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Research Article

EFFECTS OF HYDROCHLORIC ACID IN MIXING AND CURING WATER ON STRENGTH OF HIGH-PERFORMANCE METAKAOLIN CONCRETE

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ABSTRACT
This paper presents the results of an experimental investigation carried out to study the effect of aggressive chemical environment on High performance concrete with metakaolin in which Ordinary Portland cement is partially replaced by 20% of metakaolin by weight and aggressive chemical environment is simulated by subjecting the concrete to different concentrations of Hydrochloric acid (HCl) in deionised water during mixing and curing. Compressive strengths and split tensile strengths were determined at 7, 28 and 90 days. The results indicate that the compressive strength and split tensile strength decrease with the increase in concentration of HCl when compared with concrete without HCl in mixing and curing water..

Key Words: *Ordinary Portland Cement, Metakaolin, Compressive Strength, Split Tensile Strength, Hydrochloric Acid*

INTRODUCTION
Concrete is a widely used construction material around the world, and its properties have been undergoing changes through technological advancement. Farzadni *et al.,* (2011) stated that with a fast population growth and a higher demand for housing and infrastructure, accompanied by recent developments in civil engineering, such as high-rise buildings and long-span bridges, higher compressive strength concrete is needed. Currently, high-performance concrete is used in massive volumes due to its technical and economic advantages. Such materials are characterized by improved mechanical and durability properties resulting from the use of chemical and mineral admixtures as well as specialized production processes. Mehta and Aitcin (1990) suggested the term high performance concrete (HPC) for concrete mixtures that possess the following three properties: high-workability, high-strength, and high durability. Water is an important ingredient of concrete, which not only actively participates in the hydration of cement but also contributes to the workability of fresh concrete. Naturally available water contains many numbers of chemical impurities like chlorides, sulphates, various salts and acids in different concentrations. Generally the standard of water that is used for making concrete should be potable. I.S. 456-2000, specifies the minimum pH values as 6.0 and also permissible limits for solids in water to be fit for construction purpose. But the drinking water may not be always available abundantly for mixing and curing. The impurities in water affect the strength and durability of hardened concrete. HCl is not a common natural chemical compound, but it can cause damage to concrete in industrial environments. L.De Ceukelaire (1992) reported that the effects of hydrochloric acid on concrete are multiple. The changing mineralogy due to the leaching processes causes a loss of strength. Haung *et al.,* (2005) reported that the damage resulted from HCl corrosion is dangerous for safe application of concrete structure, especially when the structure is subjected to tensile or bending load. After HCl corrosion, the flexural strength loss of the high strength concrete is larger than that of the normal strength concrete, which indicates that the sensitivity to HCl corrosion increases with increasing concentration. The present paper, therefore attempts to provide essential information on the strength of high performance concrete with metakaolin with different concentrations of hydrochloric acid. Paiva *et al.,* (2012) stated that the formulations were prepared with

several metakaolin amounts and workability was controlled either with water or a high range water reducer admixture. The use of this can cause deflocculation of metakaolin particles, allowing workability control in concrete and leading to better efficiency and improved performance. Lagier *et al.*, (2007) stated that the higher surface area metakaolin had a greater effect. It is proposed that the presence of metakaolin may enhance dissolution of cementitious phases and/or provide additional, well-dispersed sites for nucleation of hydration products, in addition to increasing the early age concentration of solubilized aluminium (due to metakaolin dissolution). Ding and Li (2002) stated that metakaolin-modified concrete showed a better workability than silica fume –modified concrete. The two admixtures also greatly reduced the chloride diffusivity of concrete.

MATERIALS AND METHODS

Cement

Ordinary Portland (53 grade) cement of Ultratech brand was used. It was tested as per Indian Standards Specifications IS: 8112-1989. Its properties are specificgravity 3.1, normalconsistency of 33%, fineness of 5%, initial setting time is 105 minutes and final setting time is 350 minutes.

Fine aggregate

The locally available natural river and was used as fine aggregate. It was tested as per Indian Standard Specification IS: 383-1970. Its fineness modulous is 2.69 and specific gravity is 2.7.

