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Verifying Cement Compressive Strength Test Result Using the Most Effective Parameters

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Abstract

This study was conducted to analyze factors influencing the compressive strength test. The purpose is to introduce various factors affecting the accuracy of the compressive strength test in accordance with current standards and evaluate the effect of some effective parameters such as equipment (loading rate of automatic compression machine, jolting or vibrating), mortar preparation, sample preparation, etc. To check the reproducibility of the compressive strength test a program was developed to assess the possible modes through changes in loading rate, standard sand, sample preparation, and operator. The changes of each parameter were measured within 2, 7 and 28-day interval, while other conditions were considered as constant based on the EN 196-1 and ISIRI 393 standards. According to the test results, the most important factors in creating the difference in results are the type of the sand and loading rate. The changes in the reproducibility percentage using different sands with softer grains increases the coefficient of variation and reduced performance of the test. Also in some cases, with increasing the loading rate up to 40%, the compressive strength of 28 days is increased by 13%.

Keywords: *Coefficient of variation, Reproducibility, Loading rate*

1. Introduction

Compressive strength is one of the most important physical parameters in determining cement quality and usage. Due to the increasing growth of concrete structures and consequently increased consumption of cement in the world, the need for the concrete production with high durability and strength is of great importance (Taeb et al., 1995).

Among the factors affecting the compressive strength of mortar and concrete include the type and quality of the members (cement phases, softness, fineness, and aggregation), the percentage of members or concrete mix design and curing conditions (Caldarone, 2008). Since the beginning of mass production of cement, it has always been attempted to change the above factors such that the desired compressive strength is achieved by a minimum energy. So how to measure the physical parameters to determine effects of different factors on increasing the compressive strength is of particular importance. The lack of accurate measurement can lead to incorrect analysis of the impact of these factors (Taeb et al., 1995; Bekaeian, 1997). Cement compressive strength tests are usually done based on the standards EN 196-1, DIN 1164, BS 4550 or ASTM C109.

When testing the mortar, it is necessary to evaluate the accuracy and precision of the test procedure under different conditions. Statistical methodology was used for determination of the effect of chemical admixture on cementitious materials (Huang et al., 2010; Huang et al., 2010; Huang et al., 2011).

To determine the cement compressive strength the test is not performed on cement paste (Dilghani, 2001). Mortars are the composite of 1 part cement, three parts completely dry standard sand (sand type 2 discussed in Table 1) and half part water (Mindes and Young, 2004). The test is done at 20°C and a relative humidity of about 65 percent. The procedure is based on the standards EN 196-1, 2002, ISIRI 393, 2009. The prepared mortars are poured into the 16 × 4 × 4 molds and kept in containers at 20 ±2° C for 24 h. After the initial curing, the molds are opened and samples are broken by automatic compression machine at the curing times of 2, 7 and 28 days. However, in some studies, one-day compressive strength has also been tested to evaluate the initial performance of cement materials (Riding et al., 2010; Aggoun et al., 2008).

Among the factors influencing the test are the mold type and size. Cube molds have better strength than the cylindrical ones (Del Viso et al., 2008, Torreti et al., 2002). Thus, in accordance with the standard cube molds with the standard dimensions 16 × 4 × 4 are selected.

Fully dry samples have 15 to 20 percent higher strength than the fully saturated samples. According to the standard, strength measurement should be done in saturated conditions (Riding et al., 2010).

Concrete compressive strength for different types of cement in the inundated environment is about 20 kg/cm2 higher than the wet environment. Cement II compressive strength in sulfate environment in the initial periods is close to the wet environment for 14 days, but it is 20 kg/cm2 less than the wet environment in the long term. But for pozzolan cement II the difference is halved and for cement V in sulfate environment the difference is insignificant compared to the wet environment and for pozzolan cement V the difference is almost zero and in some cases, the strength is more than the wet environment (Del Viso et al., 2008).

