	304.3	751.81	501.21
37	MK10NS0C	680.4	75.6	0	264.6	793.79	529.19	85	MK10NS0F	643.88	71.54	0	304.1	751.19	500.8
38	MK10NS1C	668.2	75.5	11.33	264.26	792.78	528.52	86	MK10NS1F	632.39	71.46	10.72	303.7	750.29	500.19
39	MK10NS2C	656	75.41	22.62	263.92	791.77	527.85	87	MK10NS2F	620.92	71.37	21.41	303.3	749.39	499.59
40	MK10NS3C	643.9	75.31	33.89	263.59	790.77	527.18	88	MK10NS3F	609.49	71.28	32.08	303	748.49	498.99
41	MK20NS0C	602	150.49	0	263.36	790.08	526.72	89	MK20NS0F	569.81	142.45	0	302.7	747.87	498.58
42	MK20NS1C	589.9	150.3	11.27	263.03	789.08	526.05	90	MK20NS1F	558.46	142.28	10.67	302.4	746.98	498.99
43	MK20NS2C	577.9	150.11	22.52	262.69	788.08	525.39	91	MK20NS2F	547.13	142.11	21.32	302	746.09	497.39
44	MK20NS3C	566	149.92	33.73	262.36	787.09	524.73	92	MK20NS3F	535.83	141.94	31.94	301.6	745.2	496.8
45	MK30NS0C	524.3	224.69	0	262.14	786.41	524.27	93	MK30NS0F	496.39	212.74	0	301.4	744.58	496.39
46	MK30NS1C	512.4	224.41	11.22	261.81	785.42	523.61	94	MK30NS1F	485.17	212.48	10.62	301	743.7	495.8
47	MK30NS2C	500.5	224.12	22.41	261.48	784.43	522.95	95	MK30NS2F	473.98	212.23	21.22	300.7	742.81	495.21
48	MK30NS3C	488.7	223.84	33.58	261.15	783.45	522.3	96	MK30NS3F	462.82	211.98	31.8	300.3	741.93	494.62

(a)

(b) **(c)** **(d)**

Figure 1. (a) (b) (c) & (d). Cubes casted and subjected to acid attack during the experimental investigation

3. Experimental Procedure

To study the behaviour of MKNSHPC, all the above mixes were cast and cured for 28 days for aggregate binder ratio of 1.75 and water binder ratios of 0.3, 0.325,0.35,0.375,0.4 and 0.425. Below is an explanation of the nomenclature used to designate the various mixes in Table 1. The first two characters represents Metakaolin as an admixture, followed by its partial replacement of cement at 0,10,20 and 30%. The next two characters denote Nano silica as a supplementary admixture, followed by numeric 0,1,2,3 denoting cement replacement of 0, 1.5, 3, and 4.5% respectively. The final character (A-F) in the mix designation indicates water binder ratio, between 0.30 and 0.425. Alphabet 'A', for example, indicates a mix with a W/B ratio of 0.30, whereas Alphabet 'F' indicates a mix with a W/B ratio of 0.425. The relative proportion for the mixes were obtained by Absolute volume method and tabulated in Table 2. Concrete specimens of size 100x100x100 mm were cast to find residual compressive strength of the cubes after ageing for 30, 60 and 90 days of immersion in different acids Figure1(a-d).

3.1. Method of Test for Acid Attack

Cubes of standard sizes are cleaned thoroughly and greased properly. All the mixes are prepared as per the mix proportion calculated by Absolute volume method. Initially Nano silica is mixed with cement uniformly, and then it is mixed with fine and coarse aggregate in the dry form along with Metakaolin in the concrete mixer. Small quantity of water is added to superplasticizer and the remaining water calculated is added to get a uniform mix. The mix so prepared is poured into the moulds in 3 layers and are placed in a table vibrator and then kept undisturbed for 24 hours. The moulds are demoulded after 24 hours and immersed in clean water for 28 days. The specimens cured for 28 days are removed from the mould and dried in shade. 3 specimens are tested for each mix in the compression testing machine and the loads are noted as 28 days Cube compressive strength. The remaining cubes are immersed in 5% concentration of HCl, H_2SO_4 and $MgSO_4$ acids in distinct tanks and cured for 30, 60 and 90 days. To maintain the same 5% concentration, they were replaced with fresh solution after a week. After 30, 60 and 90 of exposure in acids, the specimens were cleaned, dried and then tested in compression testing machine. Residual compressive strength obtained for each specimen is recorded.

Table 3. Residual Compressive strength of MKNSHPC mixes with HCl immersion

MIX	**Compressive strength (MPa)**	**Residual Compressive strength (MPa)**			**MIX**	**Compressive strength (MPa)**	**Residual Compressive strength (MPa)**			**MIX**	**Compressive strength (MPa)**	**Residual Compressive strength (MPa)**		
	28 days	30 days	60 days	90 days		28 days	30 days	60 days	90 days		28 days	30 days	60 days	90 days
MK0NS0A	77	70.68	66.37	62.85	MK0NS0C	72.92	66.58	62.29	58.49	MK0NS0E	68.65	62.51	58.31	54.67
MK0NS1A	83.31	77.64	73.71	70.02	MK0NS1C	75.36	70.61	66.08	62.97	MK0NS1E	71.4	66.81	62.23	59.01
MK0NS2A	89.87	84.15	80.76	76.87	MK0NS2C	84.38	79.87	74.66	71.75	MK0NS2E	76.67	73.41	69.33	65.86
MK0NS3A	86.84	81.42	77.52	74.4	MK0NS3C	82.54	77.24	72.14	69.32	MK0NS3E	75.86	71.74	67.73	63.34
MK10NS0A	87.25	81.24	78.23	73.02	MK10NS0C	81.33	75.39	72.43	67.39	MK10NS0E	77.81	71.76	67.91	64.33
MK10NS1A	97.82	91.67	88.23	83.68	MK10NS1C	94.42	87.26	83.74	79.96	MK10NS1E	88.08	82.08	77.81	74.58
MK10NS2A	101.45	96.95	93.92	89.79	MK10NS2C	97.89	92.67	89.33	85.64	MK10NS2E	94.08	88.67	84.91	81.75
MK10NS3A	100.04	94.88	90.82	88.13	MK10NS3C	95.67	90.51	86.46	83.47	MK10NS3E	91.67	86.29	82.58	79.34
MK20NS0A	79.98	74.02	69.72	65.17	MK20NS0C	75.76	69.59	65.32	61.41	MK20NS0E	71.23	65.08	60.89	57.31
MK20NS1A	86.53	80.92	77.41	73.02	MK20NS1C	80.29	74.52	71.33	67.19	MK20NS1E	74.17	68.73	64.94	62.55
MK20NS2A	93.43	87.88	84.03	80.62	MK20NS2C	87.49	82.97	77.99	75.99	MK20NS2E	80.67	76.36	71.11	69.09
MK20NS3A	90.13	84.83	81.17	77.92	MK20NS3C	85.59	80.26	76.36	73.34	MK20NS3E	78.82	73.74	69.54	67.09
MK30NS0A	75.53	69.35	66.24	61.04	MK30NS0C	71.69	65.44	61.28	57.48	MK30NS0E	67.42	61.41	57.83	53.75
MK30NS1A	81.64	76.13	72.34	68.55	MK30NS1C	74.56	68.99	65.44	62.55	MK30NS1E	70.16	64.68	61.1	58.03
MK30NS2A	88.12	82.53	78.73	75.36	MK30NS2C	82.97	77.54	73.74	70.49	MK30NS2E	75.75	71.58	68.99	64.61
MK30NS3A	85.19	79.9	76.32	72.97	MK30NS3C	80.93	75.71	72.13	68.85	MK30NS3E	74.37	69.4	65.53	62.82
MK0NS0B	74.7	68.66	63.98	61.04	MK0NS0D	70.15	64.23	60.99	55.66	MK0NS0F	67.24	61.25	57.78	53.64
MK0NS1B	78.26	75.01	69.65	66.95	MK0NS1D	73.16	67.95	63.99	61.11	MK0NS1F	69.05	65.33	61.31	58.11
MK0NS2B	86.81	82.51	78.21	75.14	MK0NS2D	80.92	77.11	71.99	68.62	MK0NS2F	72.98	72.29	67.59	63.75
MK0NS3B	84.5	80.11	74.25	72.11	MK0NS3D	79.62	75.12	69.75	66.23	MK0NS3F	71.88	70.35	65.45	61.12
MK10NS0B	83.3	78.65	74.88	70.49	MK10NS0D	78.83	73.45	70.12	65.34	MK10NS0F	74.18	70.12	66.61	63.14
MK10NS1B	95.73	89.14	86.03	82.23	MK10NS1D	91.54	84.99	80.12	77.11	MK10NS1F	83.35	80.59	75.99	73.66

