ASSESSMENT OF STRENGTH TESTING BY READY-MIXED CONCRETE PLANTS IN RIYADH, SAUDI ARABIA

Abdulaziz I. Al-Negheimish[1], Abdulrahman M. Alhozaimy[2]

1: Assistant professor, Civil Engineering Department, King Saud University
2: Associate professor, Civil Engineering Department, King Saud University

E-mail: negaimsh@ksu.edu.sa

ABSTRACT

The compressive strength test is the main criterion to judge compliance of concrete strength with specifications; however, the reliability of the compressive strength test results may be undermined due to wide variation resulting from nonstandard practice in sampling, curing and testing of concrete. In Riyadh, there are many aspects of sampling and testing practice by ready-mixed concrete (RMC) plants which was observed to be in violation of internationally accepted norms and standards. In particular, drying of cubes prior to testing and using fast rate of loading during testing are common testing irregularities. In addition, the accuracy and performance of compression testing machines is another source of uncertainty.

In this study, the reliability of compressive strength test results, done internally by RMC plants was evaluated. This study covered 13 out of the 25 plants operating in Riyadh. The performance of the plant testing machine was evaluated by interlaboratory comparison with good quality reference machine located at King Saud University. The results showed majority (54%) of RMC plants having non-matching results to the reference samples tested at King Saud University. The results revealed that 5 out of the 13 plants investigated (38%) are using defective or inaccurate testing machines.

Keywords: *Compressive strength, Concrete, Testing Machines, Interlaboratory study, Variability, Quality Scheme, Riyadh-Saudi Arabia.*

الملخص

يعد اختبار قوة الخرسانة ذا أهمية كبيرة لكونه المعيار الأساسي في الحكم على الجودة و مدى توافق قوة الخرسانة مع المواصفات، إلا أن نتائج الاختبار ستكون عديمة الفائدة إذا لم يتم الالتزام الكامل بالطرق القياسية في أخذ العينات ومعالجتها واختبارها. و يوجد مشاكل جوهرية فيما يخص اختبار قوة ضغط الخرسانة في مصانع الخرسانة الجاهزة العاملة في مدينة الرياض حيث تجفيف العينات قبل اختبارها واستخدام معدل تحميل سريع عند الاختبار من الممارسات الشائعة. كما أن دقة و أداء مكائن اختبار الضغط في هذه المصانع مصدر آخر لعدم الاطمئنان

في هذه الدراسة ؛ تم تقويم مدى موثوقية نتائج اختبار قوة الضغط والتي تقوم بها مصانع الخرسانة الجاهزة وقد غطت هذه الدراسة ١٣ من أصل ٢٥ مصنعاً عاملاً في مدينة الرياض. وتم تقويم أداء مكائن الاختبار في المصانع من خلال برنامج مقارنة مع ماكينة اختبار مرجعية ذات جودة عالية متوفرة في جامعة الملك سعود. لقد أظهرت النتائج أن أغلبية مصانع الخرسانة الجاهزة (٥٤%) أعطت نتائج غير متوافقة مع العينات المرجعية التي اختبرت في جامعة الملك سعود. كما أظهرت النتاج أن ٥ مصانع من ١٣ مصنعاً تمت دراستها (٣٨ %) تستخدم مكائن اختبار غير دقيقة أو بها خلل.

1. INTRODUCTION

Compressive strength testing of hardened concrete is the most widely used tool to check the quality of concrete and to judge compliance with specifications. In the ready-mixed concrete (RMC) industry, the results of strength testing are used mainly to monitor the quality of concrete production. In addition, strength testing is sometimes done in parallel with that of outside agencies in charge of compliance testing to protect the interest of the RMC producer in case of dispute.

The concept of the compressive strength test is very simple, yet the test is very sensitive to variations in testing procedure. The standard procedures for sampling molding, curing and testing are described in BS 1881 [1983] for cubes and in ASTM C39 [ASTM, 2001] and other related standards for cylinders. The test must be carried out strictly according to these standard procedures so that the results from different testing laboratories are comparable [Mindess and Young, 1981]. Unfortunately, following these standard procedures in day-to-day practice is not a sure matter. The following are the principal discrepancies in testing procedures which are the main sources of variations in strength results:

- Improper sampling procedures
- Variations due to fabrication techniques (poor quality molds, incomplete consolidation, handling and curing of newly made cylinders or cubes)
- Changes in curing (temperature variation, variable moisture, delay in bringing specimen to the laboratory)
- Moisture state of the specimens during testing
- Poor testing procedures (improper placement in testing machine, incorrect rate of loading)
- Faulty testing machine (platens out of specifications, inaccurate load indication)

Top

Effects of these variations on the measured compressive strength could be substantial with most deviations resulting in reduction of the measured strength [Dewar and Anderson, 1988].

There many documented cases where perceived problems with concrete quality were the results of not following correct concrete testing procedures. In 1972, British Ready-mixed Concrete Association (BRMCA) carried out a national accuracy and efficiency check on concrete test laboratories [Kirkbride, 1975]. About a third of the UK's estimated 300 testing authorities were included in the survey. The Cement and Concrete Association comparative cube test was used to check discrepancies between machines complying with BS 1610 load scale indication requirements. More than half produced results significantly different (4 percent or more) from reference, with some more than 30% out. It was concluded that "at least half the testing authorities in the country should be investigating their curing procedures, their testing procedures, their testing machines, or all three". Lavon and Fradua [1994] describes recent experience with a construction project in which high percentage of results were below the specified required strength as a result of bad testing practice.

