International Journal of Structural and Civil Engineering Research

ISSN 2319 – 6009 www.ijscer.com
Vol. 2, No. 4, November 2013

Research Paper

DETERMINATION OF FLOW RATE OF WATER IN CONCRETE BY RILEM TUBE METHOD

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The Concrete is today's main building material. Our age of globalization requires a stable and fully-functional infrastructure that connects people and markets. This infrastructure is based on concrete. Modern road and bridge construction would be inconceivable without concrete, as would skyscrapers and industrial buildings. Bigger, higher, wider the global construction boom constantly sets new challenges for materials and technology, as the size and number of buildings increase. That's why concrete will remain the Number one building material in the future. The Water is the primary agent of deterioration and cause of many physical processes of deterioration, or it can be a vehicle for transport of aggressive ions which cause chemical process of deterioration. The movement of water in concrete is controlled by the permeability of concrete. Permeability is the most important indicator of durability of concrete. The Concrete is a versatile building material, used especially in civil engineering in combination with steel. However, concrete and steel are vulnerable to harmful substances that penetrate into the building material by means of moisture. This can result in costly concrete damage due to reinforcement corrosion. This is an undesired characteristic and can lead to deteriorating outcomes, affecting its physical functionality, aesthetics and durability in service life. The Only effective preventive measures such as hydrophobic impregnation provide reliable protection for concrete structures in turn prolong service life and durability. Thus in the present investigation an attempt has been made to study the effectiveness and performance of Impregnate material on rate of flow of water in concrete with two different Grades of concrete and hydrophobic impregnates by conducting RILEM tube test method. Results will provide comparative data to analyze and determine the difference in performance between the impregnate materials, and identify the most effective performing agent.

Keywords: Water ingress, Durability, Flow rate of water, Impregnation, Hydrophobicity, RILEM tube test

INTRODUCTION

The Water has long been associated with deterioration processes affecting Concrete or steel, and masonry materials. Its presence within the interior pore structure of concrete can result in physical destruction if the material

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undergoes wet/dry or freeze/thaw cycling. The latter is particularly damaging if the masonry material has a high clay mineral content. The Moisture is probably the primary ingredient for the deterioration of brick. Moisture, as the catalyst to deterioration of brick, can cause the following: create or magnify doors, carry harmful pollutant gases into the envelope, Magnify the effects of spalling from freeze-thaw cycles, cause wood studs, blocking, and structural members to rot, Encourage growth of biological organisms (mold, mildew), Cause steel stud backup, ties, and masonry reinforcing to corrode, dissolved latent salts and deposit them on the surface as efflorescence, and cause finishes on the inside of exterior walls to fail prematurely and to strain. Perhaps of greater importance is the fact that the presence of moisture is a necessary precondition for most deterioration processes. Pollutant gasses are harmful when they are dissolved in water; fluorescence phenomena are dependent on the migration of salts dissolved in water; moisture is a requirement for the growth of biological organisms. Because of these factors, the water permeability of a concrete material is related to its durability. Results obtained using Test method 11.4 can be used to predict potential vulnerability of untreated, un-weathered concrete or masonry materials to water-related deterioration. Test method 11.4 can also provide useful information when carried out on weathered masonry surfaces. The Water permeability of a material is affected when its surface is obscured by the presence of atmospheric soiling or biological growth, or when there are hygroscopic salts within the interior. The formation of a weathering crust due to mineralogical changes occurring on the exposed (weathered) surface may substantially affect water permeability measurements. By comparing data obtained on masonry that has been exposed to the elements with measurements made on un-weathered samples, it is possible to measure the degree of weathering that has occurred. Finally, RILEM Test method 11.4 can be used to evaluate the performance of a water repellent treatment. An effective treatment should substantially reduce permeability of the masonry material to water. By doing so, the treatment will reduce the material's vulnerability to water-related deterioration. A comparison of test results obtained on treated masonry samples with those obtained on untreated samples provides information about the degree of protection that can be provided by the water repellent treatment. The RILEM tube test is time consuming because it test only a very small area (approximately 1 square inch) at a time and is representative of only that small area. This is especially true when only one RILEM tube is used. In fact some professionals believe that this type of test is not accurate, dependable, or reliable because the pressure on the surface being tested is not constant. However, the general consensus seems to be that the varying pressures caused by changing water levels in the tube are consistent with actual wind conditions because wind does not blow at a steady velocity. The changing levels of water in the tube are caused by the masonry absorbing the water, which lowers the water level and consequently, the pressure in the tube replacing lost water. Its known fact that, replacing lost water in the tube increases the water level and pressure accordingly. There are also variations in the RELIM tube design that allow it to be used to test water absorption of concrete unit masonry and concrete. The term "RILEM", is the acronym for Reunion Internationale des Laboratoires D'essais et de Recherches sur les Materiaux et les Constructions (RILEM) is the International Union of Testing and Research Laboratories for Materials and Structures. As with our American Society for Testing and Materials (ASTM), Technical Committees are formed within RILEM to develop standard methods for measuring properties and evaluating the performance and durability of many different building materials. One such technical committee, Commission 25-PEM, has developed tests to measure the deterioration of stone and to assess the effectiveness of treatment methods. The standard tests drafted by Commission 25-PEM fall within several categories, including methods for determining internal cohesion (III.), for measuring mechanical surface properties (IV.), and for detecting the presence and movement of water (II.). Test method No.11.4 is designed to measure the quantity of water absorbed by the surface of a masonry material over a definite period of time. RILEM Test Method 11.4 provides a simple means for measuring the rate at which water moves through porous materials such as masonry. The test can be performed at the site or in the laboratory and can be used to measure vertical or horizontal water transport. Water permeability measurements obtained in the laboratory can be used to characterize un-weathered, untreated masonry. Measurements made at the site (or on samples removed for laboratory testing) can be used to assess the degree of weathering that the material has undergone. Test method 11.4 can also be used to determine the degree of protection afforded by a water-repellent treatment. A description of the equipment and procedure for conducting this test is provided in paragraphs below. The theoretical basis for the method and interpretation of test data are discussed. In further investigation to the porosity and water absorption of these concrete cubes, the RILEM tube test is then carried out to help determine which form of impregnate material preforms most efficiently.