Table 3. Continued

MK10NS2B	99.22	94.88	91.45	88.46	MK10NS2D	95.62	90.69	86.77	83.46	MK10NS2F	89.92	87.81	84.22	80.78
MK10NS3B	97.24	92.56	89.96	87.02	MK10NS3D	94.33	87.88	84.17	81.04	MK10NS3F	86.73	85.11	81.36	77.88
MK20NS0B	77.61	71.23	68.06	63.87	MK20NS0D	72.87	67.23	62.96	59.22	MK20NS0F	69.92	64.34	59.69	56.29
MK20NS1B	83.22	77.5	74.12	70.98	MK20NS1D	77.89	71.55	68	65.13	MK20NS1F	71.71	67.65	62.58	60.21
MK20NS2B	91.62	84.88	80.95	79.69	MK20NS2D	84.85	79.87	74.23	72.31	MK20NS2F	77.41	75.22	69.73	66.97
MK20NS3B	88.15	82.34	79.17	76.56	MK20NS3D	82.58	76.88	72.58	70.55	MK20NS3F	74.76	72.55	67.56	65.01
MK30NS0B	73.69	67.11	64.33	59.24	MK30NS0D	68.99	63.34	60.15	55.78	MK30NS0F	66.04	60.99	56.87	52.78
MK30NS1B	77.18	71.99	69.14	66.44	MK30NS1D	72.28	66.78	63.55	60.22	MK30NS1F	68.27	63.67	60.47	56.64
MK30NS2B	85.18	79.89	76.85	73.11	MK30NS2D	79.32	74.96	72.12	67.19	MK30NS2F	71.68	70.67	66.78	63.75
MK30NS3B	82.84	77.56	73.99	71.45	MK30NS3D	78.11	72.16	69.23	65.74	MK30NS3F	70.11	68.32	64.37	61.38

Table 4. Residual Compressive strength of MKNSHPC mixes with $MgSO_4$ immersion

MIX	Compressive strength (MPa)	Residual Compressive strength (MPa)			MIX	Compressive strength (MPa)	Residual Compressive strength (MPa)			MIX	Compressive strength (MPa)	Residual Compressive strength (MPa)		
	28 days	**30 days**	**60 days**	**90 days**		**28 days**	**30 days**	**60 days**	**90 days**		**28 days**	**30 days**	**60 days**	**90 days**
MK0NS0A	77	70.37	65.67	61.15	MK0NS0C	72.92	66.23	61.56	57.53	MK0NS0E	68.65	62.16	57.45	53.69
MK0NS1A	83.31	77.12	73.16	68.99	MK0NS1C	75.36	69.54	65.39	62.03	MK0NS1E	71.4	65.49	61.39	57.97
MK0NS2A	89.87	84.02	79.93	76.34	MK0NS2C	84.38	78.94	74.41	71.08	MK0NS2E	76.67	71.64	67.88	63.89
MK0NS3A	86.84	81.3	77.38	73.91	MK0NS3C	82.54	76.39	71.67	68.86	MK0NS3E	75.86	69.34	66.31	62.15
MK10NS0A	87.25	80.67	75.75	74.96	MK10NS0C	81.33	74.94	70.09	68.94	MK10NS0E	77.81	71.62	66.96	64.61
MK10NS1A	97.82	91.09	86.34	82.69	MK10NS1C	94.42	87.21	82.83	78.14	MK10NS1E	88.08	81.67	77.15	73.67
MK10NS2A	101.45	95.63	91.46	90.58	MK10NS2C	97.89	92.09	87.89	84.9	MK10NS2E	94.08	88.18	84.37	81.46
MK10NS3A	100.04	94.15	90.07	87.81	MK10NS3C	95.67	90.12	86.02	83.13	MK10NS3E	91.67	86.03	82.33	79.53
MK20NS0A	79.98	73.41	68.71	64.69	MK20NS0C	75.76	69.21	64.42	60.34	MK20NS0E	71.23	64.97	58.33	55.6
MK20NS1A	86.53	80.46	76.09	72.32	MK20NS1C	80.29	74.31	70.05	66.67	MK20NS1E	74.17	68.4	64.24	61.03

Table 4. Continued

MK20NS2A	93.43	87.66	83.58	80.38	MK20NS2C	87.49	81.87	77.82	75.71	MK20NS2E	80.67	75.13	71.29	68.41
MK20NS3A	90.13	84.67	80.73	77.74	MK20NS3C	85.59	79.56	75.54	72.23	MK20NS3E	78.82	73.23	69.72	66.15
MK30NS0A	75.53	69.08	64.51	61.95	MK30NS0C	71.69	65.11	60.59	56.97	MK30NS0E	67.42	61	56.36	52.71
MK30NS1A	81.64	75.73	71.59	69.17	MK30NS1C	74.56	68.77	64.74	65.39	MK30NS1E	70.16	64.33	60.36	58.56
MK30NS2A	88.12	82.42	78.45	74.81	MK30NS2C	82.97	77.25	73.21	71.08	MK30NS2E	75.75	73.17	66.43	64.49
MK30NS3A	85.19	79.78	75.95	72.47	MK30NS3C	80.93	75.11	71.14	68.41	MK30NS3E	74.37	69.08	63.98	62.05
MK0NS0B	74.7	67.98	63.18	59.12	MK0NS0D	70.15	63.99	59.15	55.45	MK0NS0F	67.24	60.41	55.82	51.95
MK0NS1B	78.26	73.12	69.15	65.17	MK0NS1D	73.16	67.45	63.22	59.87	MK0NS1F	69.05	63.66	59.81	56.28
MK0NS2B	86.81	81	77.08	73.58	MK0NS2D	80.92	74.86	70.95	67.35	MK0NS2F	72.98	70.05	66.19	62.23
MK0NS3B	84.5	78.99	74.21	72.01	MK0NS3D	79.62	73.04	68.76	65.02	MK0NS3F	71.88	67.41	64.58	59.06
MK10NS0B	83.3	77.56	73.02	72.58	MK10NS0D	78.83	73.11	68.25	66.88	MK10NS0F	74.18	69.94	65.28	62.92
MK10NS1B	95.73	89.12	84.62	80.25	MK10NS1D	91.54	84.59	79.68	75.25	MK10NS1F	83.35	79.77	75.36	71.95
MK10NS2B	99.22	93.67	89.64	88.74	MK10NS2D	95.62	90.32	86.01	83.11	MK10NS2F	89.92	86.51	82.66	79.91
MK10NS3B	97.24	92.35	88.32	85.91	MK10NS3D	94.33	87.89	84.22	81.41	MK10NS3F	86.73	84.21	80.62	77.69
MK20NS0B	77.61	71.13	66.21	63.13	MK20NS0D	72.87	67	61.61	57.69	MK20NS0F	69.92	63.18	56.64	53.88
MK20NS1B	83.22	77.54	72.98	70.12	MK20NS1D	77.89	71.53	67.12	63.55	MK20NS1F	71.71	66.71	62.58	59.47
MK20NS2B	91.62	84.25	79.98	79.18	MK20NS2D	84.85	78.44	74.36	71.55	MK20NS2F	77.41	73.26	69.75	66.38
MK20NS3B	88.15	82.28	77.96	76.15	MK20NS3D	82.58	76.14	72.77	69.58	MK20NS3F	74.76	71.51	67.97	64.06
MK30NS0B	73.69	67.11	62.35	60.01	MK30NS0D	68.99	63.09	58.51	54.69	MK30NS0F	66.04	59.15	53.76	50.36
MK30NS1B	77.18	72.14	68.19	68.02	MK30NS1D	72.28	66.24	62.56	62.01	MK30NS1F	68.27	62.68	58.64	54.34
MK30NS2B	85.18	79.54	75.77	73.14	MK30NS2D	79.32	76.05	69.77	69.16	MK30NS2F	71.68	69.31	64.64	60.67
MK30NS3B	82.84	77.06	73.21	71.07	MK30NS3D	78.11	72.99	68.05	66.01	MK30NS3F	70.11	67	61.18	58.34