Metakaolin

Metakaolin obtained from KOAT manufacturing company, Vadodara, Gujarat, India is used in this investigation. The properties are Bulk Density (Gms / Ltr) 300 to 340, Average Particle Size 1.5 – 2.5 micron, Residue (> 45 micron) (max. %) 0.5 – 2%, Moisture content ≤ 1%, Specific Surface Area BET (m2/gm) 12 – 18.

Super-plasticizer

GLENIUM B233 is the super-plasticizer of BASF company. The properties are Aspect: Light brown liquid, Relative Density: 1.08 ± 0.01 at 25°C, PH: >6, Chloride ion content: < 0.2%

Variables studied

(a) Concrete mix: The mix ratio of cement: sand: corse aggregate is 1:0.76:1.8 with water/ binder ratio as 0.3. The dosage of superplasticizer is 1% by weight of cement. 20 % of Cement was replaced with of Metakaolin.
(b) Mixing and curing environment: Four different concentrations of HCl (50 mg/L, 100 mg/L, 400mg/L and 800 mg/L) were adopted during the mixing in the deionised water and cured in same condition.
(c) Exposure period: Specimens were tested periodically after the specified curing periods of 7, 28 and 90 days.
(d) Size of specimens: 150mm x150mm x150mm size of cubes for compressive strength test and 150mm dia- 300mm height of cylinders for splittensile strength test.
(e) Samples for XRD and SEM testing: The cubes with maximum concentration of HCl after 90 days testing are collected and grinded and sieved under 40 micron sieve. This powder sample is sent for XRD testing and the broken pieces of cube samples are sent for SEM testing. A total of 135 cubes and 135 cylinders were cast in the laboratory. After 72 hours, all the specimens were demoulded and cured in water in a curing tank at room temperature. After specific exposure period, specimens were tested for compressive strength, split tensile strength in accordance with test procedure IS 516: 1959.

RESULTS AND DISCUSSION

Effect of HCl on compressive strength

The effect of HCl concentration on the compressive strength and splittensile strength of HPC with and without metakaolin is presented in table: 1, 2, 3 and 4 and figures 1, 2, 3 and 4. Continuous decrease in

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Table 1: Compressive strength in N/mm^2 for different concentrations of HCl

S No	Dosage of HCl mg/L	Compressive strength (N/mm^2)					
		7 days		28 days		90 days	
		OPC	MK	OPC	MK	OPC	MK
1	0	39.5	60	58	78	63.45	80
2	50	36.56	55.67	55.6	70.37	59	75.89
3	100	28.45	48.06	44.78	62.48	45	62.08
4	400	26.197	38.83	35.15	47.46	37	48.26
5	800	23.157	35.72	26.54	37.75	24.67	35.94

Table 2:%age change in compressive strength for different concentrations of HCl

S No	Dosage of HCl mg/L	%age change in compressive strength					
		7 days		28 days		90 days	
		OPC	MK	OPC	MK	OPC	MK
1	0	----	----	----	----	----	----
2	50	-7.44	-7.21	-4.14	-9.78	-7.01	-5.14
3	100	-27.97	-19.90	-22.79	-19.90	-29.08	-22.40
4	400	-33.68	-35.29	-39.40	-39.16	-41.69	-39.67
5	800	-41.37	-40.46	-54.24	-51.60	-61.12	-55.07

Table 3: Split tensile strength in N/mm^2 for different concentrations of HCl

S No	Dosage of HCl mg/L	Split tensile strength (N/mm^2)					
		7 days		28 days		90 days	
		OPC	MK	OPC	MK	OPC	MK
1	0	4.19	5.3	5.35	6.05	5.67	6.15
2	50	3.82	4.86	5.04	5.95	5.23	5.95
3	100	3.14	4	3.8	4.53	4.25	4.87
4	400	2.497	3.49	3.1	3.94	3.35	4.15
5	800	1.86	3.17	2.34	3.48	2.76	3.63

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Table 4:%age change in split tensile strength for different concentrations of HCl