The loading rate of the test machine is another factor affecting the change in compressive strength. Very low applied rate results to creep phenomenon, and as the loading rate increases, the compressive strength of mortar increases as well (Aggoun et al., 2008).

The weight ratio of the members includes 1 part cement, three parts sand and 0.5 part water (water-cement ratio is 0.5) (Mohamad et al., 2007). The applied sand must be approved by the Iranian National Standard No. 3040. The reference sand is natural, silica and curved particles free from any organic impurities with specified particle size distribution. Reference sand moisture should not be more than 0.2% and the silica content is less than 98%. The use of inappropriate cement weight has an impact on the strength and its development process in the mortar (Huang et al., 2011).

For the standardization of cement, two types of sand are used: Standard German sand and Ottawa standard sand. Each of these sands according to their defined standards in their countries have specific specifications, including: grain size, silica content, rounding, as well as compressive and flexural strengths (Iranian National Standard, 2004).

2. Materials and methods

In this study, nine samples of cement type 1-425 were analyzed in terms of the effect of changing the sand, sample preparation method and loading rate (EN 196-1, 2018, ISIRI 393, 2009). Loading rate 2 was 1.5% higher than the standard loading rate. The loading rate of the automatic compression machine for each sample was measured by a rate of 2400 Newton per second (loading rate 1) and with 50% increase in rate (loading rate 2).

Other conditions such as the applied water in making the mortar and maintenance tank, mix design, moisture and identical samples were considered based on the reference standard.

In preparing the mortar two types of reference sand with different aggregation was used. Type 1 sand had a softer aggregation than type 2 (reference sand). Grain size distribution and limit PSD of used reference sand according to EN 196-1 is included in Table 1. Also, Grain size curve for two types of sand is shown in fig. 1.

Table 1. Grain size distribution and limit PSD of used reference sand

Mash size (mm)	Lower limit	sand 1	sand 2	Upper limit
2	0	0	0	0
1.6	2	1.1	2.1	12
1	28	35.2	34.96	38
0.6	62	57.6	63.4	72
0.15	82	83.5	90.65	92
0.075	98	97.8	98.1	100

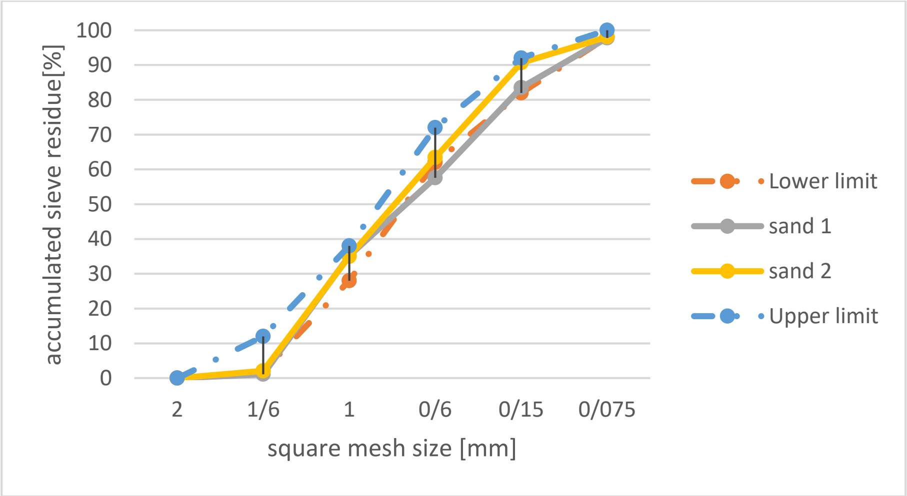

Figure 1. Grain size curve for two types of sand

Also preparing the mortar by vibrator was based on standards and also for higher accuracy of the preparation it was accompanied by the jolting.