Table 5. Residual Compressive strength of MKNSHPC mixes with H_2SO_4 immersion

MIX	Compressive strength (MPa)	Residual Compressive strength (MPa)			MIX	Compressive strength (MPa)	Residual Compressive strength (MPa)			MIX	Compressive strength (MPa)	Residual Compressive strength (MPa)		
	28 days	30 days	60 days	90 days		28 days	30 days	60 days	90 days		28 days	30 days	60 days	90 days
MK0NS0A	77	69.93	64.63	59.44	MK0NS0C	72.92	65.74	60.31	55.59	MK0NS0E	68.65	61.41	56.32	51.75
MK0NS1A	83.31	76.51	71.26	66.56	MK0NS1C	75.36	68.86	63.56	59.64	MK0NS1E	71.4	64.39	60.11	55.78
MK0NS2A	89.87	83.63	78.58	74.39	MK0NS2C	84.38	77.83	73.17	68.93	MK0NS2E	76.67	69.98	66.02	62.07
MK0NS3A	86.84	80.93	76.04	71.99	MK0NS3C	82.54	76.41	71.72	67.56	MK0NS3E	75.86	69.35	65.46	61.54
MK10NS0A	87.25	80.09	74.64	69.17	MK10NS0C	81.33	74.2	68.95	63.41	MK10NS0E	77.81	70.64	65.43	60.16
MK10NS1A	97.82	90.49	84.9	79.19	MK10NS1C	94.42	86.91	81.48	75.64	MK10NS1E	88.08	80.67	75.47	69.91
MK10NS2A	101.45	94.67	89.43	84.67	MK10NS2C	97.89	90.72	85.91	81.01	MK10NS2E	94.08	86.97	82.11	77.23
MK10NS3A	100.04	93.47	88.41	83.71	MK10NS3C	95.67	89.04	84.04	79.28	MK10NS3E	91.67	84.85	80.05	75.39
MK20NS0A	79.98	73.03	67.69	62.43	MK20NS0C	75.76	68.71	63.12	58.32	MK20NS0E	71.23	64.37	59.01	54.23
MK20NS1A	86.53	79.85	74.49	69.47	MK20NS1C	80.29	73.63	68.4	63.91	MK20NS1E	74.17	67.41	62.87	58.43
MK20NS2A	93.43	87.04	82.02	77.65	MK20NS2C	87.49	80.81	76.32	71.8	MK20NS2E	80.67	74.04	69.93	65.64
MK20NS3A	90.13	84.03	79.23	75.01	MK20NS3C	85.59	79.25	74.79	70.35	MK20NS3E	78.82	72.44	68.46	64.22
MK30NS0A	75.53	68.64	63.48	58.43	MK30NS0C	71.69	64.61	59.27	54.62	MK30NS0E	67.42	60.38	55.28	50.85
MK30NS1A	81.64	75.04	69.9	65.26	MK30NS1C	74.56	68.1	63.02	58.95	MK30NS1E	70.16	63.31	58.97	54.91
MK30NS2A	88.12	81.97	77.15	72.99	MK30NS2C	82.97	76.49	72	67.73	MK30NS2E	75.75	69.17	65.21	61.39
MK30NS3A	85.19	79.37	74.64	70.66	MK30NS3C	80.93	74.76	70.34	66.19	MK30NS3E	74.37	67.99	64.09	60.38
MK0NS0B	74.7	67.74	62.33	57.45	MK0NS0D	70.15	63.45	58.26	53.56	MK0NS0F	67.24	59.62	54.39	49.87
MK0NS1B	78.26	72.59	67.19	62.97	MK0NS1D	73.16	66.25	61.76	57.46	MK0NS1F	69.05	62.52	58.25	53.99
MK0NS2B	86.81	80.66	75.78	71.65	MK0NS2D	80.92	73.86	69.56	65.66	MK0NS2F	72.98	68.19	64.06	60.29
MK0NS3B	84.5	78.56	73.67	73.57	MK0NS3D	79.62	72.67	68.44	64.35	MK0NS3F	71.88	67.49	63.68	59.58
MK10NS0B	83.3	77.12	71.67	71.43	MK10NS0D	78.83	72.39	67.06	61.67	MK10NS0F	74.18	68.76	63.65	58.38
MK10NS1B	95.73	88.76	83.05	82.99	MK10NS1D	91.54	83.65	78.23	72.63	MK10NS1F	83.35	78.74	73.59	68.02

Table 5. Continued

MK10NS2B	99.22	96.54	87.56	87.16	MK10NS2D	95.62	88.77	83.99	79.03	MK10NS2F	89.92	85.08	80.18	75.37
MK10NS3B	97.24	91.19	86.12	86.27	MK10NS3D	94.33	86.83	81.89	77.26	MK10NS3F	86.73	82.92	78.21	73.54
MK20NS0B	77.61	70.58	65.19	65.14	MK20NS0D	72.87	66.45	61.17	56.33	MK20NS0F	69.92	62.58	52.29	52.44
MK20NS1B	83.22	76.54	71.23	71.33	MK20NS1D	77.89	70.47	65.35	61.11	MK20NS1F	71.71	65.63	56.57	56.58
MK20NS2B	91.62	83.85	79.09	79.01	MK20NS2D	84.85	77.33	73.24	68.59	MK20NS2F	77.41	72.19	68.02	63.86
MK20NS3B	88.15	81.46	69.98	69.87	MK20NS3D	82.58	75.69	71.46	71.36	MK20NS3F	74.76	70.59	66.63	62.46
MK30NS0B	73.69	66.56	61.27	61.44	MK30NS0D	68.99	62.54	57.44	57.39	MK30NS0F	66.04	58.69	53.51	48.97
MK30NS1B	77.18	71.48	66.39	66.22	MK30NS1D	72.28	65.58	61.01	61.22	MK30NS1F	68.27	61.46	57.2	53.09
MK30NS2B	85.18	79.33	74.65	70.34	MK30NS2D	79.32	72.69	68.58	68.39	MK30NS2F	71.68	67.3	63.29	59.53
MK30NS3B	82.84	82.58	72.33	68.39	MK30NS3D	78.11	71.23	67.11	67.22	MK30NS3F	70.11	66.21	62.31	58.59

4. Results and Discussion

Residual compressive strength obtained after immersion in different acids for various Metakaolin and Nano silica based high performance concrete mixes for different water binder ratios are presented in Table 3, 4 and 5.

4.1. Influence of W/B Ratio on Residual Compressive Strength

As depicted in Figure (2-10), residual compressive strength after 30, 60, and 90 days immersion in HCl, $MgSO_4$, and H_2SO_4 declined as the water binder ratio increased for all percentage replacements from the present investigation. After 30 days of immersion in HCl acid, the residual compressive strength of the mix MK10NS2A was 96.95 MPa, decreasing 87.81 MPa as the water binder ratio increased from 0.3 to 0.425. The figures clearly illustrate the decreasing trend in residual compressive strength as the W/B ratio increases. This trend holds true for all of the acids tested in this investigation, namely HCl, $MgSO_4$, and H_2SO_4. The reason for the decrease in residual compressive strength as the W/B ratio increases may be due to the formation of a porous transition zone as a result of the increased water content, which allows the acid to penetrate deeply and disintegrate the C-S-H gel. When the W/B ratio is 0.3, the compressive strength decreases by a smaller proportion than when it is at other water binder ratios since less water is available for hydration in concrete, resulting in early strength gain.

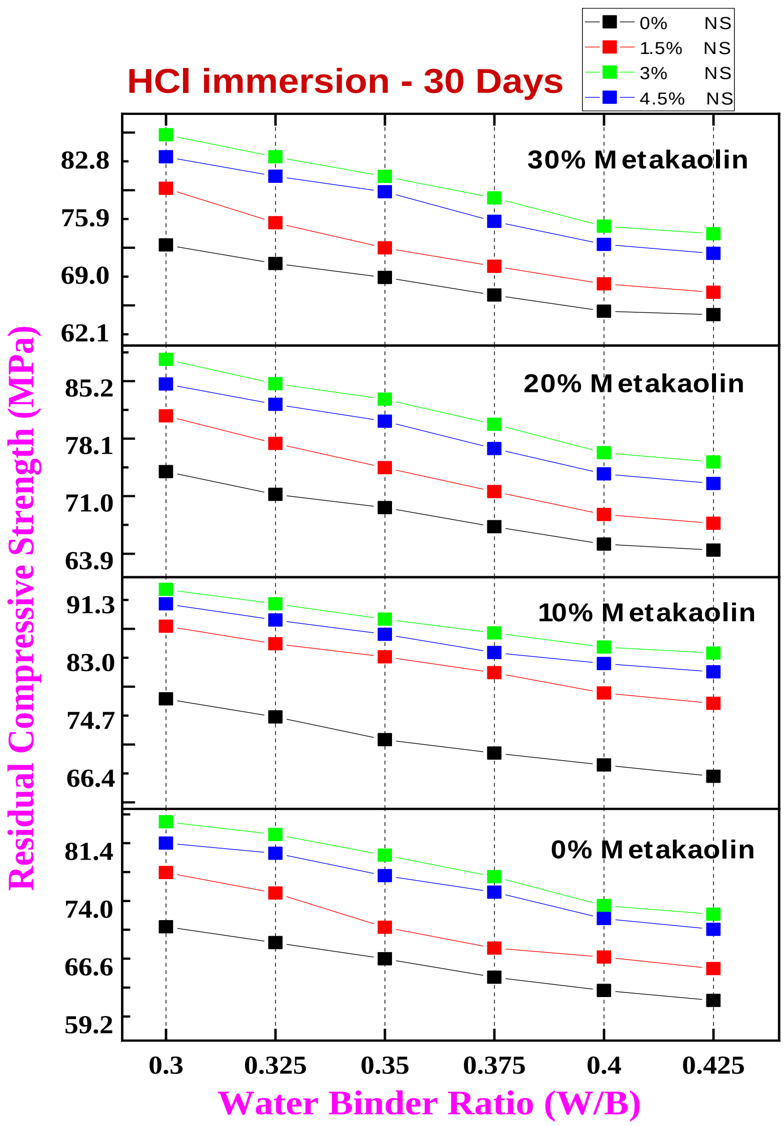

Figure 2. Graph of Residual compressive strength Vs Water binder ratio for MKNSHPC mixes in HCl acid immersion for 30days.

