Pak. j. sci. ind. res. Ser. A: phys. sci. 2022 **65A**(3) 290-301

Effect of Hydrochloric Acid on Different Ratios of Cement-sand Mortar

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(received September 23, 2020; revised August 26, 2021; accepted September 13, 2021)

Abstract. Quality evaluation and quality assurance are the most important parameters which ensure the quality of any building material. For this reason, building materials are always analyzed by using different international test methods for checking and confirming their quality provided in the standard specifications. For this, first raw materials are examined (physically and chemically) and their results are compared with the international standard specifications to confirm their suitability. Cement-sand mortar cubes of different proportions are prepared and cured for 28 d. The physical suitability of mortar is ensured by calculating compressive strengths, while cement sand proportions are re-confirmed by adopting the test method BS 4550: 1970. The samples of known proportion were treated with the different concentrations of hydrochloric acid (HCl) which vary from 5 M to 11 M and each molar solution was further classified as 1:7 and 1:9 and 1:11 dilution with water. Dilution of the HCl solution has proved to be ineffective in the proper decomposition of hydrates of cement. Cement contents do not dissolve in the solution completely and deviation in results is observed. The reactivity order of HCl solution with respect to its ratios is 1:7>1:9 >1:11 for all molarities. Great variations in the results from 5 M (1:11) to 11 M (1:7) have been observed when graphs are plotted between mix ratio results and molarities. Linearity in a graph is achieved with a high concentration of HCl i-e 11 M (1:9), the solution gives the most accurate result. Accuracy in the results of mortar samples cannot be achieved utilizing different diluted HCl solutions. It is concluded from the data that by diluting HCl solution, test results drastically changed from standard values.

Keywords: mortar, British standards, hydrates of cement, cement-sand mix ratio, building material

Introduction

A vast range of building materials is available due to the great diversity of their properties and requirements. Building materials are sub divided into separate groups due to their specific properties but their applications are pre-determined by their principal properties. Rational choice of material depends upon the comprehensive knowledge of the properties of materials for specific service conditions. A mixture of fine aggregate (sand) and binding materials (lime, gypsum, clay or cement) which turns to a paste by adding water which further turns to a hard mass when it sets is known as Mortar. It is mainly used in masonry construction to fill the gaps between the bricks and blocks as a binding material. In addition, it is also used as rendering to produce a better aesthetic look (Joseph, 1850). Mortar is usually defined by its composition rather than properties and proportions of ingredients are generally taken in weight or volume. There are different types of mortars commonly used such as cement mortar, lime mortar, lime cement mortar, etc. Cement-sand mortar is also called cement mortar which has been used in more than ten thousand buildings (houses, hospitals, schools, etc.) only in Pakistan.

Cement is used as a binder in mortar. It is mostly used in bricks or blocks based structures for joining building units (Raziuddin, 1967). In 1824, Joseph Aspedin of Yorkshire (United Kingdom) patented a new modern method of that time to manufacture cement by the heating mixture of limestone and clay at high temperature in a furnace.

Cement-sand and water are mixed to prepare cement mortars of specific proportions required for a specific project. Portland cement mortars were found productive in stiffness, bond strength, water retention, flexibility than all other types (Pavia and Brennan, 2019). It has been observed that there are some factors such as the number of water vapours and porosity effects on the

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properties of cement (Zhang *et al*., 2018). It has been studied that cementitious gel had a strong affinity towards the water and it contributes to strength (Powers, 1958) .

The strength of cement mortars depends upon cement sand proportion and the strength of joining materials like blocks, bricks etc. Cement mortars should be strong enough to resist abrasion, erosion and other factors affecting durability. If the strength of mortars is higher than the strength of block units or bricks, settlement or shrinkage cracks may become large (Varghese, 2005). The compressive strength of different class mortars was also monitored (Eskandari-Naddaf and Kazemi, 2017). Different methods have been used to test the basic physico-chemical properties, reactivity and performance of cement (Zaleska *et al*., 2018). Different proportions of cement and sand are fixed for different requirements such as 1:3 mortar ratio is used in an arch and pointing work. Whereas, a higher ratio of mortar like 1:6 is suitable for brickwork. The selection of the mortar ratio is mainly dependent on compressive strength (Singh *et al*., 2015).

The compressive strength of Portland cement can be increased by using the blend of 30% natural Pozzolana and 20% of limestone filler with Portland cement (Forde 2009; Kakali *et al*., 2000). This blend was found flexural, compressive and resistant against acid and sulfate attack (Ghrici *et al*., 2007). The quality of cement mortar is tested either checking its compressive strength or mix ratio analysis done by different techniques such as thermal, gravimetric or X-ray diffraction analysis (Genestar *et al*., 2006).

In the present study the analysis is carried out by gravimetric method (Test Method BS 4550: 1970). This method is used till date in all Pakistani government testing laboratories even in India and Bangladesh. In this method HCl is used as a separating medium that separates binder and aggregate from mortar (Alvarez *et al*., 1999). It has been observed that different mortars react differently with varying the concentrations of HCl (De Ceukelaire, 1992). Test Method BS 4550: 1970 (Smith and Halliwell, 1979) does not tell clearly about the exact concentration of HCl to be used for the analysis of mortar. Here detailed and comprehensive study is conducted to signify the importance of solvent effect (HCl dilution) on standard mortar samples and explained that how by changing the slight concentration of HCl the test results drastically deviate (Vayghan *et al*., 2013; Quarcioni and Cincotto, 2006).