2.1. Parameters' matrix

Reproducibility of compressive strength test is the close agreement between the obtained results from similar cement samples in different laboratories under the factors such as different systems, the likelihoods of different reference cements and the possibility of their performance time. In the case of the 28-day compressive strength, reproducibility between the laboratories with conventional operation and the above-mentioned conditions should be less than 4% which is discussed as the coefficient of variation (Huang et al., 2010). Accordingly variables influencing the compressive strength test are evaluated by the following matrix and other factors are considered fixed and uniform. The equipment used in the compressive strength test is calibrated. The test method from the step of preparation up to measuring the strength is fully in accordance with the conditions mentioned in ISIRI1 393 and EN 196-1 standards and listed in Table 2.

Table 2. Evaluation matrix of effective parameters in the compressive strength test

	Curing	Loading rate	Type of the sand	Mortar preparation
Curing	-	*	*	*
Loading rate	*	-	*	*
Type of the sand	*	*	-	*
Mortar preparation	*	*	*	-

3. Results and discussion

3.1. 2-day strength results

For this purpose, two types of sand and two loading rates were used and 9 tests were conducted for each mode. Sand type II was based on the standard sample and sand type I was softer than it. In the first case loading rate was based on standard and in the second case loading rate was 0.5 times greater than the standard.

The results of the above conditions are listed in Table 3 for the strength age of 2-day. Also for the analysis of the effect of vibration and knocking in preparing the samples with different loading rate for two types of cement is shown in Table 3 for a 2-day compressive strength.

Table 3. Results of 2-day compressive strength of the base cement by changing cement and loading rate

Loading rate conditions	Type of the sand	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9
Loading rate 1(L1)	Sand 1	237	201	233	212	224	129	240	167	192
	Sand 2	196	190	196	206	201	110	196	161	170
Loading rate 2(L2)	Sand 1	240	210	230	216	230	135	244	170	202
	Sand 2	199	195	198	212	207	113	198	166	180
%CV(*)	L1	13.39	3.98	12.20	2.03	7.65	11.24	14.27	2.59	8.59
	L2	13.21	5.24	10.57	1.32	7.44	12.55	14.72	1.68	8.14
%CV(**)	Sand 1	0.89	3.10	0.92	1.32	1.87	3.21	1.17	1.26	3.59
	Sand 2	1.07	1.84	0.72	2.03	2.08	1.90	0.72	2.16	4.04

%CV(*): the comparison of CVs regarding different mortar sand in constant loading rate.
%CV(**): the comparison of CVs regarding different loading rate in same mortar.

According to Table 3 it can be observed that increasing the loading rate increases the compressive strength by 1.92 percent in cements prepared by sand type 1 and it is 1.84% for the mortars prepared with reference sand. However, change in the type of sand has led to a further increase in the 2-day compressive strength. As at a constant loading rate, an average of about 13% growth is observed in 2-day compressive strength of softer sand mortar.