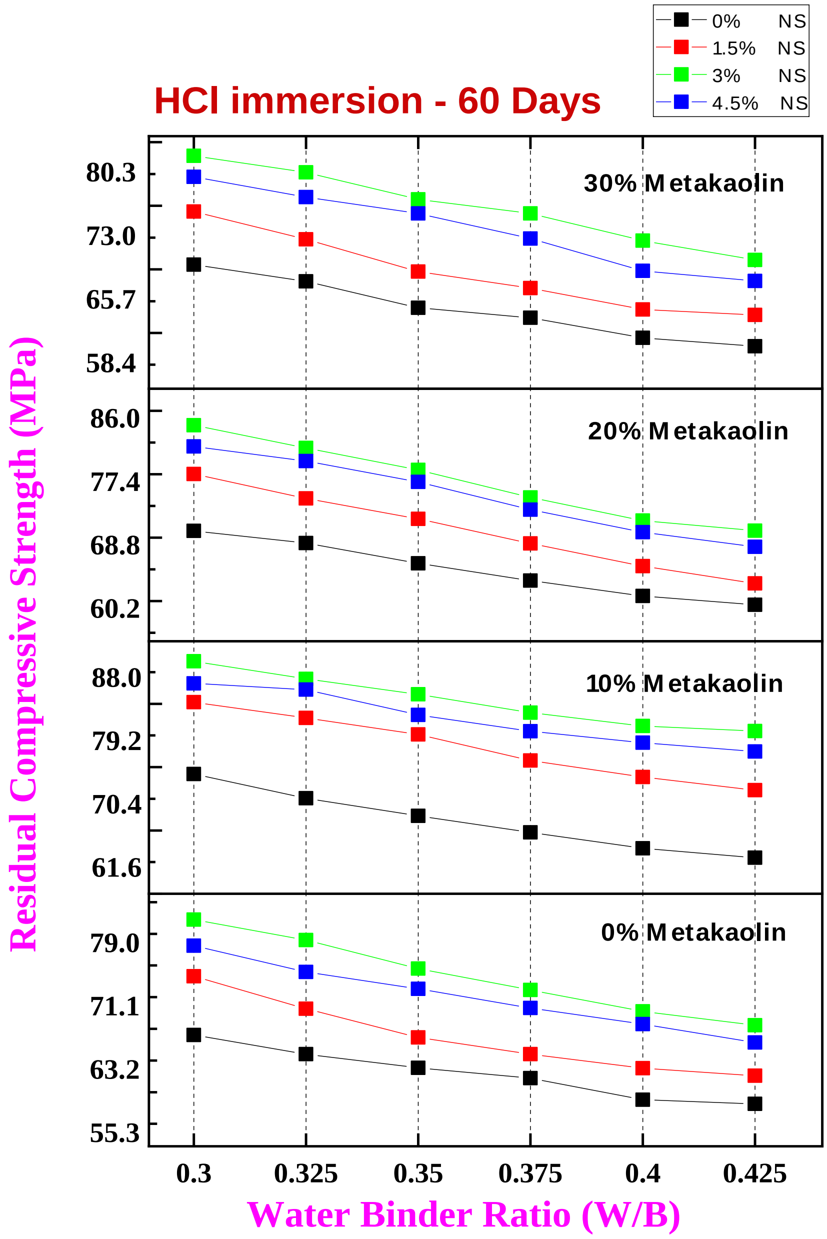

Figure 3. Graph of Residual compressive strength Vs Water binder ratio for MKNSHPC mixes in HCl acid immersion for 60days.

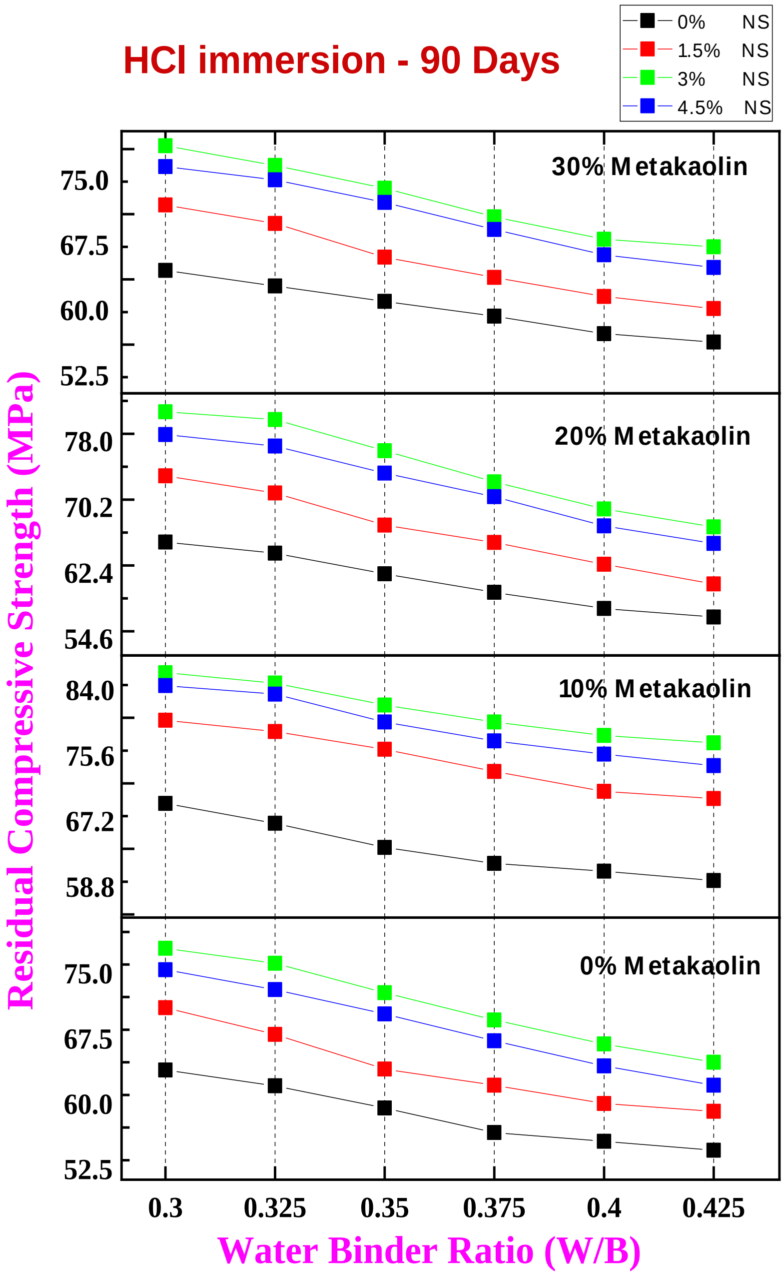

Figure 4. Graph of Residual compressive strength Vs Water binder ratio for MKNSHPC mixes in HCl acid immersion for 90days.