2. EXPERIENCE WITH NON-MATCHING RESULTS IN STRENGTH TESTING

A weakness in the compressive strength testing is highlighted when nominally identical specimens are tested in two or more laboratories with non-matching results [Akers, 1990]. This may cause dispute and litigation if the results of such tests are used for compliance purposes. The problem of non-matching results in compressive strength testing is also a serious issue when testing is done as part of surveillance activities of regulatory agencies. First hand experience with this problem were faced by the authors in the past few years through their technical involvement with quality scheme for RMC plants in Riyadh being implemented by the Municipality of Riyadh.

The scheme was started in early 1995 with the objective of making sure that all RMC plants in Riyadh produce and maintain good quality concrete [Al-Negheimish et al., 1999; Alhozaimy and Al-Negheimish, 1999]. As part of the scheme activities, compressive strength is monitored through concrete samples collected randomly from each RMC plant at the rate of 1-3 samples per month. Reports on the results of the random samples are submitted to the RMC plants on monthly basis. Failure to meet the specified strength for that grade of concrete resulted in warning and a penalty. Initially, many complaints were received from RMC plant alleging that Municipality testing provided lower results than plants' testing. This was surprising since all aspects of testing were strictly in accordance with standards. Nevertheless, these complaints were taken seriously for its implication on the credibility of the scheme.

Preliminary investigation of the testing practice of RMC plants in Riyadh revealed that many aspects of their sampling and testing are in violation of internationally accepted norms and standards [Municipality of Riyadh, 1997]. In particular, drying of cubes prior to testing and using fast rate of loading during testing are common testing irregularities. In addition, many of the compression testing machines used are old and outdated which is another source of uncertainty about the performance of these machines in strength testing. It should be noted that all testing machines in RMC plants are calibrated annually as per the requirement of the Municipality Quality Scheme. To examine the complaints more thoroughly, a study to evaluate the performance of compressive strength testing of RMC plants operating in Riyadh is required.

3. DESCRIPTION OF THE STUDY

In the study, total of 13 out of the 25 plants operating in Riyadh were evaluated. The study involves inter-laboratories comparison of compressive strength cube test results between the RMC plant's quality control (QC) laboratory and King Saud University (KSU) Laboratory which serves as a reference. The performance of the plant testing machine is evaluated by interlaboratory comparison with good quality reference machine located at King Saud University. Guide for proficiency testing by interlaboratory comparisons given by ASTM E 1301-95 [ASTM, 2001] was followed in conducting this study.

The method of comparing the performance of the compression machine to a reference machine of proven performance has been used in the UK by the Cement and Concrete Association (C&CA) [Foote, 1983]. The C&CA comparative cube test allowed a machine user to check whether such discrepancy exists between results of his machine and results on the Association's reference machine. Difference in strength results of 4% or more from reference is judged to be significantly different. It has been stated that the maintenance of the performance of the reference machine is a vital element in ensuring the validity of the comparative cube testing. Its performance is also compared regularly with another high quality, carefully maintained machine using the comparative cube test [Foote, 1983]. These precautions were followed for the KSU machine where the performance of the machine is checked regularly by comparing to other compression testing machines as part of the quality assurance program for the Quality Scheme for ready-mixed Concrete of the Municipality of Riyadh [Municipality of Riyadh, 2000].

In addition to testing at KSU, a commercial testing laboratory (CTL) was used to check and verify the testing by KSU. The inter-laboratories testing program followed for each RMC plant is outlined in Figure 1. Each casting was done on different days by the same team of technicians. For each plant, sixteen cubes were cast by the team at the RMC plant using concrete procured from one of the trucks. Cubes were transported to KSU laboratory the next morning where they are demolded and cured under standard curing conditions. At the age of 28 days, the specimens are divided into four groups each consisting of 4 cubes. The first group is to be tested at the King Saud University (KSU) Laboratory and serve as a reference.

Top

The second group is to be tested by a commercial testing laboratory (CTL). The third and fourth groups of cubes are to be tested at the plant; one group tested using the plant common procedure (PCP) and the other group with the plant following standard procedure as per BS 1881 (PSP). Plant common procedure (PCP) in most cases involves drying the specimens for few hours prior to testing and using faster rate of loading for the test.

In addition to these four groups, cubes prepared at the same time by the plant's QC staff following their own sampling and curing procedures and referred to thereafter as the plant sample (PS) were also tested. This was done to evaluate the combined effects of sample preparation, mold and consolidation, curing and testing procedure and machines on the results when compared with standard sampling and testing procedures (KSU-samples). All facets of casting, curing and testing procedures were in accordance with BS 1881 standards, except when noted otherwise.

4. RESULTS AND DISCUSSION

The average compressive strength tests results and the associated coefficient of variation (COV.) for all plants are given in Table 1. The results were analyzed and compared in order to evaluate the performance of compression machines and factors affecting the reliability of testing.