S No	Dosage of HCl mg/L	%age change in split tensile strength					
		7 days		28 days		90 days	
		OPC	MK	OPC	MK	OPC	MK
1	0	----	----	----	----	----	----
2	50	-8.83	-8.25	-5.79	-1.73	-7.76	-3.24
3	100	-25.06	-24.54	-28.97	-25.13	-25.04	-20.82
4	400	-40.41	-34.02	-42.06	-34.84	-40.92	-32.59
5	800	-55.61	-40.21	-56.26	-42.46	-51.32	-40.96

Table 5: Compounds and their intensities for samples of HPC's with out HCl

SNO	Angle in degrees	Compound	Intensity	
			HPC without metakaolin	HPC with metakaolin
1	12.58	C-S-H Gel	76	132
2	17.94	$Ca(OH)_2$	266	66
3	21.18	C-S-H Gel	32	86
4	24	$Ca(OH)_2$	110	72
5	34.34	C-S-H Gel	124	154
6	37.3	C-S-H Gel	34	72
7	42.24	$Ca(OH)_2$	64	38
8	50.76	C-S-H gel	90	120

Table 6: Compounds and their intensities for samples of HPC's with HCl

SNO	Angle in degrees	Compound	Intensity	
			HPC without metakaolin	HPC with metakaolin
1	10.92	Jennite	78	64
2	12.32	C-S-H gel	56	68
3	15.7	C-S-H gel	38	52
4	18.22	Portlandite	268	64
5	20.38	Jennite	44	38
6	22.8	C-S-H gel	44	58
7	28.74	Jennite	100	72
8	28.8	Portlandite	102	52
9	31.32	C-S-H gel	64	78
10	36.3	C-S-H gel	44	72
11	44.16	C-S-H gel	58	78
12	46.6	Jennite	56	42

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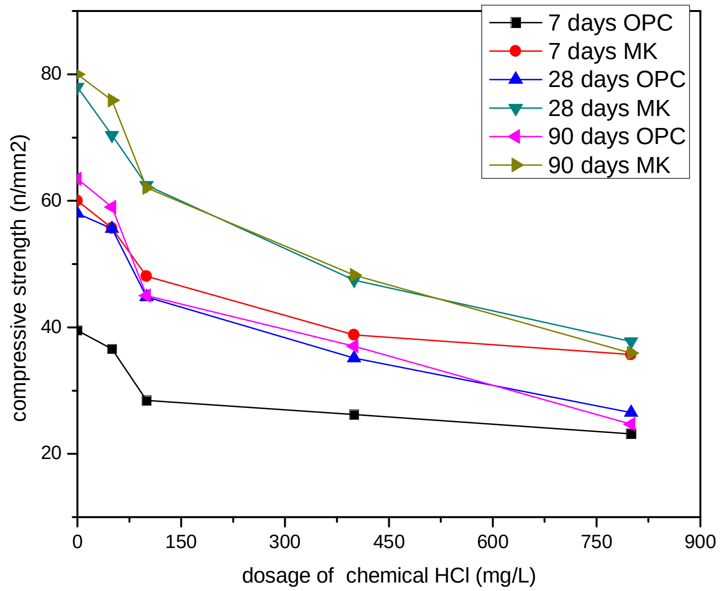