Materials and Methods

Water. Water used in this research was chemically tested before its use as per ASTM methods and BS 1377 part 3 to confirm its suitability for the preparation of cement mortars and its analysis is given in Table 1.

Cement. Ordinary Portland Cement (OPC) with the trademark "Maple Leaf Cement" was purchased from the local market of township Lahore Pakistan. To ensure the quality of cement both physical testing following ASTM C109, ASTM C191, ASTM C430, ASTM C151 /C151M, using specification ASTM C183 and chemical testing in accordance British Standard BS 4550-2:1970 were conducted Table 2.

Fine aggregate (sand). Sand from different sources (Ravi Sand, Chenab Sand and Ghandapur, Kasur Sand)

Table 1. Chemical analysis of water

Description of tests	Determined values	Permissible limits for construction purposes
Total soluble salts	0.01%	0.15%
Total sulphate content	Traces	0.05%
Total chlorides content	Nil	0.036%
pH-value	7.2	6 to 8
Total solid content	Nil	0.05%

Table 2. Description of cement-testing

Description of tests	Test method	Determined values	Permissible limits
Compressive strength (3 d)	ASTM C109 - 16a	2295 Psi	1740 Psi
Compressive strength (7 d)		2962 Psi	2760 Psi
Initial setting time (min)	ASTM C191 - 19	209 min	Not less than 45 min
Final setting time (min)		351 min	Not more than 375 min
Fineness	ASTM C430 -08	98.8 %	Not less than 90%
Cement expansion	ASTM C151 / C151M-09	0.833 mm	10 mm (max)

was collected from respective areas and tested in Laboratory. After respective testing of all these samples, they were found unfit to use for the preparation of cement mortars according to ASTM C144-04 (Standard Specification for Aggregate for Masonry Mortar, 2006).

This problem was solved by using manufactured sand which fulfilled all the limits given in ASTM C144-04 (Standard Specification for Aggregate for Masonry Mortar) reported by Ayan *et al*. (2015). The most volume of mortar is based on fine aggregate (sand). It was observed that the grading of sand caused an impact on the properties of masonry units reported by (Ahmad, 2013; Reddy and Gupta, 2008).

Preparation of cement mortar sample. Three cement mortar samples of 1:4, 1:5 and 1:6 proportions (cement: sand) were prepared using a specific quantity of water (0.484 water: cement) in mixer machine and nine cubes of (2"×2"×2") dimensions of each proportion were separately filled and kept at room temperature for one day. The cubes were cured in the water bath for 28 d. After determination of compressive strengths of cubes, crushed samples were kept in an oven at 100 °C for 24 h for drying. Samples were then cooled at room temperature and converted into a powder that can pass through sieve no. 40. This powder sample of each proportion was analyzed chemically for mix ratio determination and solvent effect.

Testing methodology. ***Removal of unreacted sand as insoluble residue.*** The cement and sand are easily separated from cement mortar by using HCl. All components of cement and trace of sand form their respective chlorides which are soluble in water, while major components of sand remain unreacted with HCl. Three cement mortar samples of 1:4, 1:5 and 1:6 proportions (50 g of each) were treated with the different HCl solutions of different molarities ranging from 5 M-11 M and different ratios such as 1:7, 1:9 and 1:11 (HCl: water). When HCl comes in contact with the mortar, it penetrates the hydrates of cement (gel type and crystal) where it reacts. Chlorides of metals get dissolved but crystalline silica, unreacted hydrates and some complexes remain insoluble. Samples were then filtered. The residue was washed three times to make sure that no cement contents remain in the residue. The unreacted materials obtained from all three mortar samples were properly washed with HCl solution of similar molarities and ratio and collected over filter paper as insoluble residue. It was properly dried in an oven and weighed again.

Removal of soluble silica. The filtrate obtained from the above step containing reactive silica. It has to be removed for the accurate measurement of lime in the sample. So, the drying method was used which converts the reactive silica into nonreactive silica which is easily removed in the form of a gel. The volume of the filtrate was made up to 1000 mL using distilled water. Out of which 50 mL was taken and heated on water bath till complete dry. The sample was then kept in an oven at 100 °C for 1 h. Then 5 mL of respective molar HCl and 40 mL of distilled water were added to the sample and gently heated. It was then filtered and the residue was washed with hot water three times.

Removal of metals in the form of hydroxides except for calcium. Different metals are present in the above filtrate in the form of chlorides (NaCl, $FeCl_2$, $FeCl_3$, $AlCl_3$, $MgCl_2$, $CaCl_2$, KCl). All metallic chlorides are converted into metallic hydroxides except $CaCl_2$ by treating the filtrate with NH_4O and NH_4OH. It was then filtered and the residue was washed thrice.

Conversion of calcium in the form of calcium oxalate. The filtrate from the above step was heated with 50 mL (5% m/v) ammonium oxalate and 5 mL ammonia solution (1:2) till boiling. Precipitates were allowed to settles for 30 min and then filtered. Ammonium oxalate in the presence of ammonium hydroxide converted the soluble calcium into insoluble calcium oxalate.

Ignition of calcium oxalate. Calcium oxalate obtained in the above step ignited in the electric furnace at 1000 °C, where calcium oxalate is converted into calcium oxide.