4.1 Criteria For Judging Variability Between Laboratories

How much variability is allowed before the results from different testing laboratories are judged to be not comparable is an important question. In the UK, for highly controlled testing done using the Cement and Concrete Association (C&CA) comparative cube test, difference in strength results of 4% or more from reference is judged to be significantly different [Foote, 1983]. Amendment to BS 1881, part 116 [BSI, 1991] gives the differences in the strength results at the 95% confidence level for both repeatability (within-laboratory) and reproducibility (between laboratory) conditions. For 150mm cubes, a value of 9 and 13.2% is given for the difference under repeatability and reproducibility conditions, respectively. In the USA, ASTM C39 [ASTM, 2001] gives limit on the range under repeatability condition but still does not provide any guidance on the range of difference in compressive strength test results between two separate laboratories. Day [1995] has argued for along time that a difference in compressive strength of 2 MPa between two competent laboratories is unavoidable in strength testing and should be allowed for. This translates into a difference of 5% for grade 40 MPa concrete.

Based on the preceding discussion, criteria given in Table 2 have been adopted as reasonable tool for judging difference in the average strength of nominally identical specimens tested between two laboratories. These criteria stipulate "good agreement" when the difference in the average strength between the two laboratories is less than ± 5%; "questionable agreement"

Top

when the difference is in the range of ± (5 to 10%); and "unacceptable" when the difference exceeds ± 10 %. Accordingly, the performance of the laboratory is judged to be questionable or unacceptable once the difference in the average strength exceeds ± 5%.

Table 2: Criteria for judging the difference in compressive strength between two laboratories

Differences in the average strength	**Agreement Level**
Less than (± 5%)	Good
In the range of (± 5 to ± 10%)	Questionable
More than (± 10%)	Unacceptable

The adequacy and consistency of the adopted criteria are examined by comparing the results from KSU laboratory and the Commercial Testing Laboratory (CTL). Both laboratories have a state of the art testing machine with digital display and controlled rate of loading (Figure 2). Both machines are properly calibrated and operated by qualified and reliable engineers and technicians. Control of testing in these two laboratories for this inter-laboratory testing program is excellent as indicated by the low COV. shown in Table 1.

The results of compression strength for the reference samples tested at King Saud University and commercial testing laboratory (CTL) are compared in Figure 3. In this figure, the compressive strength test results from KSU are plotted against the values of the reference samples tested at CTL. The results show some variations in the compressive strength between the two laboratories with KSU being consistently higher. The range of the differences is between -1.1 and -7.2% with a mean value of -5.2%. By applying the criteria to the differences in test results between KSU and CTL, it was found that 54% of results are judged to be in good agreement (the difference is about 5% or less) 46% of results questionable agreement and 0% non-matching. The reason for the relatively high number of questionable cases is not known; however, subsequent and still continuing interlaboratory testing program has revealed that the results of CTL are consistently lower than that of other laboratories [Muncipality of Riyadh, 2000]. Based on this analysis, the criteria adopted for judging variability has been shown to be a consistent and reasonable tool for evaluating the performance of strength testing of RMC plants in Riyadh.

4.2 Effect of Testing Procedure

The effect of testing procedure generally includes the effects of rate of loading, and the moisture state of concrete specimens during testing. The effect of not adhering to the specified rate of loading is investigated by comparing the results of the plant common procedure (FCP) and the plant standard procedure (PSP) since the only difference in testing

Top

procedure between the two is the use of fast rate of loading during testing by some operator for FCP samples. In Figure 4, the compressive strength test results using FSP samples are compared to the FCP samples. The figure shows small effect resulting from variations in the testing procedure for most plants with twelve plants showing good agreement between FCP and FSP (difference in the range of ± 5%). Only one plant has result of compressive strength of FSP testing greater than the result of FCP by more than 5%. This is consistent with findings from another study [Al-Negheimish and Alhozaimy, 2001] which showed that using fast rate of loading increased strength test results by less than 4% (Figure 5).

The effect drying of cube specimens prior to testing on the compressive strength test results was evaluated separately. Twenty eight cubes were cast using typical RMC mix with 350 kg/m^3 cement content supplied by one of the RMC plants. All specimens were demolded after 24 hours and transferred to curing tank. Specimens were removed from the curing tank to dry in the laboratory atmosphere for the prescribed time periods prior to testing at the age of 28 days. The ratio of the compressive strength of cubes tested at the prescribed drying period to the strength of control specimens tested in the saturated condition are plotted against the drying time and shown in Figure 6. From the figure, it is clear that the compressive strength increases with the increasing of drying time. However, For drying time of up to 6 hours, the increase in strength is marginal. After 4 days of drying in the laboratory environment, an increase of about 13% in the compressive strength compared to the control specimens tested in a saturated condition is reached.

4.3 Effect of Testing Machines

Compression testing machines used by RMC plants in Riyadh are manually-operated and old. They are mostly made in USA, England, Germany, and Italy with manual control of the rate of loading. All machines have been calibrated in the last six months as indicated by the calibration stickers attached to them. Figure 7 shows typical type and condition of compression machines used by the RMC plants in Riyadh.