Figure 1: Compressive strengths

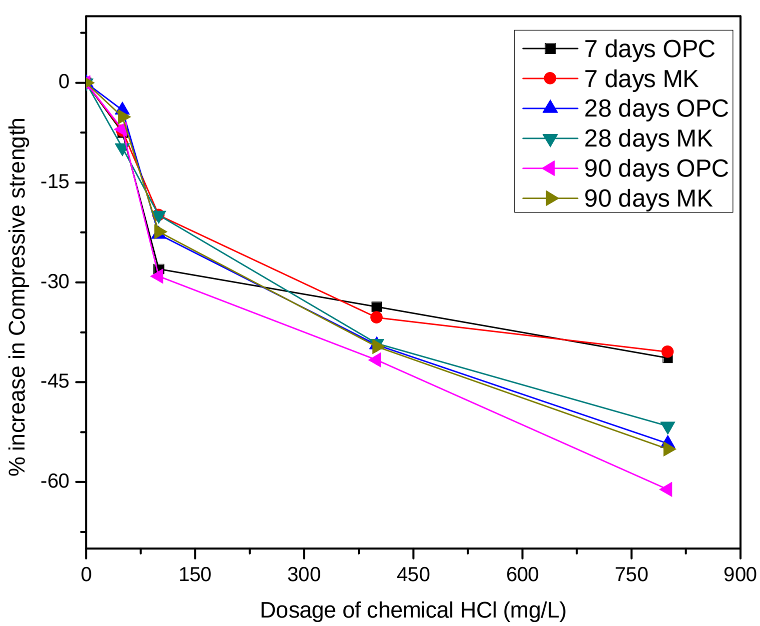

Figure 2: %age decrease of compressive strengths

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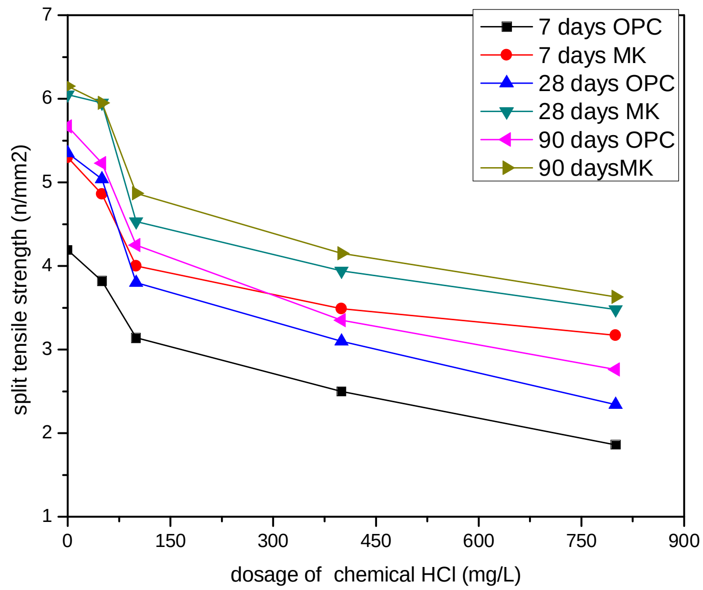