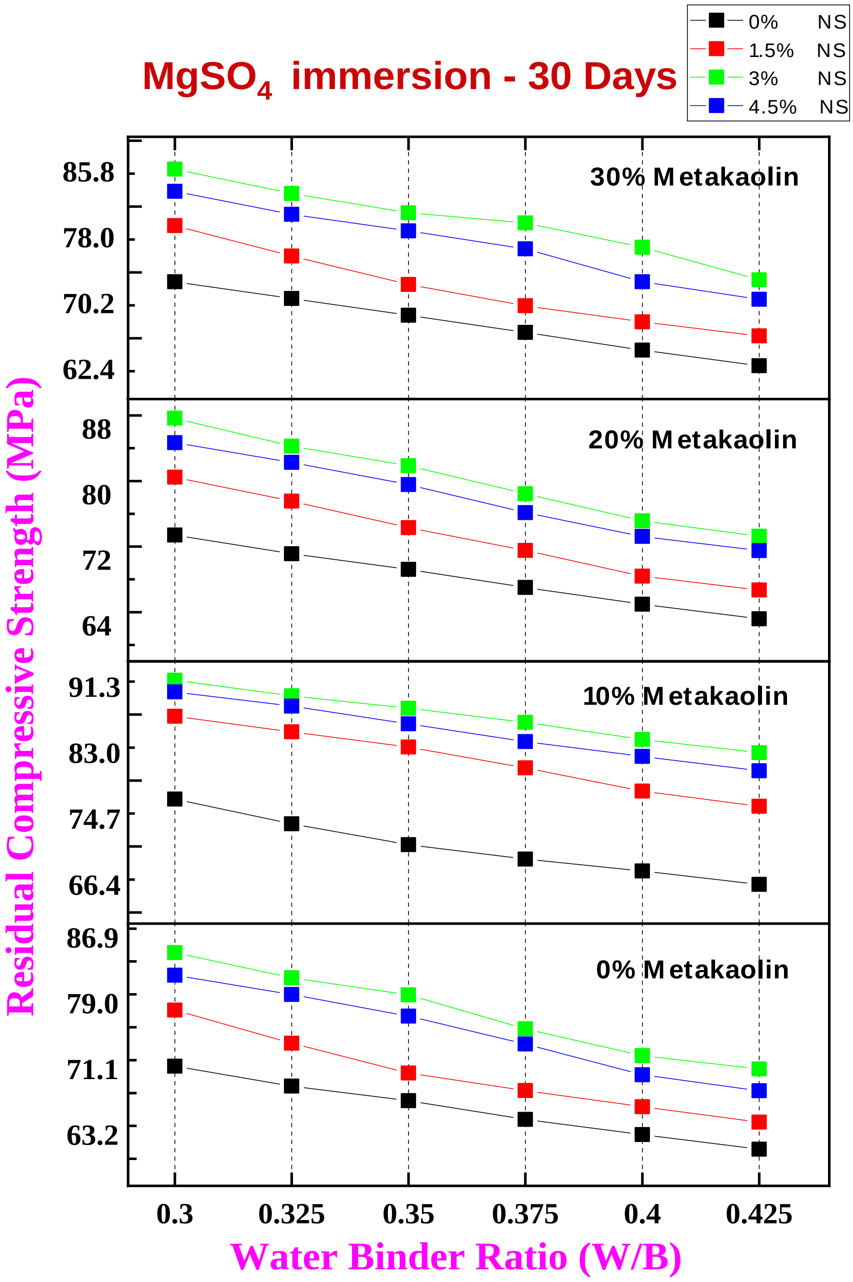

Figure 5. Graph of Residual compressive strength Vs Water binder ratio for MKNSHPC mixes in $MgSO_4$ acid immersion for 30days.

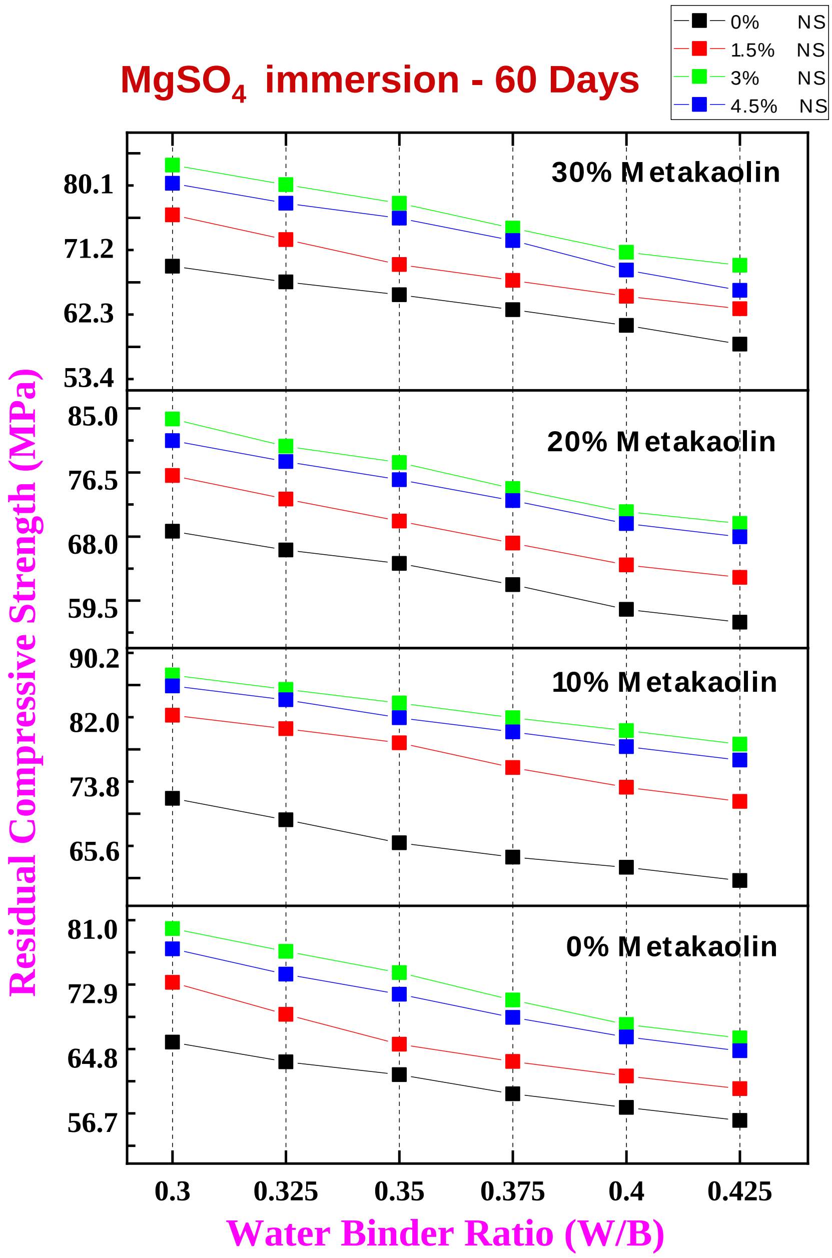

Figure 6. Graph of Residual compressive strength Vs Water binder ratio for MKNSHPC mixes in $MgSO_4$ acid immersion for 60days.

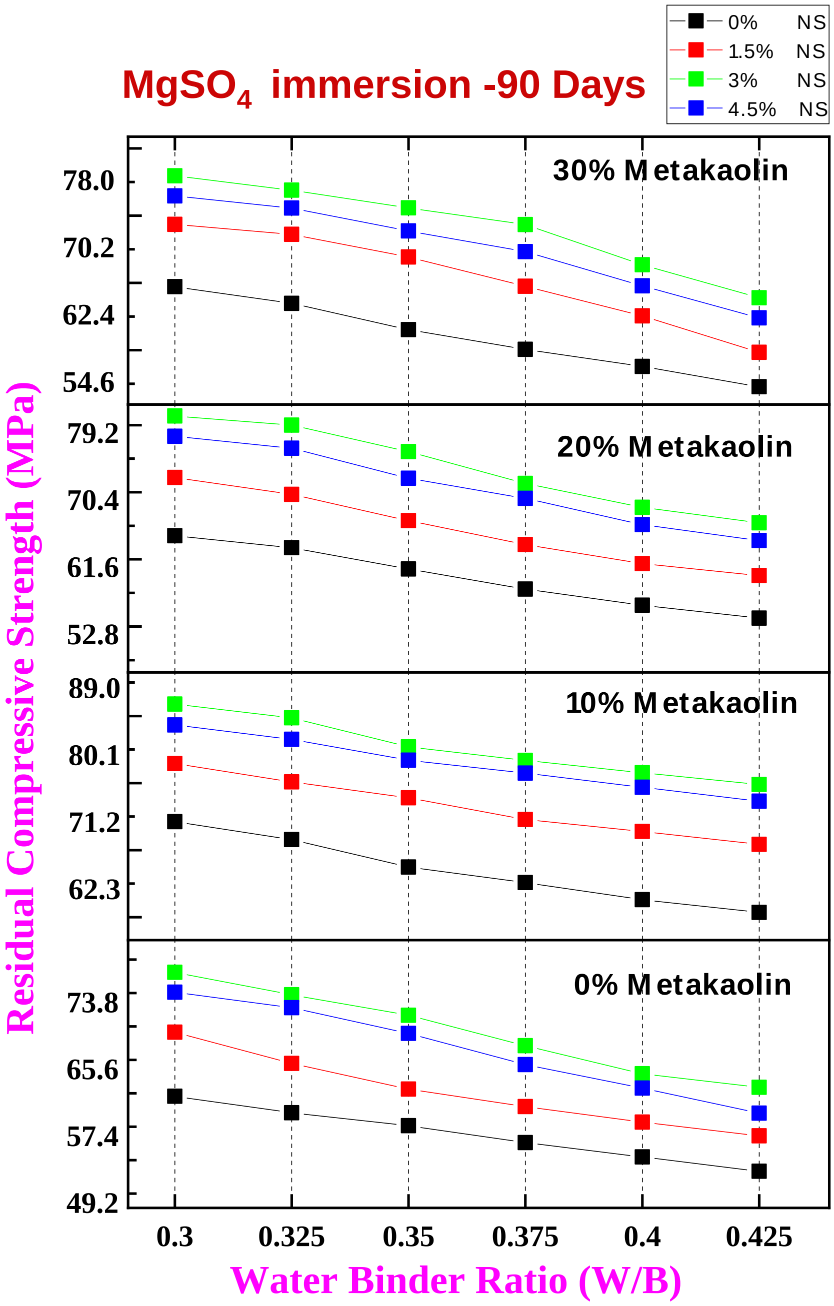

Figure 7. Graph of Residual compressive strength Vs Water binder ratio for MKNSHPC mixes in $MgSO_4$ acid immersion for 90days.