The performance of compression testing machines was evaluated by comparing the results from the plants standard testing (PSP) to the KSU reference samples. Figure 8 shows the difference of PSP from reference (KSU) as percentage of the reference for each of the 13 laboratories investigated. The figure shows also the ±5 limits and ±10% limits used to judge the differences. From this figure, eight plants were found to have results of compressive strength under standard testing in good agreement with the reference (in the range of ± 5%) with 6 out of 8 plants given a difference of less than 1.5%. Five RMC plants were found to give questionable or non-matching results with all five given lower values than reference. Therefore, it can be stated that 5 out of the 13 plants investigated (38%) are using defective or inaccurate compression testing machines.

Top

The high percentage of defective or inaccurate compression testing machines points to a potential problem with the veracity of calibration certificates issued by some independent laboratories providing calibration services in Riyadh. However, the following additional factors are known to decrease the strength results and are not detectable by normal calibration procedures:

- Faults associated with platens cube interface conditions
- Load indication faults not shown by BS 1610 calibration
- Faults in the platen stability not shown by strain cylinder measurement

Most of these faults have been recognized and rectified in the new generation of compression testing machines [Denton, 1976].

4.4 Effect of Sampling, Curing and Testing Procedures Combined

The reliability of compressive strength testing by RMC plants can be assessed by comparing the test results of plant samples (PS) with the reference samples tested at KSU. Figure 9 shows the difference of PS from reference (KSU) expressed as percentage of the reference for each of the 13 laboratories investigated. The comparison reflects the combined effects of variation in sample preparation, molds, fabrication, curing and testing. To clarify the influence of testing machine, the FSP sample is shown on the figure. Also, the ±5 and ±10% limits are shown as a guide to judge the differences. It should be pointed out that those ± 5% limits maybe too stringent for judging the difference since other factors besides the testing machine are involved. However, a difference of about ±10% or more may indicate a genuine problem with the strength testing by the RMC plant.

The data in Figure 9 show that for PS sample, differences near or exceeding the 10% limits are registered by 7 out of 13 plants (54%). Four of these plants are those already found to have inaccurate or defective machines. Also, the figure shows 5 plants with results exceeding the reference by more than 5%. This increase was not expected as both PSP and PCP samples for all plants were similar or less than reference. The cause of this increase is most likely due to drying the test cubes prior to testing as drying is one of the few testing discrepancies which cause increase in the apparent strength of concrete specimens.

These results means that more than half the plants investigated have a problem with their compressive strength testing. This very high percentage is surprising and indicates a low degree of reliability of the plant testing. This clearly demonstrates the urgent need for accreditation scheme for testing laboratories including those of the RMC plants. Regulating the testing laboratories in the Kingdom will assure the reliability of testing and encourage improvement and professionalism.

Top

5. CONCLUSIONS AND RECOMMENDATIONS

In this paper, the results of an inter-laboratory study carried out to assess the reliability of strength testing by RMC producers in Riyadh are reported. Based on the results of this study, the following conclusions can be made:

1. Standard procedures for sampling, curing and testing concrete are not followed by most RMC plants. Testing concrete cubes in a dry condition and the use of fast rate of loading are very common testing irregularities.
2. Significant number of RMC plants have problems with their concrete testing machine. Testing machines in five out of 13 plants investigated (38%) were found to be inaccurate.
3. The percentage of plants with results not matching the KSU-reference sample was found to be 54%. This very high percentage points to a serious problem with RMC plant sampling and testing practice and indicates low reliability in the plant testing.

The results of this research make it clear that concrete testing by RMC plants is bad. The performance of commercial testing laboratories is suspected to suffer from similar problems. Therefore, independent evaluation of testing laboratories in the Kingdom is required. Also, accreditation scheme for material testing laboratories including concrete testing is urgently needed to ensure the quality of testing and to restore the integrity of testing laboratories.

ACKNOWLEDGEMENT

The authors wish to express their appreciation to the Municipality of Riyadh for providing them with the opportunity to work as consultants to the Quality Scheme for RMC in Riyadh. The cooperation and assistance of the rest of the scheme management team is also gratefully acknowledged. This study was funded by KACST under Grant No. LG-1-54. The help of the staff at the Concrete Laboratory of King Saud University and the cooperation of the participating laboratories is gratefully acknowledged.

REFERENCES

1. Akers, D. J., 1990, Testing Practices Affect Concrete's Perceived Quality, *Concrete International*, No. 4, pp.42-45.
2. Alhozaimy, A, Al-Negheimish A., "Introducing and Managing Quality Scheme for RMC Industry in Saudi Arabia," *J. Construction Engineering and Management*, *ASCE*, V.125, No. 4, July-Aug. 1999, pp. 249-255.
3. Al-Negheimish A, Alhozaimy, A., and Al-Kharashi, I., 1999, "Proposed plan for implementing quality scheme for the RMC industry in Saudi Arabia," *Proceedings, Fifth*

Top

Saudi Engineering Conference, V. 3, pp. 49-58. Umm-Al-Qura University, Makkah Al-Mukramah. (In Arabic).