Result and Discussion

The reactivity of HCl solutions drastically changes from 11 M (1:7) to 5 M (1:11). Linearity in the curves of 1:7 and 1:9 has been observed till 7 M. It gives the best understanding of the solvent effect. After 7 M graph becomes straight because of the low gradient potential and less penetrating ability of HCl to react with hydrates of cement. 1:11 curve provides the best knowledge about the limiting reactivity and solvent effect of HCl in comparison with 1:7 curves, which is shown in Table 3 and Fig. 1.

In the light of evaluated data of 1:4 cement mortar samples, it is observed that both the test results of insoluble residue and lime show a similar increasing reactivity trend of Hydrochloric acid from 5 M (1:11) solution to 11 M (1:7) and provide the best information to understand the solvent effect of different solutions

Table 3. Determination of cement sand proportion based on insoluble residue (standard cement-sand proportion used 1: 4)

HCl molarities	HCl Dilution	Weight of filter paper (g)	Sum of the weight of filter paper (g)	Weight of filter paper and residue (g)	Weight of filter paper papers and residue (g)	Sum of the weight of filter papers and residue	Weight of residue (g)	Sand %	Cement %	Mix ratio result (By weight)	
										Cement	Sand
		1.4280		12.5838	12.5838						
	1:7	1.4356	4.2844	15.6014	15.6014	40.9154	36.6310	73.2620	26.7380	1.00	2.74
		1.4208		12.7302	12.7302						
		1.3821		11.8642	11.8642						
11 M	1:9	1.3955	4.1992	14.9768	14.9768	41.6047	37.4055	74.8110	25.1890	1.00	2.97
		1.4216		14.7637	14.7637						
		1.3991		11.8642	11.8642						
	1:11	1.3864	4.2193	14.9768	14.9768	42.3990	38.1797	76.3594	23.6406	1.00	3.23
		1.4338		15.5580	15.5580						
		1.4212		9.9657	9.9657						
	1:7	1.3856	4.2314	13.3563	13.3563	41.7626	37.5312	75.0624	24.9376	1.00	3.01
		1.4246		18.4406	18.4406						
		1.4199		14.3279	14.3279						
10 M	1:9	1.4081	4.2740	11.1321	11.1321	42.1675	37.8935	75.7870	24.2130	1.00	3.13
		1.4460		16.7075	16.7075						
		1.4453		18.0442	18.0442						
	1:11	1.4654	4.3404	13.4131	13.4131	42.8725	38.5321	77.0642	22.9358	1.00	3.36
		1.4297		11.4152	11.4152						
		1.4542		17.2583	17.2583						
	1:7	1.4480	4.3681	12.3448	12.3448	42.9786	38.6105	77.2210	22.7790	1.00	3.39
9 M		1.4659		13.3755	13.3755						
	1:9	1.4602	4.3238	17.1196	17.1196	43.2373	38.9135	77.8270	22.1730	1.00	3.51
		1.4202		13.5973	13.5973						
		1.4434		12.5204	12.5204						
		1.4546		12.8866	12.8866						
	1:11	1.4388	4.3138	16.4941	16.4941	43.5147	39.2009	78.4018	21.5982	1.00	3.63
		1.4204		14.1340	14.1340						
		1.4137		14.6805	14.6805						
	1:7	1.3940	4.2107	14.4277	14.4277	43.0250	38.8143	77.6286	22.3714	1.00	3.47
		1.4030		13.9168	13.9168						
		1.4042		13.7804	13.7804						
8 M	1:9	1.3932	4.2184	17.6257	17.6257	43.6476	39.4292	78.8584	21.1416	1.00	3.73
		1.4210		12.2415	12.2415						
		1.3995		11.8452	11.8452						
	1:11	1.4620	4.3291	14.0043	14.0043	44.4672	40.1381	80.2762	19.7238	1.00	4.07
		1.4676		18.6177	18.6177						
		1.4382		12.4708	12.4708						
	1:7	1.4225	4.3018	17.7391	17.7391	43.4793	39.1775	78.3550	21.6450	1.00	3.62
		1.4411		13.2694	13.2694						
		1.3794		18.8499	18.8499						
7 M	1:9	1.4107	4.1928	12.4962	12.4962	43.7927	39.5999	79.1998	20.8002	1.00	3.81
		1.4027		12.4466	12.4466						
		1.4154		16.0575	16.0575						
	1:11	1.4469	4.3008	15.9798	15.9798	44.7406	40.4398	80.8796	19.1204	1.00	4.23
		1.4385		12.7033	12.7033						
		1.4526		16.7521	16.7521						
	1:7	1.4427	4.3202	12.4127	12.4127	43.6364	39.3162	78.6324	21.3676	1.00	3.68
		1.4249		14.4716	14.4716						
		1.4433		14.1765	14.1765						
6 M	1:9	1.4084	4.2742	15.4967	15.4967	43.9428	39.6686	79.3372	20.6628	1.00	3.84
		1.4225		14.2696	14.2696						
		1.4662		16.7655	16.7655						
	1:11	1.4395	4.3774	12.6468	12.6468	45.2570	40.8796	81.7592	18.2408	1.00	4.48
		1.4717		15.8447	15.8447						