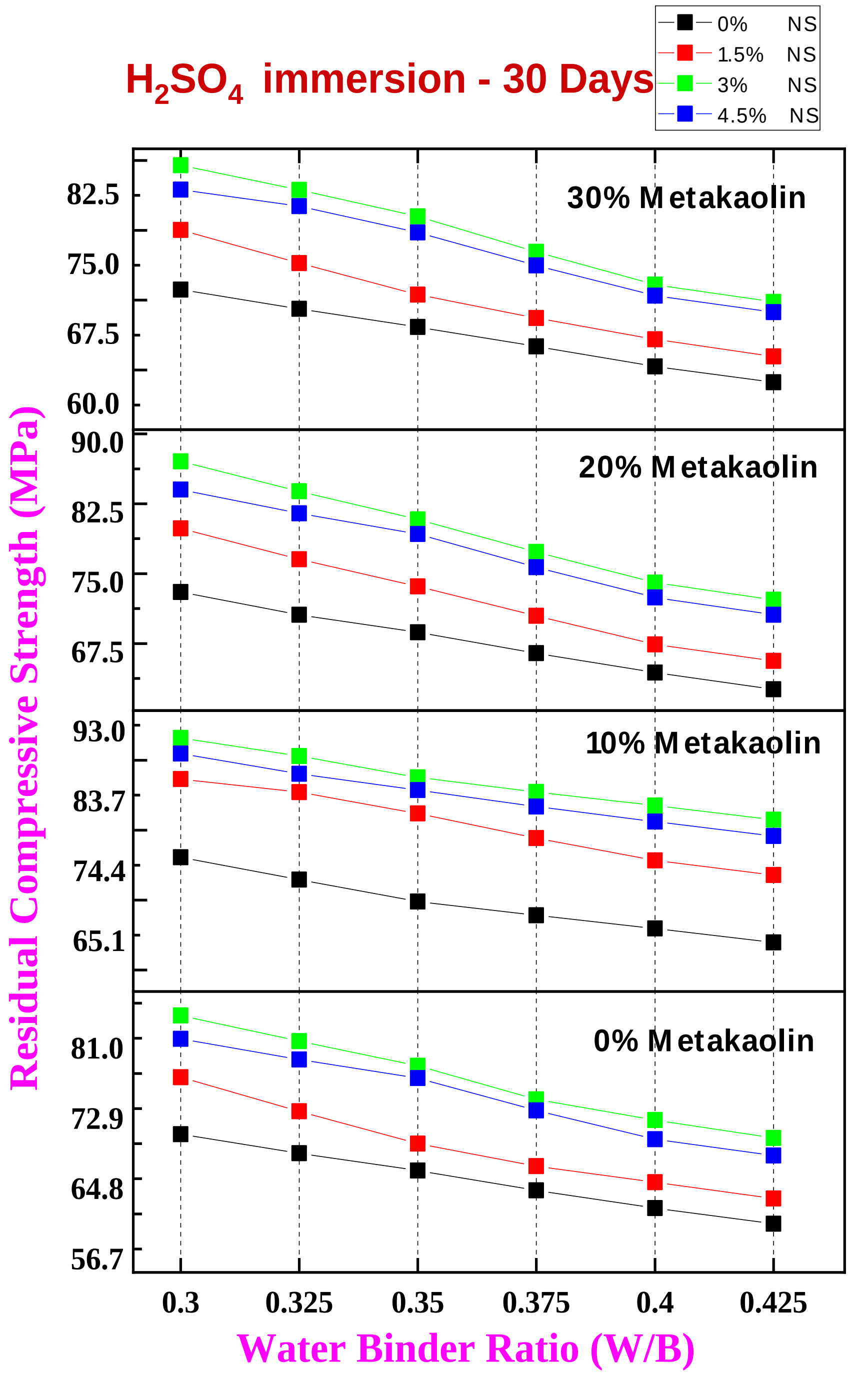

Figure 8. Graph of Residual compressive strength Vs Water binder ratio for MKNSHPC mixes in H_2SO_4 acid immersion for 30days.

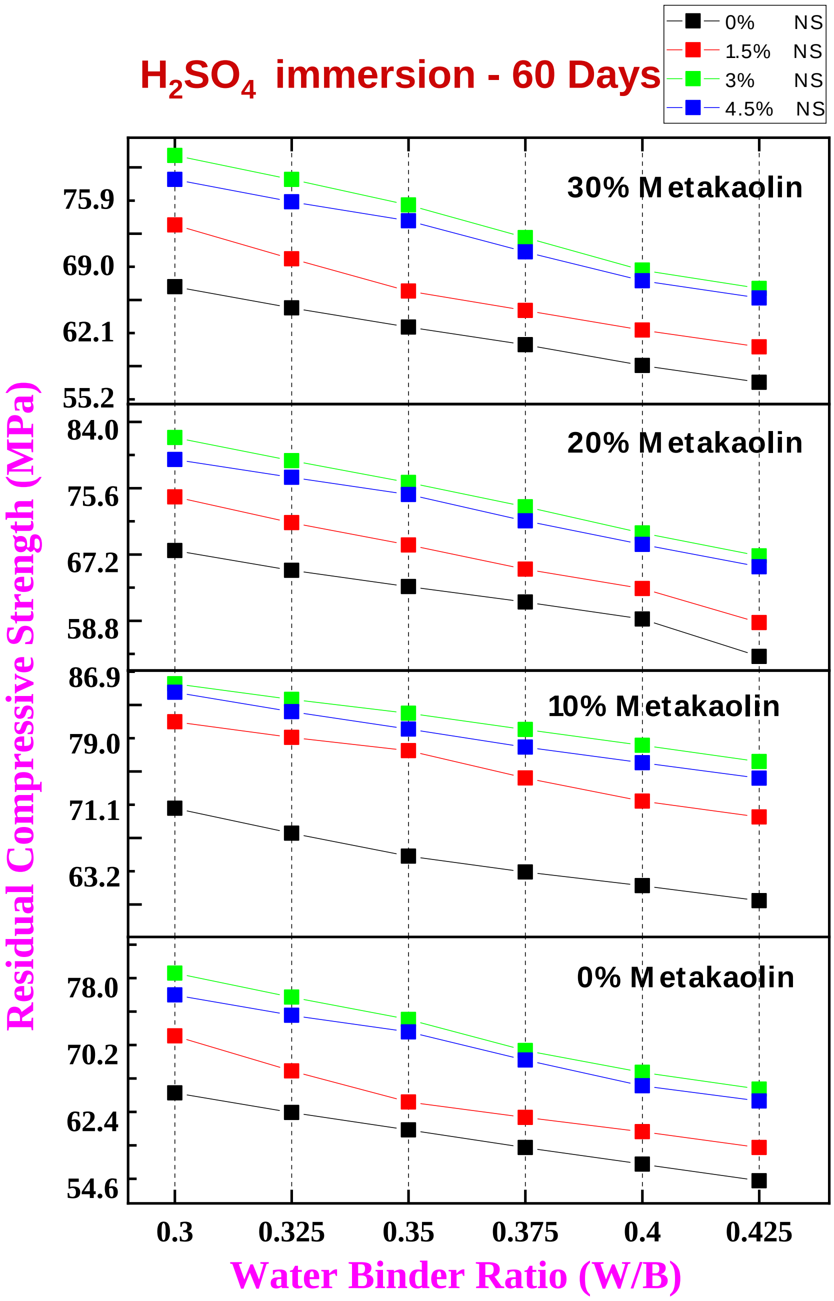

Figure 9. Graph of Residual compressive strength Vs Water binder ratio for MKNSHPC mixes in H_2SO_4 acid immersion for 60days.