4. Al-Negheimish A. and Alhozaimy, A., 2001, “Ready-mixed Concrete Problems Associated with Hot and Dry Weather in Riyadh,” Final Report, King Abdulaziz City for Science and Technology (KACST), Grant No. LG-1-54, Riyadh, Saudi Arabia.
5. ASTM, 2001, Section 4: Construction, American Society for Testing and Materials, Philadelphia, USA.
6. ASTM, 2001, Section 14: General Methods and Instrumentations, American Society for Testing and Materials, Philadelphia, USA
7. British Standard Institute, 1983, BS 1881: Part 116, BSI, London.
8. British Standard Institute, 1991, Amendment to BS 1881: Part 116 (AMD 6720), BSI, London
9. Day, K. W., 1995, Concrete Mix Design, Quality Control and Specification, E & FN Spon, London, UK.
10. Dewar, J. D. And Anderson, R. (1988), Manual of Ready-mixed Concrete, Blakie and Son Ltd., London.
11. Denton, P. E., 1976, The technology of compression machines, *Concrete*, pp. 23-26
12. Foote, P., 1975, Comparative cube testing - A review, Concrete, London.
13. Kirkbride, T., 1975, Testing the Testers, *Civil Engineering*, pp.-23-27.
14. Lavon, B., Fradua, M. 1994, When Should Concrete Cylinder Test Results be Questioned?, *Concrete International*, No. 12, pp.43-46.
15. Mindess and Young, 1981, Concrete, Prentice-Hall Inc., New Jersey, USA.
16. Municipality of Riyadh, 1997, Compressive Strength Testing by RMC Plants in Riyadh, Internal Report, Riyadh.
17. Municipality of Riyadh, 2000, Quality Assurance Program for RMC Quality Scheme, Internal Reports 1 through 4, Riyadh.