LITERATURE REVIEW

It is a well-known fact that buildings, bridges, aqueducts, monuments, statues, carved facades and other structures which constitute Europe's cultural heritage are subject to varying degrees of cosmetic damage as a result of the combined effect of natural weathering and deposition of industrial pollutants. Ironically, pollution is a product of industrial growth, a sign of prosperity in industrialized countries. Some of the structures often become damaged to the extent that there is loss of strength and danger to the public. The general problem of weathering has been recognized for many years. For example, the Building Research Establishment first published '*The Weathering of Natural Building Stones*' in 1931 which was reprinted in 1972 as inferred by (Schaffer, 1972). The application of surface treatments has become recognized as one of the most practical methods of conserving historic structures. Various types of protective treatments have been developed over the years, varying from natural materials such as lime washes to polymeric coatings. Heritage organisations responsible for the maintenance of structures tend to prefer the former, but these have the disadvantage of coloring in turn whitening the surface of the stone, and require to be reapplied at regular intervals. Many types of sophisticated polymers and protective coatings are now commonly used in many countries to counter the problem of stonework degradation due to natural weathering or to prevent premature corrosion of steel reinforcement in highway concrete bridges. Most have the advantage of not changing the original color of the surface. However, these new treatment materials have finite lives and therefore need to be renewed after approximately 15 years due mostly to degradation caused by the effects of ultra-violet radiation (Pefer and Scali, 1981; Sauder and Rauber, 1995). There has been considerable interest in developing methods for assessing the performance of surface treatments which can enable owners of structures to appreciate when treatment has been properly applied or when the need arises to re-treat an already treated but subsequently weathered surface. For instance, Whiting *et al.* (1992) investigated methods of evaluating the effectiveness of penetrating sealers as part of an SHRP program. The National Bureau of Standards (Skeater, 1997), Heritage Institutions and the European Commission (Tilly *et al.,* 1996; Vanhees *et al.,* 1995) have all sponsored investigations involving methods of assessing the efficacy of coatings on porous building materials in recent years. Other examples include the EC programs on the 'effects of air pollution on listed buildings' [1986-1990], the STEP program on the 'Protection and Conservation of the European Cultural Heritage' [1989-1992], EC environmental program on the 'Environmental Protection and Conservation of Europe's Cultural Program' [1991-1994]. Further investigations have also been carried out on the efficacy of surface treatments on different historic structures in England (Butlin *et al.,* 1991), and other European countries (Litman *et al.*, 1993; Ross *et al.*, 1990). Literature on this subject reveal an array of previous research and published works focused mostly on laboratory-based and destructive site methods (Ross *et al.*, 1990; Metz andKnofel, 1992; Gerdes, 1995; Bunte and Rostasy, 1989; Wendler *et al.,* 1993). A few standard recommendations exist for non-destructive site assessment of surface-treated structures. However, a good number of these, including that proposed by RILEM (1980), are based on the use of a single test method, which can only provide a partial and sometimes ambiguous picture of the condition of the treated surface. The moisture content of a surface is an important indicator of the state of wetness of the substrate. It is a useful parameter in interpreting the results from all the other test methods. Measuring a parameter of free water in the solid directly which provides information on moisture content of a solid materials. The permitivity of water is far higher than that of most other materials used in the construction industry. This, therefore, suggests that the accuracy of the measurement may only be affected by the presence of other materials with permitivity values comparable to that of water or salts. The equipment used for this test was a commercial moisture meter comprising of a sensor and microprocessor. Measurements were made by placing the equipment on the test surface and noting the digitally displayed moisture content value. Three sets of measurements were taken, each having at least 20 readings. Consistency in measurement was insured by taking the readings on a pre-determined grid at a density of 200/m^2. Previous laboratory work by the authors (Nwaubani *et al.,* 1997; Nwaubani, 1999) have shown that in turn high moisture content indicates that the surface is probably untreated, or that the treatment has become ineffective, or simply an indication of moisture entering the substrate via untreated areas; and at areas near ground level, high moisture content may be due to water infiltrating from below ground level by capillary action.