Figure 3: Split tensile strengths

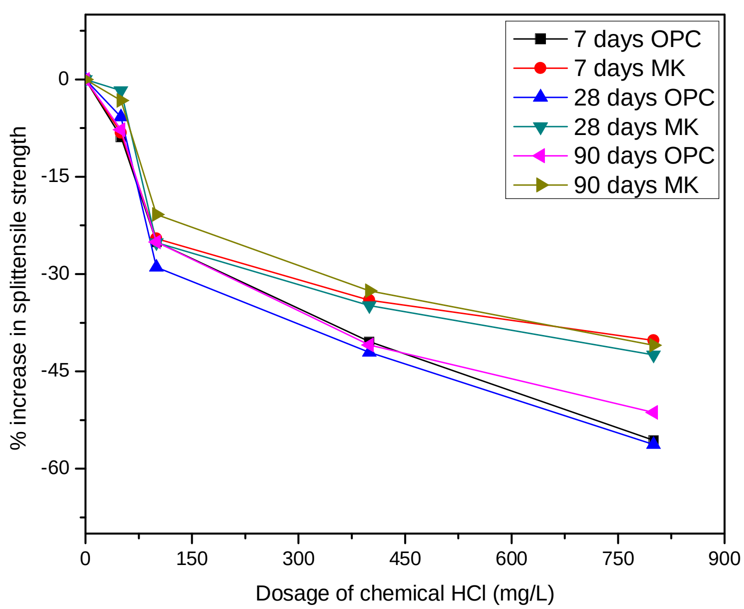

Figure 4: %age decrease of split tensile strengths

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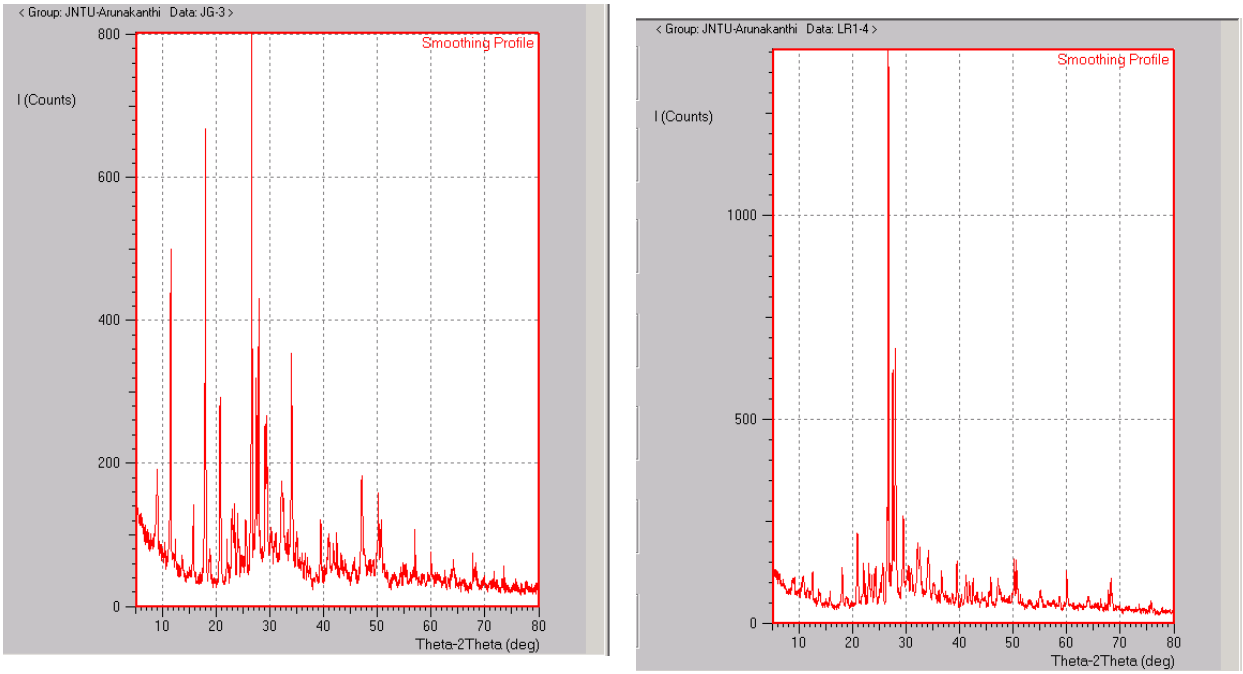