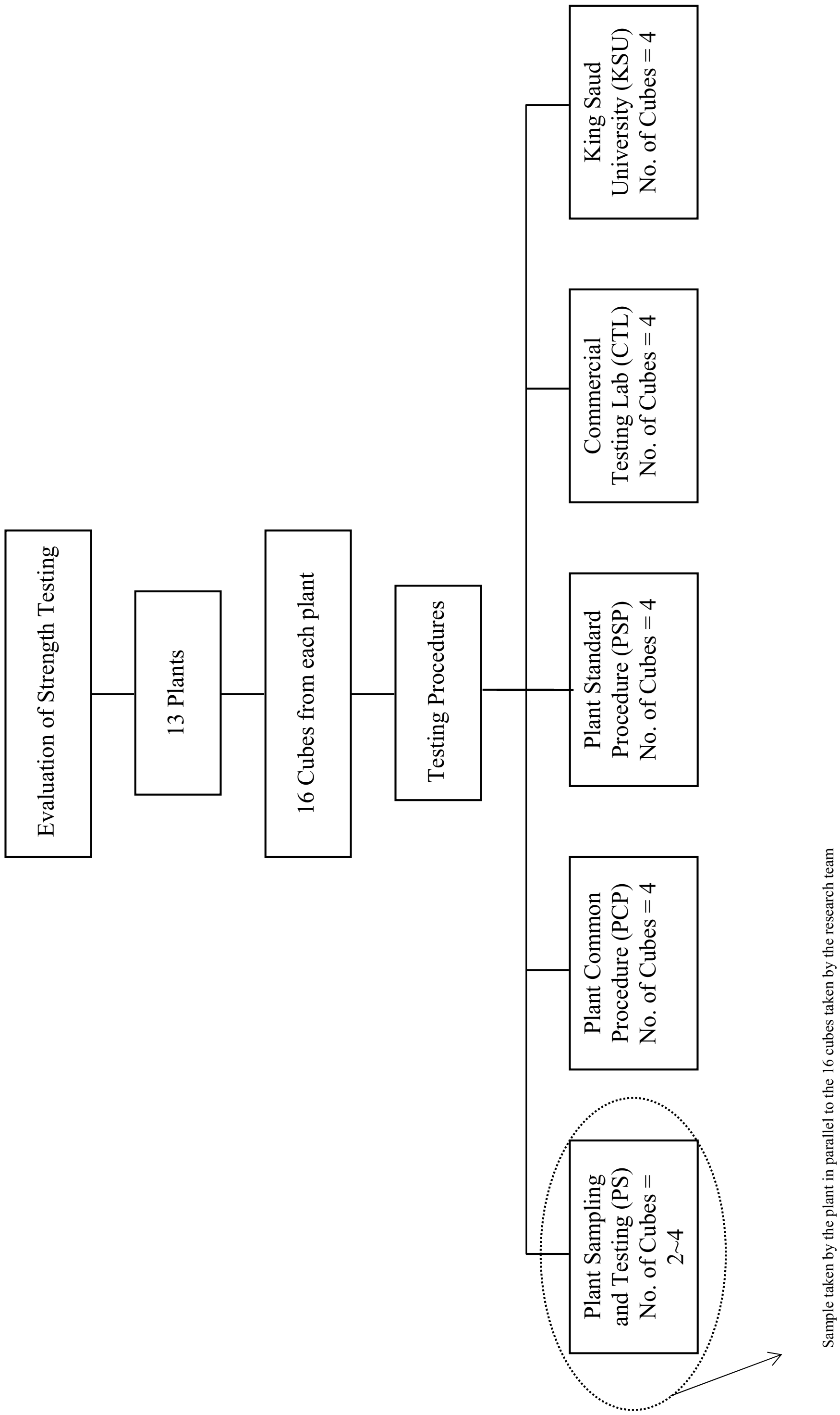


Figure 1. Details of the Inter-laboratories Testing Program

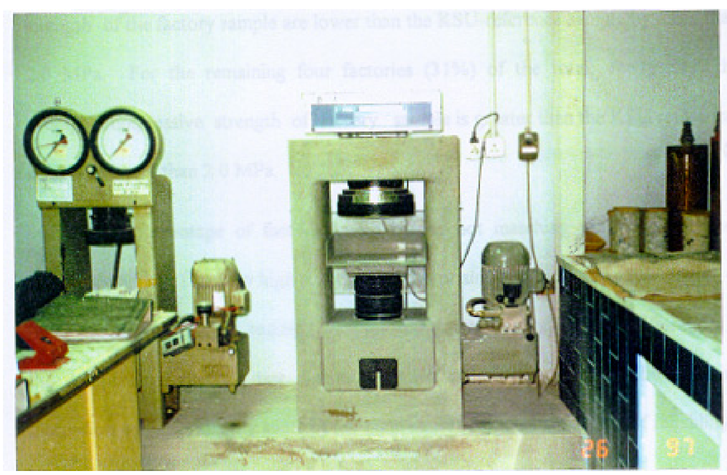
Top

Table 1: Summary of compressive strength test results.

Factory No.	KSU		CTL		FST		FCP		Factory-sample (FS)	
	Strength (MPa)	COV. (%)	Strength (MPa)	COV. (%)	Strength (MPa)	COV. (%)	Strength (MPa)	COV. (%)	Strength (MPa)	COV. (%)
1	28.40	2.63	26.30	3.83	25.20	3.37	26.00	5.74	25.50	1.18
2	41.60	1.95	38.60	1.13	41.60	13.00	42.80	3.13	37.80	11.60
3	40.00	0.55	37.90	2.39	38.70	1.90	39.10	2.45	42.60	2.15
4	35.40	2.45	33.30	2.61	34.50	3.43	35.50	4.31	39.00	2.52
5	36.10	0.72	33.80	1.98	28.30	3.06	28.60	5.24	28.70	3.54
6	34.00	1.67	31.80	2.64	30.60	1.80	29.70	3.79	35.90	16.15
7	37.70	2.44	34.90	3.96	28.20	1.91	25.40	13.35	33.00	12.86
8	49.50	4.76	48.30	5.27	48.80	3.47	47.90	2.74	44.00	1.12
9	43.50	2.33	41.80	0.74	40.50	2.87	41.10	5.47	39.10	4.20
10	34.60	0.80	32.20	2.11	34.60	4.52	35.60	2.30	37.50	2.87
11	52.90	3.34	52.30	1.71	53.40	5.57	53.20	5.73	57.10	0.50
12	49.20	5.19	48.30	3.08	48.70	2.43	48.50	3.58	50.30	6.92
13	40.70	1.72	38.70	2.24	40.50	1.67	40.10	1.43	36.70	6.39
Ave.	**40.28**	**2.35**	**38.32**	**2.59**	**37.97**	**3.77**	**37.96**	**4.56**	**39.02**	**5.54**

Top

a) Testing machine at KSU



b) Testing machine at CTL

Figure 2: Testing Machines used at KSU and CTL.

Top

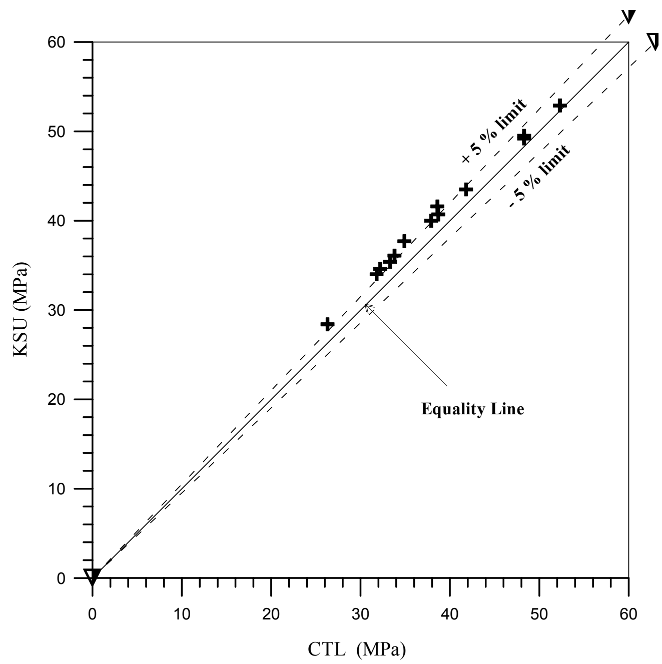


Figure 3: Comparison of KSU vs. CTL Test Results.