The water absorption test provides a measure of the susceptibility of the surface to take up water through the exposed surface. The test was carried out using the standard Karsten tube, which is a graduated tube with a diameter of 2.7 cm and 4-ml capacity. At the bottom there is an opening of 2.5 cm, which makes contact with the test surface as described in RILEM Commission 25-PEM procedure 11.4 (RILEM, 1980). The test is conducted by attaching the Karsten tube to the test surface using a commercial modelling clay; filling the tube with water, and recording the volume of water absorbed after 1, 2, 3, 4, 5, 10, 15, 20, 30, 45 and 60 min. The following numerical and qualitative criteria established from their previous study Nwaubani, 1999) was used in the assessment of the results confirmed that, water absorption as measured using the Karsten tube and RILEM procedure, of freshly treated stone, irrespective of whether the treatment is hydrophobic or consolidating, is typically 0.35 kg/m^2/ h. It's also confirmed from results that a high moisture content of about 0.35 kg/m^2/ h, indicates that the surface is probably untreated, or that the treatment has become ineffective, or simply an indication that moisture is entering the substrate, via untreated areas. Further more rapid absorption of a water drop is indicative of no treatment, or an ineffective treatment and the presence of a long incubation phase period during which no water is absorbed by the surface is an indicative of an effective treatment. Total absence of an incubation period or a very short incubation period suggests that surface treatment is absent or ineffective. Thus finally the interpretation of shape of the water absorption curve against time also provides information about the effectiveness of the treatment. The objective of this investigation was to verify the practicability of the proposed methods under field conditions. An appraisal of the surface condition of stone structures previously treated with hydrophobic and or consolidating compounds is presented.

The concrete is a well-known construction material in civil engineering practice used in many forms and applications. However concrete suffers from being a porous material, allowing moisture to penetrate the surface and enter through its surface pores. This is an undesired characteristic which could lead to deteriorating outcomes, affecting its physical functionality, aesthetics and durability in service life. In fact application of impregnate materials treatment have been developed to protect building materials such as masonry and concrete from water ingression which in turn will prolong service life and durability. The hydrophobic impregnate materials is the one which lines the surface pores providing protection from water ingress, but allows the substrate to breathe, moisture to diffuse out and not become trapped internally. Thus in the present research work an attempt was made to investigation, the effect of Hydrophobicity by considering two different Grades of concrete and hydrophobic impregnates in case of RILEM tube test to procure rate of flow of water with differential time duration without hydrophobic impregnate material.