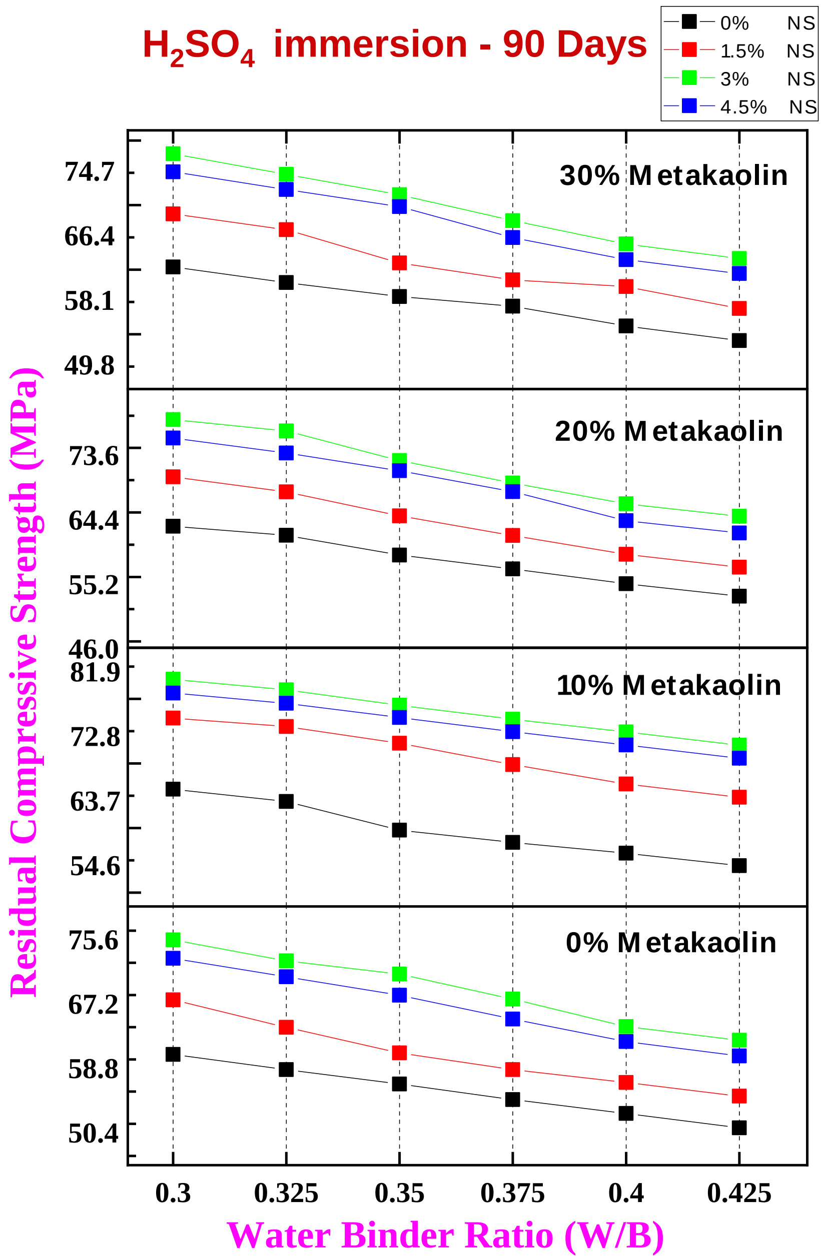

Figure 10. Graph of Residual compressive strength Vs Water binder ratio for MKNSHPC mixes in H_2SO_4 acid immersion for 90days.

4.2. Influence of Metakaolin on Residual Compressive Strength

As seen from the investigation, the inclusion of mineral admixture increased the resistance of HPC to acid damage by up to 10% replacement. As can be seen from these statistics, the residual compressive strength increased up to 10% replacement for all three mineral admixtures and then began to decrease at 20% and 30% replacement levels of metakaolin. In case of metakaolin based HPC, the maximum residual compressive strength has been obtained for mix MK10NS2A for all acids and for all exposure durations for W/B -0.3. As the Metakaolin percentage increased from 10, 20 and 30%, the increase in residual compressive strength was 14.94% and 4.72% and decrease in residual compressive strength was 1.88% for 30 days HCl immersion and w/b-0.3 when compared to plain HPC mix. For 60 days immersion increase in residual compressive strength was 17.87% and 5.05%, while decrease in residual compressive strength was 0.21%. Similar trend was observed for 90days and for different acids with varying water binder ratios. Finally, the conclusion drawn is 10% replacement of cement with Metakaolin is the optimum to resist the three acid attacks.

As a result, Metakaolin at a 10% cement substitution level is best suited as mineral admixtures evaluated in this study, which might be related to their strong pozzolanic reactivity and tiny particle size, which contributed to the best acid resistance.

4.3. Influence of Nano Silica on Residual Compressive Strength

As the Nano Silica percentage increased from 1.5, 3.0 and 4.5%, the increase in residual compressive strength was 9.85%, 19.05% and 15.19% compared to normal HPC mix at 30 days immersion in HCl for water binder ratio 0.3. For 60 days immersion, the increase in residual compression strength observed was 11.05%, 21.68% and 16.79. For 90 days, the increase in residual compression strength observed was 11.41%, 22.31 % and 18.38% compared to conventional HPC mix. Similar trend was observed for other acids and varying water binder ratios. Finally, the results indicate, 3% replacement of cement with Nano silica was shown to be the most effective in resisting the three acid attacks. The addition of nano-silica in the cement paste may have increased the porosity and increased the average chain length of silicate chains and the pozzolanic reaction with calcium hydroxide increased the amount of C–S–H in the matrix, resulting in increased matrix density and improved durability.

4.4. Influence of Effect of Age on Acid Immersion on Residual Compressive Strength

The graphs demonstrate the influence of age of acid immersion on residual compressive strength for Metakaolin-and Nano silica based HPC mixes with various water binder ratios and three distinct acids are shown in Figure 11-13. These results depicts that the residual compressive strength falls as the age of acid immersion increases. This is true for all of the acids investigated in this study. After 90 days of acid immersion, the greatest decrease of residual compressive strength was observed. For example, for the mix MK10NS2A when the duration of HCl acid immersion is increased from 30 to 90 days, a drop of 7.39% occurs. Also, for $MgSO_4$ acid immersion from 30 to 90 days, a drop in residual compressive strength of 5.28%was observed. Similarly, when the same mix is immersed in H_2SO_4 acid for 30 to 90 days, the residual compressive strength decreases by 10.56 percent. At 90 days of acid immersion, the percentage drop in compressive strength is greater. The decline in residual compressive strength is expected as the age of acid immersion increases.

4.5. Influence of Type of Acid on Residual Compressive Strength

HPC and MKNSHPC mixes were subjected to acids of HCl, H_2SO_4, and $MgSO_4$ at a concentration of 5% in the research investigation. When comparing the compressive strengths of H_2SO_4 acid immersion, HCl and $MgSO_4$ acid immersion, it can be seen that H_2SO_4 acid immersion results in the greatest decrease in residual compressive strength. This holds true for each of the water binder ratios tested in this study. The immersion in HCl acid results in the smallest percent decrease in residual compressive strength of the three acids, and this is true at all replacement levels. For example, after 90 days of immersion in HCl acid, the percentage decrease in compressive strength for mix MK10NS2A, is 11.49%, whereas the same mix after 90 days of immersion in H_2SO_4 acid is 16.54% percent, indicating the severity of H_2SO_4 acid. Similar patterns can be seen in other mixes as well. Based on the findings of this study, it can be stated that H_2SO_4 attacks HPC the most severely, whereas HCl attacks it the least.

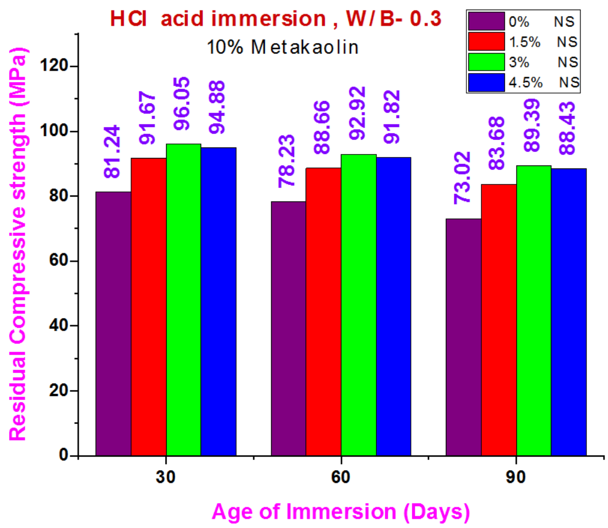

Figure 11. Graph of Residual compressive strength Vs Age of immersion in HCl acid for 10% Metakaolin replacement