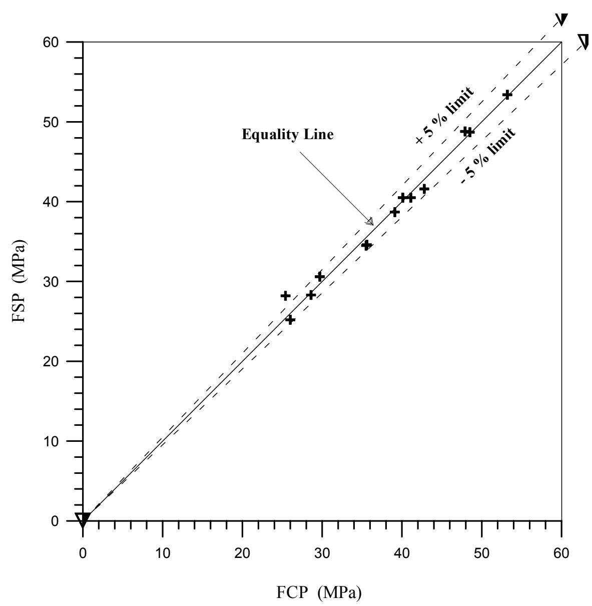


Figure 4: Comparison of PCP vs. PSP Test Results from all laboratories.

Top

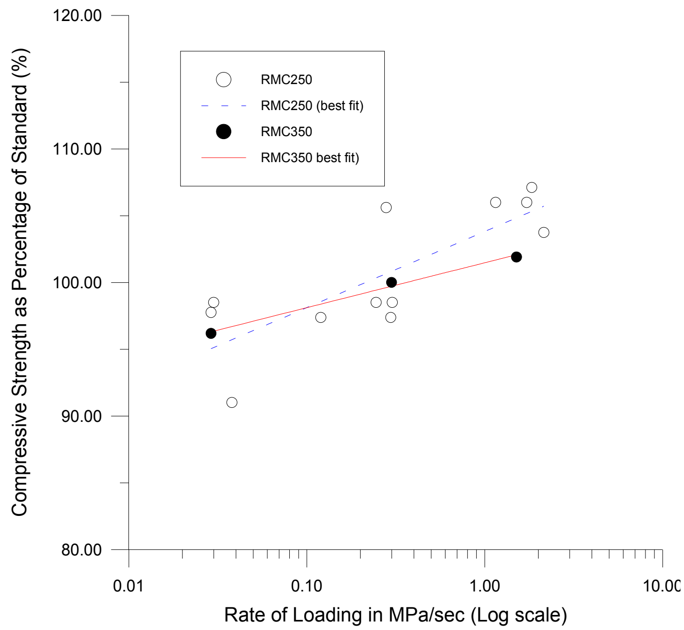


Figure 5: Effect of rate of Loading on the Compressive Strength of Concrete.

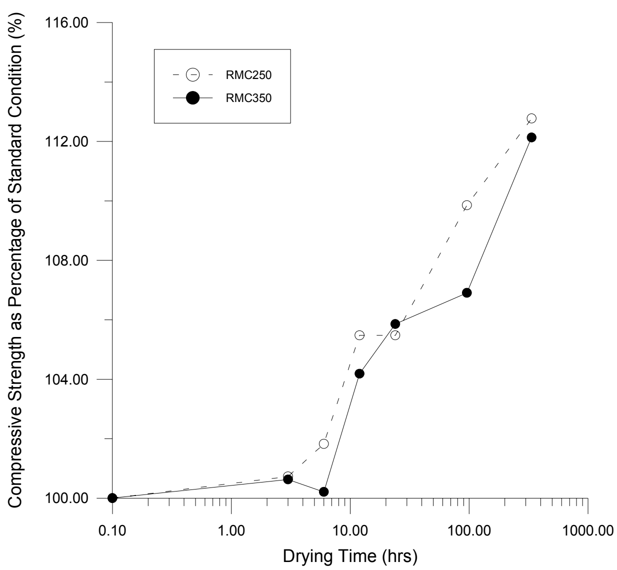
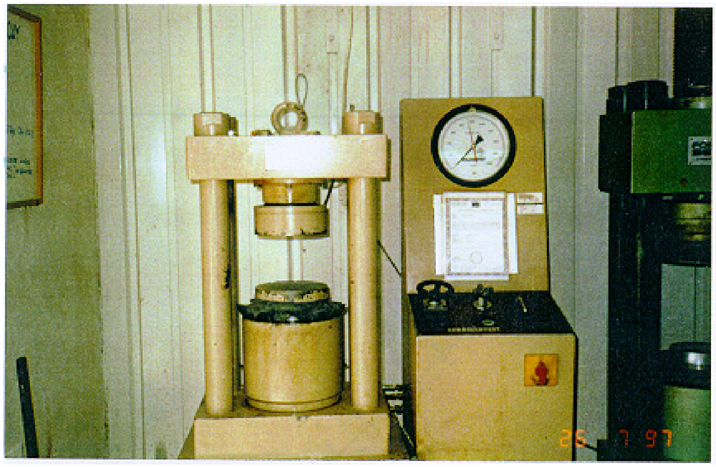
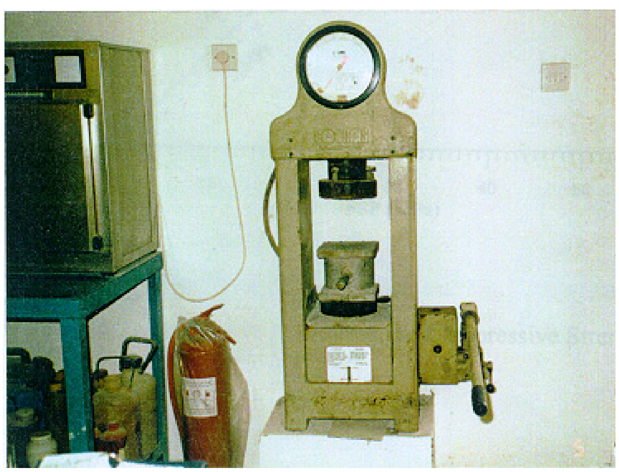


Figure 6: Effect of Period of Air-drying prior to Testing on the Compressive Strength of Concrete.