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		1.4493		11.5838	11.5838						
5 M	1:7	1.4546	4.3358	14.6014	14.6014	43.7194	39.3836	78.7672	21.2328	1.00	3.71
		1.4319		17.5342	17.5342						
	1:9	1.4401	4.3016	14.5549	14.5549	45.7820	41.4804	82.9608	17.0392	1.00	4.87
		1.4376		17.6477	17.6477						
		1.4239		13.5794	13.5794						
		1.4436		12.5838	12.5838						
	1:11	1.419	4.2844	15.6014	15.6014	45.9135	41.6291	83.2582	16.7418	1.00	4.97
		1.4218		17.7283	17.7283						

of hydrochloric acid with the same sample. The reactivity order with respect to their ratios is 1:7>1:9>1:11. Moreover, the determination of the mix ratio of cement and sand in the cement mortar sample is based on the lime (calcium oxide) content present in the respective sample. For a cement mortar sample, the determined lime (calcium oxide) content may deviate from true value up to 4% for the cement.

Furthermore, this tolerance provides a range for mix ratio (1:4) cement mortar samples i.e. from1:3.81 to 1: 4.22. By comparing the test results of the Table 4 and Fig. 2 with the above mentioned range, it was noticed that the test results of 11 M (1:9) and 10 M (1:7) solutions are within the calculated range and the remaining test results indicate small variation in the HCl solution drastically changes the test results, while 11 M (1:9) solution gives the most accurate results.

The reactivity pattern is the same as discussed in the results of 1:4 cement mortar samples but the range for 1:5 cement mortar samples is calculated from 1:4.77 to 1:5.25. By comparing the test results of the above mentioned range, it was investigated that again the test results of 11 M (1:9) and 10 M (1:7) solutions are within the calculated range and remaining test results indicates small variation in the HCl solution drastically changes the test results while 11 M (1:9) solution gives the most accurate results, which is shown in Table 5-6 and Fig. 3-4.

Table 4. Effect of dillution of HCL on mix ratio (1:4 cement mortar lime based)

HCl molarity	HCl dilution	Identification mark of platinum crucible	Weight of platinum crucible (g)	Weight of platinum crucible and residue (g)	Weight of residue (g)	%age of Lime		%age of sand	Mix ratio result (By weight)	
									Cement	Sand
11 M	1:7	1	42.9732	43.3156	0.3424	13.6960	21.0061	78.9939	1.00	3.76
	1:9	2	43.8757	44.2021	0.3264	13.0560	20.0245	79.9755	1.00	3.99
	1:11	3	41.5673	41.8768	0.3095	12.3800	18.9877	81.0123	1.00	4.27
10 M	1:7	4	44.6632	44.9757	0.3125	12.5000	19.1718	80.8282	1.00	4.22
	1:9	5	40.4589	40.7594	0.3005	12.0200	18.4356	81.5644	1.00	4.42
	1:11	6	37.7165	37.9936	0.2771	11.0840	17.0000	83.0000	1.00	4.88
9 M	1:7	7	43.4486	43.7391	0.2905	11.6200	17.8221	82.1779	1.00	4.61
	1:9	8	44.9834	45.2483	0.2649	10.5960	16.2515	83.7485	1.00	5.15
	1:11	9	23.6821	23.9292	0.2471	9.8840	15.1595	84.8405	1.00	5.60
8 M	1:7	10	41.7888	42.0681	0.2793	11.1720	17.1350	82.8650	1.00	4.84
	1:9	11	26.5283	26.7716	0.2433	9.7320	14.9264	85.0736	1.00	5.70
	1:11	12	68.9164	69.1522	0.2358	9.4320	14.4663	85.5337	1.00	5.91
7 M	1:7	1	42.9729	43.2262	0.2533	10.1320	15.5399	84.4601	1.00	5.44
	1:9	2	43.8755	44.1051	0.2296	9.1840	14.0859	85.9141	1.00	6.10
	1:11	3	41.5671	41.7852	0.2181	8.7240	13.3804	86.6196	1.00	6.47
6 M	1:7	4	44.6627	44.9143	0.2516	10.0640	15.4356	84.5644	1.00	5.48
	1:9	5	40.4587	40.6856	0.2269	9.0760	13.9202	86.0798	1.00	6.18
	1:11	6	37.7164	37.9343	0.2179	8.7160	13.3681	86.6319	1.00	6.48
5 M	1:7	7	43.4483	43.6939	0.2456	9.8240	15.0675	84.9325	1.00	5.64
	1:9	8	44.9829	45.2019	0.2190	8.7600	13.4356	86.5644	1.00	6.44
	1:11	9	23.6820	23.8997	0.2177	8.7080	13.3558	86.6442	1.00	6.49

Table 5. Effect of dilution of HCl on max ratio 1:5 cement mortar insoluble residue