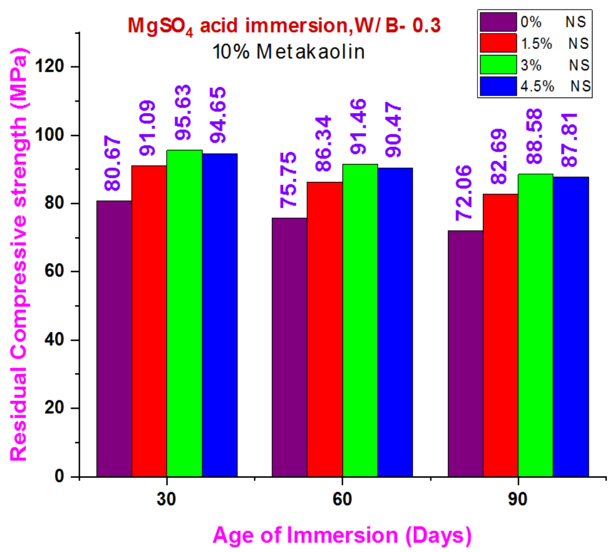

Figure 12. Graph of of Residual compressive strength Vs Age of immersion in $MgSO_4$ acid for 10% Metakaolin replacement

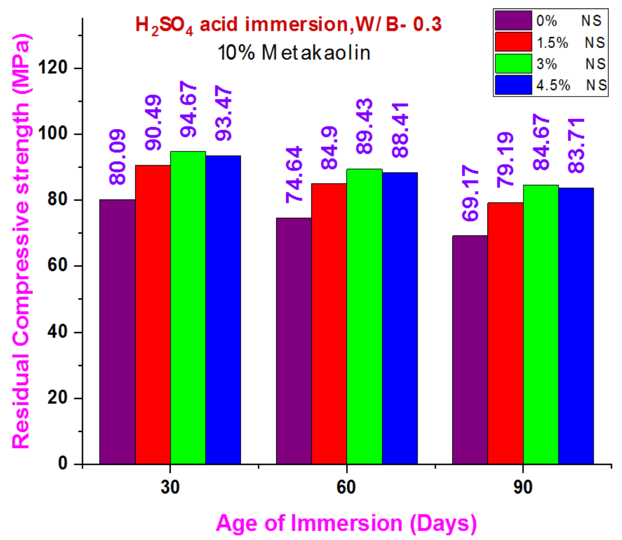

Figure 13. Graph of Residual compressive strength Vs Age of acid immersion in H_2SO_4 acid for 10% Metakaolin replacement

5. Conclusions

- For all percentage replacements of cement tried in this study, the percentage drop in compressive strength owing to acid attack increases as the W/B ratio increases.
- For W/B ratio 0.3, percentage decrease in compressive strength is less compared to other W/B ratio and is valid for all mixes, with different percentage replacements and at all ages of HCl, H_2SO_4, and $MgSO_4$ exposures.
- The HPC mixes resisted acid attack in HCl, H_2SO_4, and $MgSO_4$ better than conventional concrete at all ages of immersion.
- The percentage drop in compressive strength declined up to 10% replacement, then began to rise at 20 and 30 percent replacement levels. Hence 10% Metakaolin replacement is considered optimum dose.
- It is observed that when cement in HPC mixes is replaced with mineral admixtures 10% Metakaolin and 3% Nano silica, the loss of compressive strength due to acid attack is minimal.
- After 90 days of immersion in H_2SO_4 acid, metakaolin and Nano silica based HPC mixes lost 6.68, 11.85, and 16.54 percent of their compressive strengths at 30,60 and 90 days respectively, whereas conventional concrete lost 9.18, 16.07, and 22.81 percent. This demonstrates HPC's superior ability to withstand acid attack.
- After 90 days of acid immersion, the compressive strength has dropped to its lowest point. This is true for all of the acids tested in this study.

When compared to HCl and $MgSO_4$ acids, H_2SO_4, acid causes the greatest loss of compressive strength in HPC. This is true for each of the mixes tested in this study. HCl acid immersion results in the least loss of compressive strength of the three acids.

REFERENCES

[1] Beluah M., Prahallada M.C., "Effect of Replacement of cement by Metakaolin on the properties of High Performance concrete subjected to acid attack", *i-Manager's Journal on Civil Engineering*, Nagercoil Vol. 2 Issue.3., June - August 2012: 14-21

[2] Asma.K.C., Meera.C.M., Preetha Prabhakaran., "Effect of Mineral Admixtures on Durability Properties of High Performance Concrete"., - *International Journal of Engineering Research and Applications (IJERA)* ISSN: 2248-9622 Trends and Recent Advances in Civil Engineering (TRACE- 24th-25th January 2014). http://www.ijera.com/special_issue/Trace/IJERA%20108.pdf

[3] Shiny Brintha G., Sakthieswaran N., "Acid attack on concrete containing Industrial wastes", - *Journal of advances in chemistry*, ISSN 2321-807X, Vol 12., No.10., p4398-4401., October 2016 https://doi.org/10.24297/jac.v12i10.5421

[4] E Balaji, Dr. Senthil Selven., Vishnu Prasad P R., "An experimental study on the effect of Nano silica on strength and durability of concrete", International Journal of Civil Engineering and Technology (IJCIET) Volume 8., Issue 4., pp. 1182–1188., April 2017, http://www.iaeme.com/MasterAdmin/Journal_uploads/IJCIET/VOLUME_8_ISSUE_4/IJCIET_08_04_132.pdf

[5] Zhang P., Wan J., Wang K and Li Q., "Influence of nano-SiO2 on properties of fresh and Proceedings of hardened high performance concrete: A state-of-the-art review"., Construction and Building Materials. Volume148., pp.648–658., 1September 2017, https://doi.org/10.1016/j.conbuildmat.2017.05.059

[6] Narender Reddy., Prof T. Meena., "Comprehensive overview on performance of nano silica concrete" International Journal of Pharmacy & Technology IJPT| Vol. 9., Issue No.1., pp 5518-5529., April-2017 https://www.researchgate.net/publication/316166205

[7] P.Hou, S.,Kawashima, D.Kong., D.J.Corr., J.Qian., and S.P.Shah., "Modification effects of colloidal nanoSiO2on cement hydration and its gel property, Composites Part B: EEngineering, vol.5,Issue1,pp.440–448, February2013 https://doi.org/10.1016/j.compositesb.2012.05.056,

[8] S. Haruehansapong., T. Pulngern., and S. Chucheepsakul., "Effect of the particle size of nanosilica on the compressive strength and the optimum replacement content of cement mortar containing nano-SiO2," Construction and Building Materials., Vol.50., pp.471–477., January2014 https://doi.org/10.1016/j.conbuildmat.2013.10.002

[9] Hongjian. Du., S. Du., and X.Liu., "Durability performances of concrete with nano-silica, " Construction and Building Materials,vol.73.,pp.705–712.,December2014 https://doi.org/10.1016/j.conbuildmat.2014.10.014

[10] G. Quercia, P. Spiesz, G. H¨usken, and H.J.H. Brouwers,

"SCCmodificatio by use of amorphous nano-silica," Cement and Concrete Composites, vol.45, pp.69–81, January 2014. https://doi.org/10.1016/j.cemconcomp.2013.09.001

[11] Collepardi, S., Borsoi, A., Olagot, J. J. O., Troli, R., Collepardi, M., & Cursio, A. Q. "Influence of nano-sized mineral additions on performance of SCC", In Proceedings of the 6th International Congress, Global Construction, Ultimate Concrete Opportunities. (2015, July5- 7). https://doi.org/10.1680/aonicd.34082.0006

[12] Choolaei, M., Rashidi, A. M., Ardjmand, M., Yadegari, A., & Soltanian, H. "The effect of nanosilica on the physical properties of oil well cement", Materials Science and Engineering: A, volume538., pp288–294.,March (2012). https://doi.org/10.1016/j.msea.2012.01.045

[13] Tobón, J. I., Payá, J. J., Borrachero, M. V., & Restrepo, O. J., "Mineralogical evolution of Portland cement blended with silica nanoparticles and its effect on mechanical strength"., Construction and Building Materials, Volume36, pp736–742., November 2012. https://doi.org/10.1016/j.conbuildmat.2012.06.043

[14] Jo, B. W., Kim, C. H., Tae, G. H., & Park, J. B.. "Characteristics of cement mortar with nano-SiO2 particles"., Construction and Building Materials, Volume21., pp1351–1355., June2007 https://doi.org/10.1016/j.conbuildmat.2005.12.020

[15] Jo, B. W., Kim, C. H., Tae, G. H., & Park, J. B., "Characteristics of cement mortar with nano-SiO2 particles"., Construction and Building materials., volume21, pp1351–1355., June2007 https://doi.org/10.1016/j.conbuildmat.2005.12.020

[16] Gaitero, J. J., Campillo, I., & Guerrero, A., "Reduction of the calcium leaching rate of cement paste by addition of silica nanoparticles"., Cement and Concrete Research, Volume38, Issue8-9 pp1112–1118., August 2008 https://doi.org/10.1016/j.cemconres.2008.03.021

[17] Jalal, M., Pouladkhan, R. A., Norouzi, H., & Choubdar, G., "Chloride penetration, water absorption and electrical resistivity of high performance concrete containing nano silica and silica fume"., Journal of American Science., 8(4)., pp278–284., 2012 http://www.americanscience.org. 37