Top



a) Old but well-maintained testing machine



b) Old and out-dated testing machine

Figure 7: Typical Testing Machine at RMC plants.

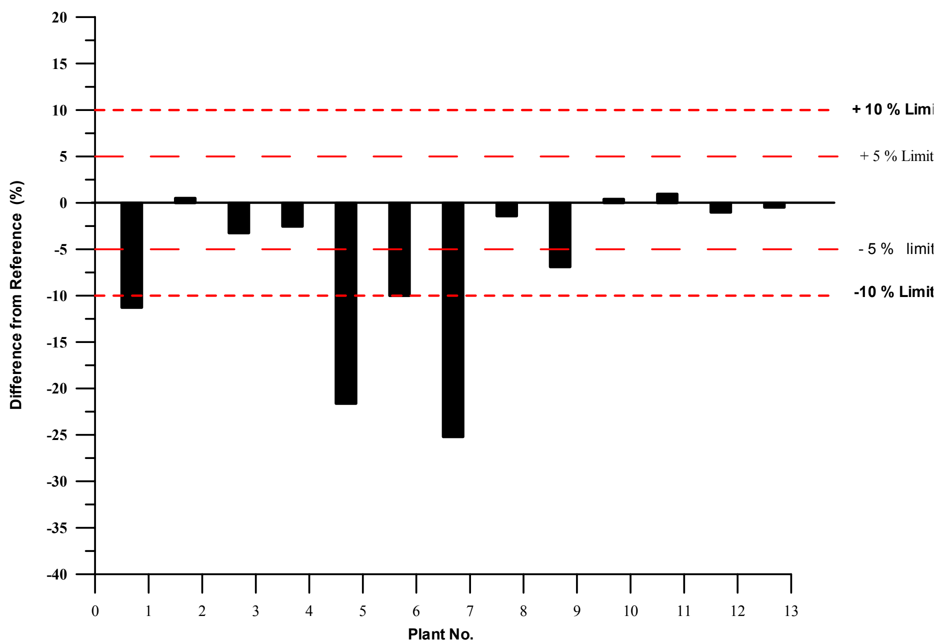


Figure 8: Variation of Plant Standard Testing (FSP) Compared to Reference (KSU) as a Percentage of Reference for all RMC Plants.

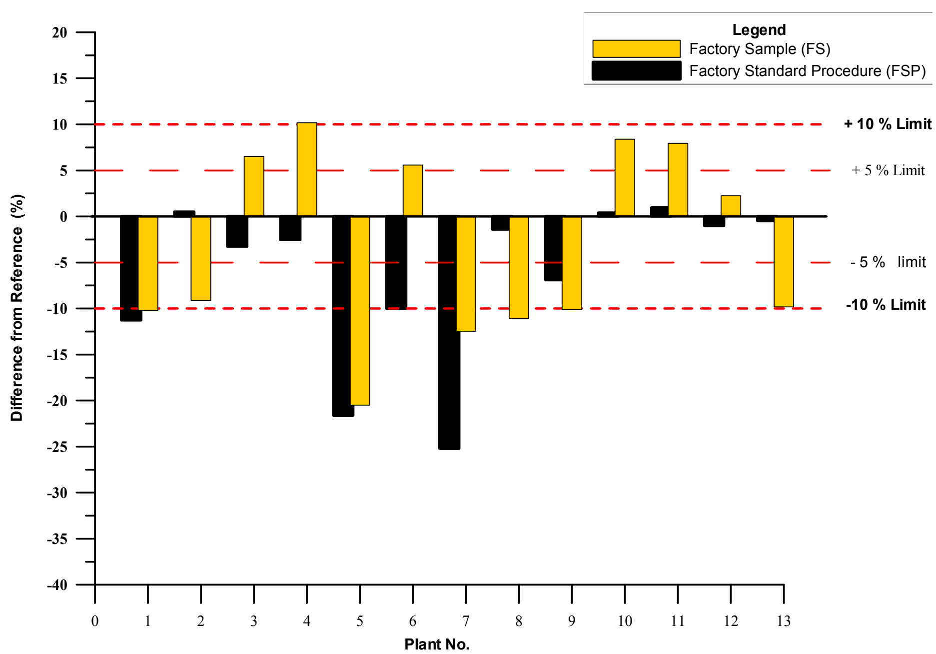


Figure 9: Variation of Plant Sample (PS) Compared to Reference (KSU) as a Percentage of Reference for all RMC Plants.

Top