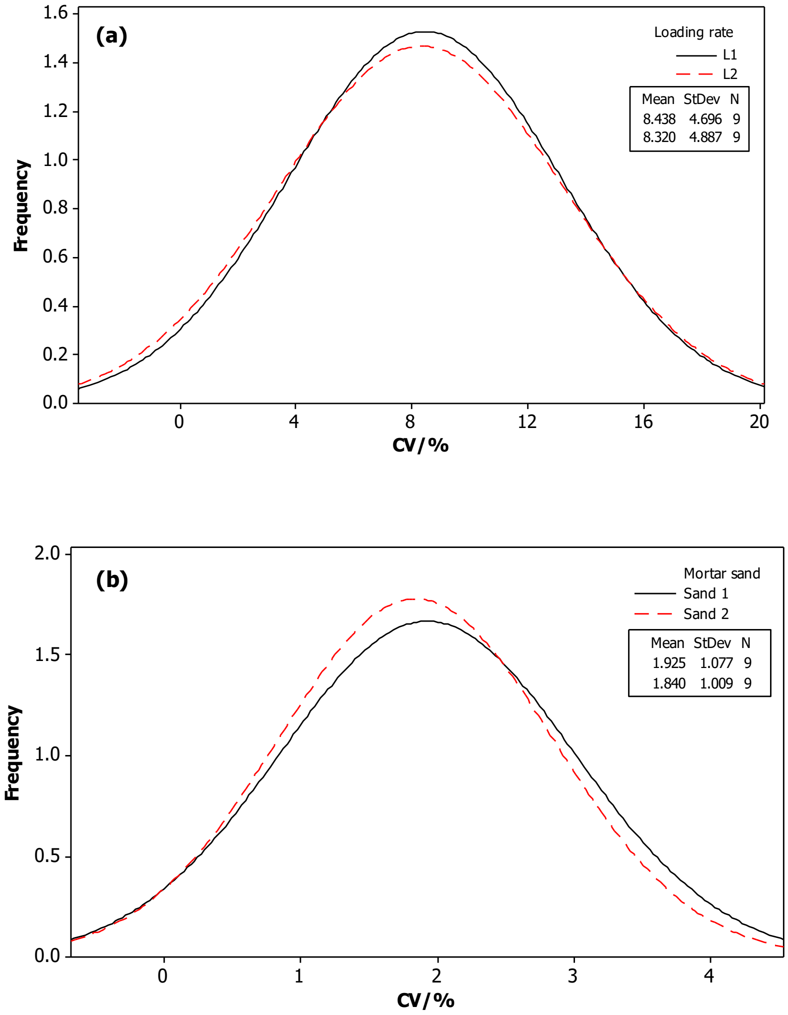

Figure 2. Compression of normal distribution of CVs from different source of variation for 2-day compressive strength (a) Comparison of mortar sand in two loading rate; (b) Comparison of loading rate in two mortar sand

The comparison of CVs regarding different source of variation (SOV) is presented in fig. 2. It showed that the comparison between softer sand and standard sand in different loading rate was not significantly different for 2-day compressive strength (fig. 2 (a)). Also, there is no significant difference between CVs of different loading rates in each of the mortars (fig. 2 (b)).

The effect of loading rate is less than the cement prepared with the different sands. Also changing the type of sand increases coefficient of variation, increase in short-term

compressive strength and reduced reproducibility.
At this stage 4 base cement samples are tested by changing the sand, loading rate and different mortar preparations (vibrator, Jolting) that results can be seen in Table 4. The effect of increased loading rate is not significant on short-term increase in strength due to the lower external loading than the higher ages. Changing the cement type leads to further increase in coefficient of variation and differences the rate of loading as well as preparing the samples. However, the use of vibrator or Jolting for the mortar that is prepared by standard sand has had no significant impact on the strength.

Table 4. Results of 2-day strength with 4 types of base cement, changing sand, test equipment and different preparation

Type of the sand	Loading rate 1 and Jolting (kg/cm^2)	Loading rate 2 and Jolting (kg/cm^2)	Reproducibility coefficient of variation	Loading rate 1 and Vibrator (kg/cm^2)	Loading rate 2 and Vibrator (kg/cm^2)	Reproducibility coefficient of variation
Type A	237	245	3	266.5	307	13
	235	243	3	264.2	304.7	13.2
	220	229	4	249	284	12
	240	248	3	269.2	304	11
Type B	219	228.7	4	218.5	234.2	6
	203	226.4	10	216.2	231.9	6.7
	201.7	212.4	5	201	211.2	4.8
	221.9	231.7	4	221.2	231.2	4.3

3.2. 7-day strength results

7-day strength results of cement samples prepared with two different sand types under different loading rates can be seen in Table 5. Similar to 2-day strength results, the difference in two types of sands changes the compressive strength. By increasing the age of compressive strength and the required force to break the sample, it can be observed that the effect of increasing the loading rate on increasing the strength has had some levels of increase compared to 2-day strength results.