Sr. no.	HCl molarity	HCl dilution	Weight of filter paper (g)	Sum of the weight of filter papers (g)	Weight of filter paper and residue (g)	Sum of the weight of filter papers and residue (g)	Weight of residue (g)	Sand %	Cement %	Mix ratio result (By weight)	
										Cement	Sand
B001	11 M	1:7	1.3922	4.2255	11.9473	42.3439	38.1184	76.2368	23.7632	1.00	3.21
B002			1.4186		12.5835						
B003			1.4147		17.8131						
B004		1:9	1.4338	4.3197	15.1090	43.0338	38.7141	77.4282	22.5718	1.00	3.43
B005			1.4474		10.7333						
B006			1.4385		17.1915						
B007			1.4397		13.7237						
B008		1:11	1.4275	4.2922	16.9944	43.7410	39.4488	78.8976	21.1024	1.00	3.74
B009			1.4250		13.0229						
B010			1.4257		17.2223						
B011		1:7	1.4181	4.2762	13.5656	42.8836	38.6074	77.2148	22.7852	1.00	3.39
B012			1.4324		12.0957						
B013			1.4147		13.8115						
B014	10 M	1:9	1.4287	4.2720	14.4833	43.2154	38.9434	77.8868	22.1132	1.00	3.52
B015			1.4286		14.9206						
B016			1.4399		18.1116						
B017		1:11	1.4501	4.3083	12.8893	44.3067	39.9984	79.9968	20.0032	1.00	4.00
B018			1.4183		13.3058						
B019			1.4665		17.3543						
B020		1:7	1.4332	4.3538	10.9999	43.8545	39.5007	79.0014	20.9986	1.00	3.76
B021			1.4541		15.5003						
B022			1.4349		12.1885						
B023	9 M	1:9	1.4295	4.2783	15.1424	44.1447	39.8664	79.7328	20.2672	1.00	3.93
B024			1.4139		16.8138						
B025			1.4353		18.2916						
B026		1:11	1.4391	4.3141	13.1025	45.7118	41.3977	82.7954	17.2046	1.00	4.81
B027			1.4397		14.3177						
B028			1.4277		11.3080						
B029		1:7	1.4389	4.3111	15.4827	44.2078	39.8967	79.7934	20.2066	1.00	3.95
B030			1.4445		17.4171						
B031			1.4442		16.4886						
B032	8 M	1:9	1.4514	4.3383	14.4650	45.3684	41.0301	82.0602	17.9398	1.00	4.57
B033			1.4427		14.4148						
B034			1.4275		12.4021						
B035		1:11	1.4364	4.3231	17.3865	46.6465	42.3234	84.6468	15.3532	1.00	5.51
B036			1.4592		16.8579						
B037			1.4441		15.3571						
B038		1:7	1.4562	4.3463	12.8373	44.6359	40.2896	80.5792	19.4208	1.00	4.15
B039	7 M		1.4460		16.4415						
B040		1:9	1.4453	4.3404	12.2328	45.5595	41.2191	82.4382	17.5618	1.00	4.69
B041			1.4654		17.1628						
B042			1.4297		16.1639						
B043		1:11	1.4369	4.3104	18.1839	46.7782	42.4678	84.9356	15.0644	1.00	5.64
B044			1.4351		15.2159						
B045			1.4384		13.3784						
B046	6 M	1:7	1.4242	4.2687	14.3085	44.8167	40.5480	81.0960	18.9040	1.00	4.29
B047			1.4186		17.2444						
B048			1.4259		13.2638						
B049		1:9	1.4444	4.4567	11.9722	45.7357	41.2790	82.5580	17.4420	1.00	4.73
B050			1.5521		15.5998						

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B051			1.4602		18.1637						
B052		1:11	1.3802	4.1982	15.6427	46.6881	42.4899	84.9798	15.0202	1.00	5.66
B053			1.4234		13.8789						
B054			1.3946		17.1665						
B055	5 M	1:7	1.4158	4.2287	18.2605	44.8976	40.6689	81.3378	18.6622	1.00	4.36
B056			1.4204		10.4268						
B057			1.3925		16.2103						
B058		1:9	1.4141	4.2431	16.9674	45.6863	41.4432	82.8864	17.1136	1.00	4.84
B059			1.4282		12.2923						
B060			1.4008		16.4266						
B061		1:11	1.4023	4.2344	13.1877	46.8452	42.6108	85.2216	14.7784	1.00	5.77
B062			1.4178		15.9169						
B063			1.4143		17.7406						

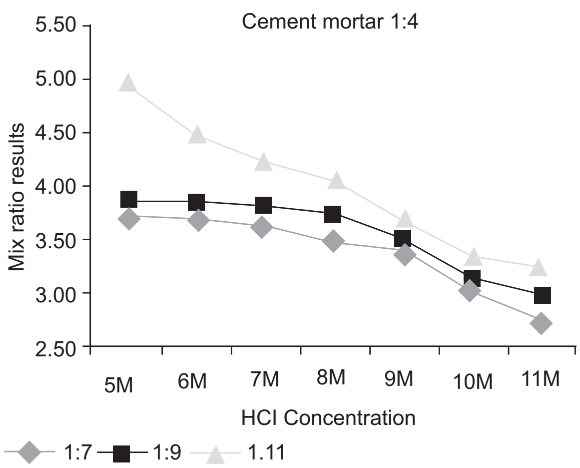

Fig. 1. Effect of dilutions of HCl on mix ratio (1:4 cement mortar insoluble residues).

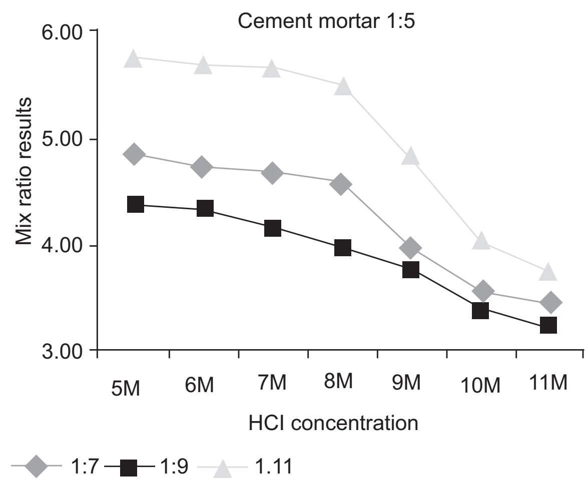

Fig. 3. Effect of dilutions of HCl on mix ratio (1:5 cement mortar insoluble residues).