Figure 5: XRD pattern of HPC i) without Metakaolin ii) with Metakaolin

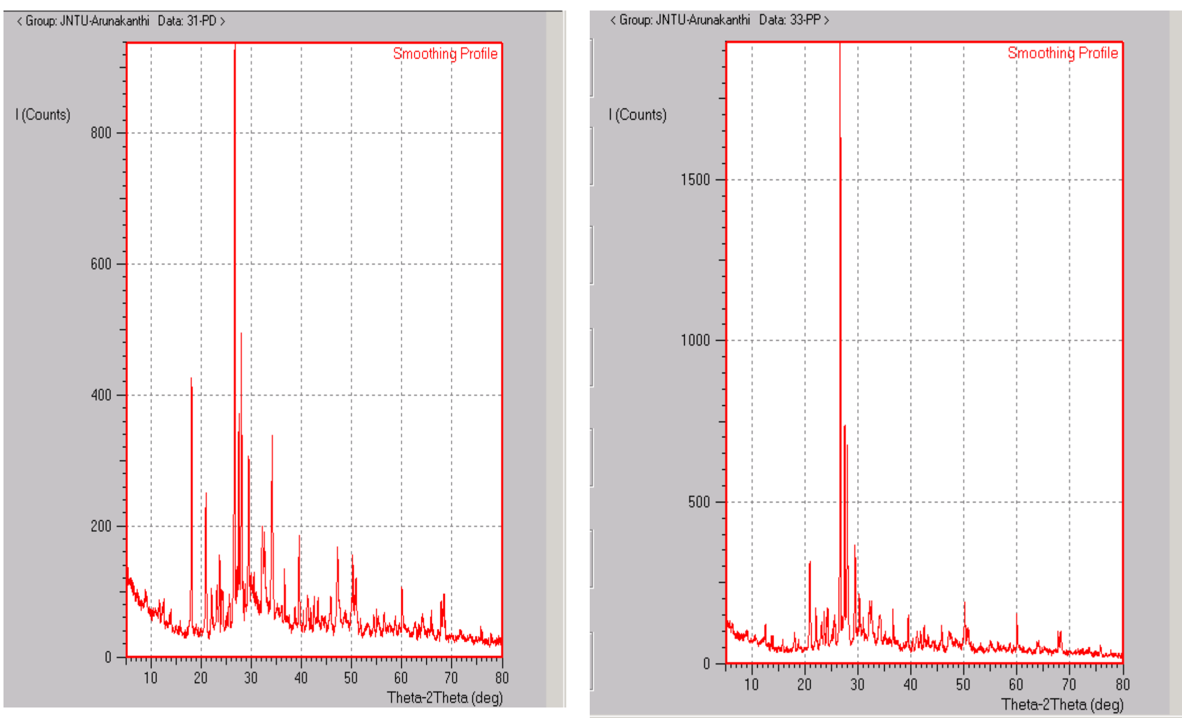

Figure 6: XRD pattern of HPC i) with out Metakaolin + HCl ii) with Metakaolin + HCl

compressive strength and split tensile strength is observed with the increase in concentration of HCl for both HPCs. If the difference is less than 10% the change is considered to be negligible and if the difference is more than 10% the change is considered to be significant. It is observed that there is significant decrease in both compressive strength and split tensile strength of both HPC's from 100 mg/L concentration of HCl. The percentage change in compressive strength and split tensile strength of HPC with and without metakaolin decreased with the increase in concentration of HCl. But the percentage change in compressive and split tensile strengths of HPC with metakaolin is less when compared with HPC without metakaolin.The XRD and SEM results show the formation of Calcium silicate hydrate (C-S-H gel) and Portlandite ($Ca(OH)_2$) in both samples with out HCl. But the intensities of C-S-H gel and Portlandite differ in two samples. The XRD patterns corresponding to HPC without metakaolin and HPC with metakaolin are shown in figures 3 and 5. By analyzing the XRD patterns of samples of two HPC's, the formation of C-S-H gel and Portlandite are formed at angles as shown in table 5 and 6. The intensity of C-S-H gel is more and the intensity of Portlandite is less for HPC with metakaolin when compared with HPC without metakaolin. This may be the cause for the strengths of HPC with metakaolin to be high under aggressive environment. The XRD tests are conducted for the two samples after 90 days with 800 mg/L concentration (maximum) of HCl. It is observed that in addition to the compounds formed above, a compound named Jennite ($Ca_9H_2Si_6O_{18}(OH)_8.6H_2$) is formed in both HPC's with HCl. So the decrease in strengths may be due to the formation of Jennite. The angles at which the compounds are formed is shown in the table 4. The XRD patterns are shown in figures 5 and 6 respectively. The compound Jennite has triclinic and pinacoidal structure. This is of massive form.

CONCLUSIONS

Based on the above results of the investigation conducted on high-performance concrete with partial replacement of cement by 20% metakaolin and subjected to various concentrations of HCl, the following conclusions can be drawn:

1. Compressive strength and split tensile strength of HPC increased with the replacement of cement by 20% metakaolin. But the stengths decreased with the increase in concentration of HCl in mixing and curing water.
2. Compressive strength and split tensile strength increase as the curing period increases for later ages of curing i.e., 7 days, 28 days and 90 days for 20% metakaolin and for 0 mg/L concentration.
3. From XRD studies it is concluded that the formation of C-S-H gel with more intensity and Portlandite with less intensity may be responsible for more strengths of HPC with metakaolin.
4. From XRD studies it is concluded that the formation of compound Jennite may be responsible for decrease in strengths with the increase in concentration of HCl.
5. Deterioration of concrete due to HCl is more for higher concentration of HCl.

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