Table 5. Results of 7-day strength with 9 types of base cement, changing sand, test equipment and different preparation

rate Loading	Type of the sand	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9
Loading rate 1(L1)	Sand 1	326	347	435	383	392	425	380	328	479
	Sand 2	315	325	402	365	371	375	368	305	461
Loading rate 2(L2)	Sand 1	360	361	450	405	407	451	407	323	519
	Sand 2	341	352	443	394	395	448	390	335	485
%CV(*)	L1	2.43	4.63	5.58	3.40	3.89	8.84	2.27	5.14	2.71
	L2	3.83	1.79	1.11	1.95	2.12	0.47	3.02	2.58	4.79
%CV(**)	Sand 1	7.01	2.80	2.40	3.95	2.65	4.20	4.85	1.09	5.67
	Sand 2	5.61	5.64	6.86	5.40	4.43	12.54	4.10	6.63	3.59

%CV(*): the comparison of CVs regarding different mortar sand in constant loading rate.
%CV(**): the comparison of CVs regarding different loading rate in same mortar.

The precision of 7-day strength data of cement mortar prepared by different mortar sand in two loading rate is significantly different. The mean value of CV of mortar by the standard loading rate was significantly smaller than each sample that the increased force required to break it (fig. 3).

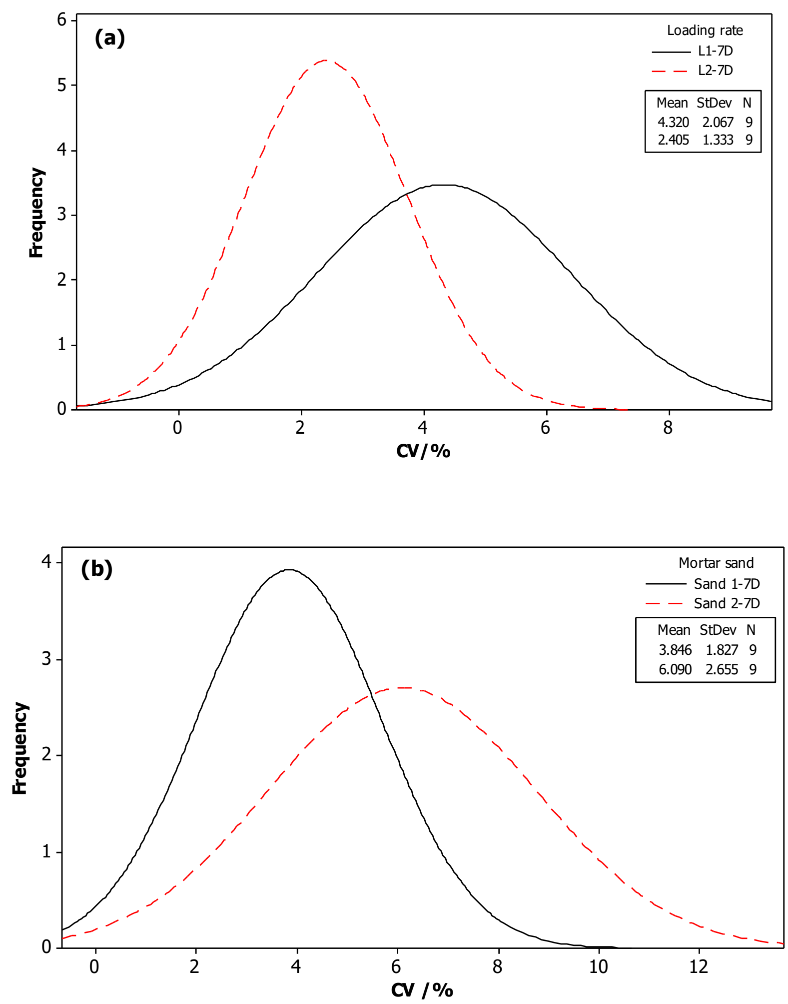

Figure 3. Compression of normal distribution of CVs from different source of variation for 7-day compressive strength (a) Comparison of mortar sand in two loading rate; (b) Comparison of loading rate in two mortar sand

3.3. 28-day strength results

28-day strength results in Table 6 indicate reduced effect of compressive strength based on the sand type. According to Table 6 it can be observed that increasing the loading rate increases the compressive strength by average 9.65 percent in cements prepared by sand type 1 and it is average 9.79% for the mortars prepared with reference sand.