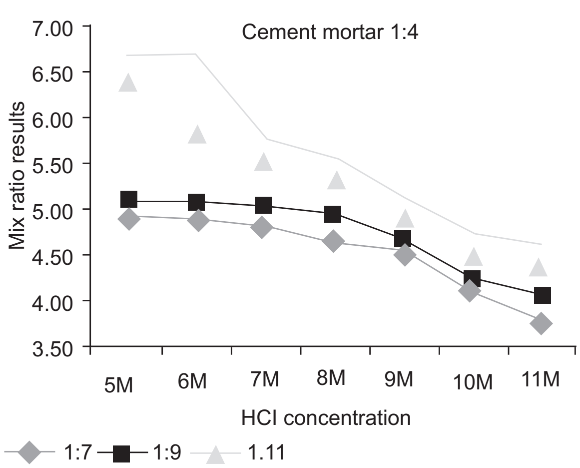

Fig. 2. Effect of dilutions of HCl on mix ratio (1:4 cement mortar lime based).

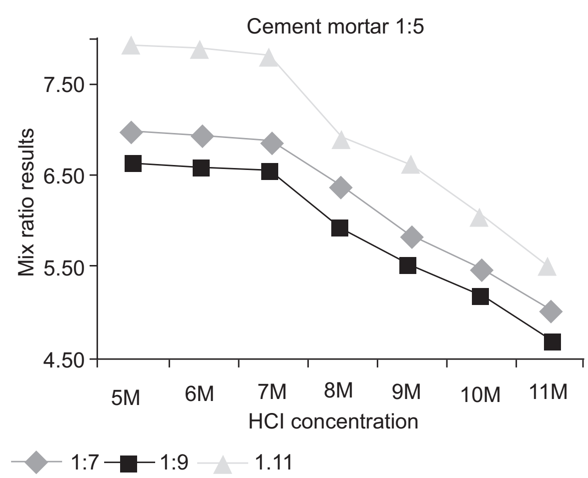

Fig. 4. Effect of dilutions of HCl on mix ratio (1:5 cement mortar lime-based).

The reactivity pattern is the same as discussed in the results of 1:4 and 1:5 cement mortar samples but the range for 1:6 cement mortar samples is calculated from 1:5.73 to 1:6.29. By comparing the test results of the above mentioned range, it was observed that again the test results of 11 M (1:9) and 10 M (1:7) solutions are within the calculated range and the remaining test results, indicate small variation in the HCl solution drastically changes the test results while 11 M (1:9) solution gives the most accurate results (Table 7&8 and Fig. 5&6).

Table 6. Determination of cement-sand proportion based on lime (standard cement-sand proportion used 1:5)

HCl molarity	HCl dilution	Identification mark of platinum crucible	Weight of platinum crucible (g)	Weight of platinum crucible and residue (g)	Weight of residue (g)	%age of Lime		%age of sand	Mix ratio result (by weight)	
									Cement	Sand
11 M	1:7	1	42.9728	43.2591	0.2863	11.4520	17.5644	82.4356	1.00	4.69
	1:9	2	43.8753	44.1465	0.2712	10.8480	16.6380	83.3620	1.00	5.01
	1:11	3	41.5671	41.8184	0.2513	10.0520	15.4172	84.5828	1.00	5.49
10 M	1:7	4	44.6622	44.9255	0.2633	10.5320	16.1534	83.8466	1.00	5.19
	1:9	5	40.4584	40.7094	0.251	10.0400	15.3988	84.6012	1.00	5.49
	1:11	6	37.7162	37.9473	0.2311	9.2440	14.1779	85.8221	1.00	6.05
9 M	1:7	7	43.4481	43.6975	0.2494	9.9760	15.3006	84.6994	1.00	5.54
	1:9	8	44.9822	45.2220	0.2398	9.5920	14.7117	85.2883	1.00	5.80
	1:11	9	23.6818	23.8958	0.214	8.5600	13.1288	86.8712	1.00	6.62
8 M	1:7	10	41.7884	42.0242	0.2358	9.4320	14.4663	85.5337	1.00	5.91
	1:9	11	26.5280	26.7496	0.2216	8.8640	13.5951	86.4049	1.00	6.36
	1:11	12	68.9158	69.1215	0.2057	8.2280	12.6196	87.3804	1.00	6.92
7 M	1:7	1	42.9727	43.1892	0.2165	8.6600	13.2822	86.7178	1.00	6.53
	1:9	2	43.8751	44.0824	0.2073	8.2920	12.7178	87.2822	1.00	6.86
	1:11	3	41.5669	41.7523	0.1854	7.4160	11.3742	88.6258	1.00	7.79
6 M	1:7	4	44.6619	44.8768	0.2149	8.5960	13.1840	86.8160	1.00	6.58
	1:9	5	40.4582	40.6638	0.2056	8.2240	12.6135	87.3865	1.00	6.93
	1:11	6	37.7161	37.8997	0.1836	7.3440	11.2638	88.7362	1.00	7.88
5 M	1:7	7	43.4477	43.6623	0.2146	8.5840	13.1656	86.8344	1.00	6.60
	1:9	8	44.9814	45.1863	0.2049	8.1960	12.5706	87.4294	1.00	6.96
	1:11	9	23.6816	23.8644	0.1828	7.3120	11.2147	88.7853	1.00	7.92