Table 6. Results of 28-day strength with 9 types of base cement, changing sand, test equipment and different preparation

rate Loading	Type of the sand	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9
Loading rate 1(L1)	Sand 1	457	518	521	514	452	515	452	452	522
	Sand 2	452	505	516	512	444	506	449	448	516
Loading rate 2(L2)	Sand 1	503	562	571	562	501	554	501	497	575
	Sand 2	501	558	565	558	496	548	495	489	562
%CV(*)	L1	0.78	1.80	0.68	0.28	1.26	1.25	0.47	0.63	0.82
	L2	0.28	0.51	0.75	0.51	0.71	0.77	0.85	1.15	1.62
%CV(**)	Sand 1	6.78	5.76	6.48	6.31	7.27	5.16	7.27	6.71	6.83
	Sand 2	7.27	7.05	6.41	6.08	7.82	5.64	6.89	6.19	6.03

%CV(*): the comparison of CVs regarding different mortar sand in constant loading rate.
%CV(**): the comparison of CVs regarding different loading rate in same mortar.

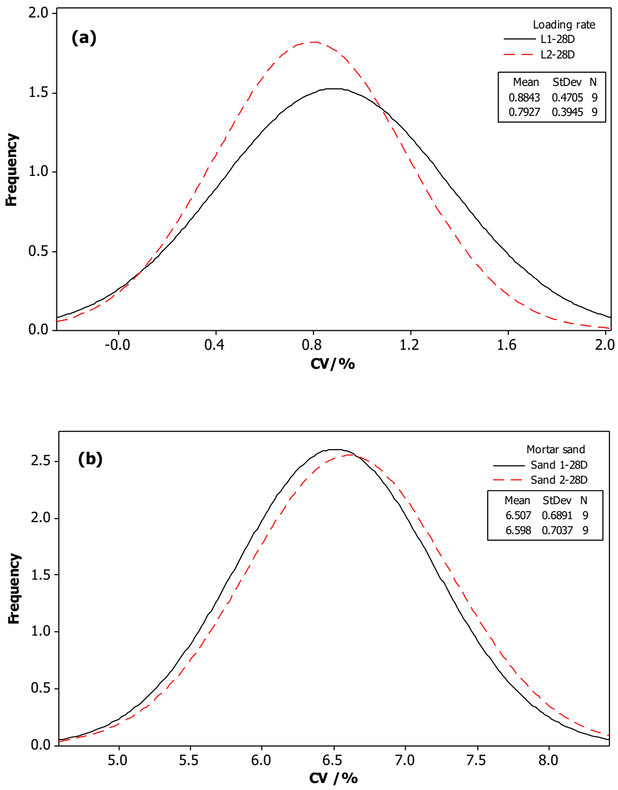

Figure 4. Compression of normal distribution of CVs from different source of variation for 28-day compressive strength (a) Comparison of mortar sand in two loading rate; (b) Comparison of Loading rate in two mortar sand

Fig. 4 showed that the distribution of data obtained from mortar prepared by different sand (fig. 4 (a)) was far more concentrated than that of different Loading rate (fig. 4 (b)). Conversely, due to the increased force required to break each sample, increasing the loading rate has a greater impact on the increase in 28-day compressive strength. These changes have reduced reproducibility for sand type 2 with higher ratio.

4. Conclusion

Based on the results of the tests the following contents are concluded:

1. Increasing the loading rate increases the compressive strength up to 15 percent. Increasing the loading rate in 28-days samples has had a greater impact on short-term increase in compressive strength.
2. Change in the method of preparation with vibrator rather than Jolting leads to 2% change in results, by changing the method of pouring the mortar in the mold it is possible to pass this error. Also the use of sand type 2 (reference sand) reduced this difference.
3. The most important factor in creating variation in results is associated with the sand type. So sand type 1 results in greater strength than the reference type. Also the reproducibility changes are increased by this type of sand.

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