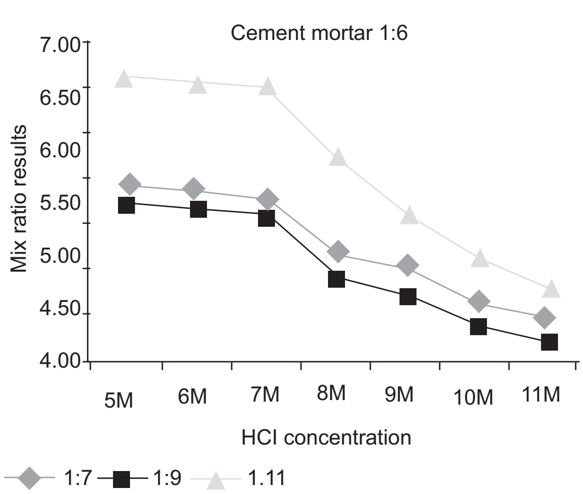

Fig. 5. Effect of dilutions of HCl on mix ratio (1:6 cement mortar insoluble residues).

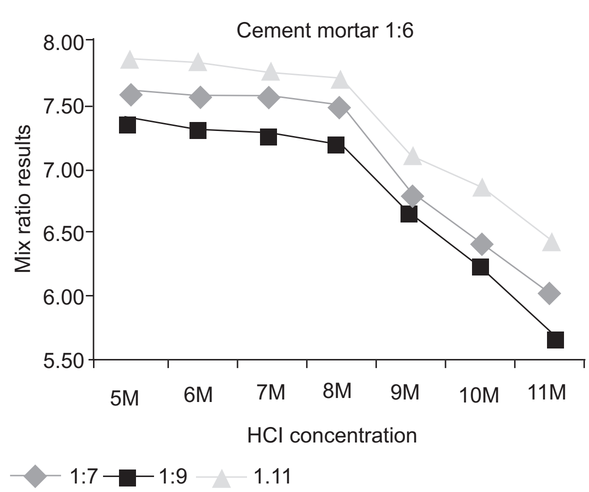

Fig. 6. Effect of dilutions of HCl on mix ratio (1:6 cement mortar lime-based).

Table 7. Determination of cement-sand proportion based on insoluble residue (standard cement sand proportion used 1:6)

HCl molarity	HCl dilution	Weight of filter paper (g)	Sum of the weight of filter papers (g)	Weight of filter paper and residue (g)	Sum of the weight of filter papers and residue (g)	Weight of residue (g)	Sand %	Cement %	Mix ratio result (by weight)	
									Cement	Sand
11 M	1:7	1.3865	4.1492	14.9321	44.4801	40.3309	80.6618	19.3382	1.00	4.17
		1.3982		12.8452						
		1.3645		16.7028						
	1:9	1.4034	4.2470	12.6896	44.9745	40.7275	81.4550	18.5450	1.00	4.39
		1.4281		17.1857						
		1.4155		15.0992						
	1:11	1.3949	4.2350	18.2587	45.4209	41.1859	82.3718	17.6282	1.00	4.67
		1.4256		13.9517						
		1.4145		13.2105						
10 M	1:7	1.3938	4.2311	16.3579	44.8319	40.6008	81.2016	18.7984	1.00	4.32
		1.4284		15.8306						
		1.4089		12.6434						
	1:9	1.4112	4.2153	18.7756	45.1369	40.9216	81.8432	18.1568	1.00	4.51
		1.4058		15.5369						
		1.3983		10.8244						
	1:11	1.3895	4.1812	11.8882	45.8037	41.6225	83.2450	16.7550	1.00	4.97
		1.3984		17.7642						
		1.3933		16.1513						
9 M	1:7	1.3777	4.1565	17.0801	45.1966	41.0401	82.0802	17.9198	1.00	4.58
		1.3842		14.9985						
		1.3946		13.1180						
	1:9	1.4135	4.2281	12.9901	45.6802	41.4521	82.9042	17.0958	1.00	4.85
		1.3907		18.1333						
		1.4239		14.5568						
	1:11	1.4338	4.2558	16.9003	46.4336	42.1778	84.3556	15.6444	1.00	5.39
		1.4154		12.2692						
		1.4066		17.2641						
		1.4153		11.8234						
	1:7	1.3944	4.2054	13.9847	45.5292	41.3238	82.6476	17.3524	1.00	4.76
		1.3957		19.7211						
		1.4111		12.5412						
8 M	1:9	1.4355	4.2739	17.8194	45.9043	41.6304	83.2608	16.7392	1.00	4.97
		1.4273		15.5437						
		1.4172		16.6112						
	1:11	1.4218	4.2559	14.8724	47.0202	42.7643	85.5286	14.4714	1.00	5.91
		1.4169		15.5366						
		1.4257		17.1628						
	1:7	1.4181	4.2383	15.3169	46.3906	42.1523	84.3046	15.6954	1.00	5.37
		1.3945		13.9109						
		1.4125		15.6628						
7 M	1:9	1.4234	4.2348	14.2597	46.5751	42.3403	84.6806	15.3194	1.00	5.53
		1.3989		16.6526						
		1.4129		14.6566						
	1:11	1.4215	4.2521	17.5351	47.6556	43.4035	86.8070	13.1930	1.00	6.58
		1.4177		15.4639						
		1.4348		16.7213						
	1:7	1.4513	4.3282	17.2703	46.5745	42.2463	84.4926	15.5074	1.00	5.45
		1.4421		12.5829						

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6 M	1:9	1.4235 1.4315 1.4278	4.2828	17.4417 13.3407 15.9159	46.6983	42.4155	84.8310	15.1690	1.00	5.59
	1:11	1.4329 1.4315 1.4364	4.3008	14.4466 17.4385 15.8434	47.7285	43.4277	86.8554	13.1446	1.00	6.61
5 M	1:7	1.4259 1.4118 1.4256	4.2633	14.4075 15.1644 16.9921	46.5640	42.3007	84.6014	15.3986	1.00	5.49
	1:9	1.4322 1.4378 1.4299	4.2999	14.8323 17.8119 14.1012	46.7454	42.4455	84.8910	15.1090	1.00	5.62
	1:11	1.4246 1.4198 1.4102	4.2546	18.1537 12.9906 16.6017	47.7460	43.4914	86.9828	13.0172	1.00	6.68

Table 8. Determination of cement sand proportion based on lime 265 (standard cement-sand proportion used 1: 6)

HCl molarity	HCl dilution	Identification mark of platinum crucible	Weight of platinum crucible (g)	Weight of platinum crucible and residue (g)	Weight of residue (g)	%age of Lime		%age of sand	Mix ratio result (by weight)	
									cement	sand
11 M	1:7	1	42.9725	43.2162	0.2437	9.7480	14.9509	85.0491	1.00	5.69
	1:9	2	43.8748	44.1078	0.233	9.3200	14.2945	85.7055	1.00	6.00
	1:11	3	41.5668	41.7861	0.2193	8.7720	13.4540	86.5460	1.00	6.43
10 M	1:7	4	44.6616	44.8877	0.2261	9.0440	13.8712	86.1288	1.00	6.21
	1:9	5	40.4581	40.6789	0.2208	8.8320	13.5460	86.4540	1.00	6.38
	1:11	6	37.7160	37.9236	0.2076	8.3040	12.7362	87.2638	1.00	6.85
9 M	1:7	7	43.4475	43.6603	0.2128	8.5120	13.0552	86.9448	1.00	6.66
	1:9	8	44.9812	45.1902	0.209	8.3600	12.8221	87.1779	1.00	6.80
	1:11	9	23.6816	23.8829	0.2013	8.0520	12.3497	87.6503	1.00	7.10
8 M	1:7	10	41.7885	41.9876	0.1991	7.9640	12.2147	87.7853	1.00	7.19
	1:9	11	26.5279	26.7194	0.1915	7.6600	11.7485	88.2515	1.00	7.51
	1:11	12	68.9154	69.1025	0.1871	7.4840	11.4785	88.5215	1.00	7.71
7 M	1:7	1	42.9724	43.1692	0.1968	7.8720	12.0736	87.9264	1.00	7.28
	1:9	2	43.8745	44.0645	0.1900	7.6000	11.6564	88.3436	1.00	7.58
	1:11	3	41.5668	41.7529	0.1861	7.4440	11.4172	88.5828	1.00	7.76
6 M	1:7	4	44.6613	44.8578	0.1965	7.8600	12.0552	87.9448	1.00	7.30
	1:9	5	40.4579	40.6479	0.19	7.6000	11.6564	88.3436	1.00	7.58
	1:11	6	37.7158	37.9004	0.1846	7.3840	11.3252	88.6748	1.00	7.83
5 M	1:7	7	43.4474	43.6419	0.1945	7.7800	11.9325	88.0675	1.00	7.38
	1:9	8	44.9809	45.1707	0.1898	7.5920	11.6442	88.3558	1.00	7.59
	1:11	9	23.6815	23.8651	0.1836	7.3440	11.2638	88.7362	1.00	7.88

Conclusion

The purpose of this study is to verify the accuracy of cement-sand mix ratio analysis in cement mortar. It provides complete awareness about the percentage values of insoluble residues and calcium oxide variation by changing the standard ratio and concentration of the hydrochloric acid solution. The increasing dilution of the HCl solution has proved ineffective in the proper de-composition of hydrates of cement. Therefore, the cement contents do not dissolve completely in the solution and deviated results are achieved. The reactivity order of molarities of HCl solutions to their ratios is 1:7>1:9>1:11 for all molarities. It is concluded that using 11 M (1:9) HCl solution confirms the standard ratios. Hence, the determination of the cement-sand ratio on a lime basis is recommended only under the standard solution condition 11 M (1:9). It is pertinent to mention here that a false common practice in the field is used to estimate the cement sand proportion of mortar samples based on insoluble residue using unstandardized HCl. The present study not only provide the importance of Test Method BS 4550: 1970 but also provide awareness to the field chemists working in civil departmental laboratories that do not estimate cement sand proportion in mortar based on insoluble residue results.

Conflict of Interest. The authors declare no conflict of interest.

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