EXPERIMENTAL PROGRAM

In order to achieve the objectives, a series of tests such as RILEM tube test could be carried out to evaluate the effectiveness of impregnation in case of impregnated as well as control concrete cube. In fact both tests were to be conducted within laboratory conditions on concrete cubes of size 100 mm^3. In which considered two Grades of concrete (C30 and C40) and produced total number of 24 concrete cubes, where in which split up into two groups of 12 for each Grade of concrete. Also selected two types of impregnate material such as Solvent Based (SB) as well as Water Based (WB) impregnant material for this investigations. To determine the effectiveness of these two impregnants, these concrete cubes will be divided into three groups such as solvent based impregnation, water based impregnation and a control variable. These cubes will undergo a series of experiments to produce comparative data to determine which form of impregnant performs the most effective. The concrete cubes will be tested via RILEM test tube, before and after impregnation is applied. For this investigation produced 24 numbers of concrete cubes, sized at 100 mm^3, with 12 cubes forming C30 and the other 12 at C40. These concrete cube samples have been made as per British Standards. The mixture ingredients used for the production of concrete cubes are as shown in the Table 1. After 28 days of curing the concrete cube needs to be fully dried and preconditioned before any tests. This requires the concrete specimens to be placed in an oven to dry off and eliminate any internal moisture that may have been left in. The oven is set at 100°C and dried overnight and wiping down the sample surface ensures that any loose aggregate is removed and therefore not considered within the results.

WATER ABSORPTION (RILEM TUBE TEST)

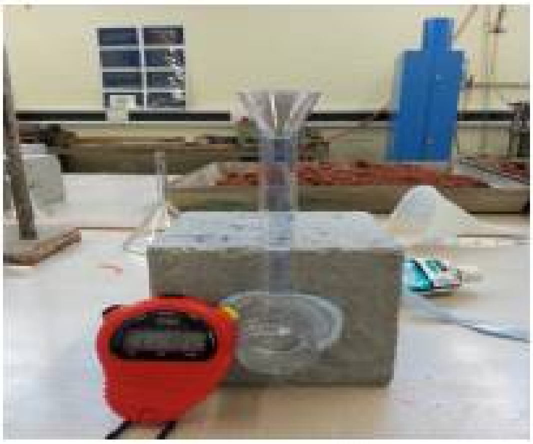
The RILEM Tube test method is also a standard water absorption test performed under low pressure in conformity with the method outlined in RILEM 25-PEM, Test 11.4(RILEM, 1980). It consists of a graduated glass tube as shown in (Figure 1), which is sealed against the surface under test with a commercial modelling clay or putty. During a test, the tube is filled with distilled water to a

Table 1: Mix Proportions of Concrete (kg/m^3)

Concrete (Grade)	Water (kg)	OPC (kg)	Sand (kg)	Aggregate (kg)	Total Mass (kg)
C30	2.3	4.3	8.9	14.3	29.8
C40	2.0	3.4	9.4	14.2	29.0

known level. The water level decreases as it is absorbed into the substrate. The volume of water absorbed is measured at 5, 10, 15, 20, and 30 min in case of Control and impregnated concrete cubes of size (100 x 100 x 100) mm. The testing apparatus is affixed by interposing a tape of putty between the flat, circular brim of the pipe and the surface of the concrete cube. To ensure adhesion, manual pressure is exerted on the cylinder. Water is then added through the upper, open end of the pipe until the column reaches the 0 gradation mark. The quantity of water absorbed by the material during a specified period of time is read directly

Figure 1: RILEM Tube Test



from the graduated tube. The periods of time appropriate for the test depend on the porosity of the material on which the measurement is being made generally 5, 10, 15, 20, 30 and 60 min intervals provide the most useful data.

DISCUSSION ABOUT RESULTS

The RILEM tube test was simple test procedure, which assess the rate of flow of water ingress under low pressures within a short period of time. This experiment is influenced by the area of the chamber of the tube in contact with the concrete, this means that the investigation is only limited to a small area of the cubes surface. Where water travels through substrates via the surface pores and the RILEM tube test is only limited to a small area in contact with the concrete. This test is also heavily influenced by the quality of the surface under testing. It is impossible to produce perfect or identical concrete samples (sizes of pores) under testing will affect the quality of results. The results show that in case of both Grades of concrete, C30 and C40, the first four cubes suffer from higher rates of water ingression, as they do not have any impregnant materials applied on its surfaces. The results also indicate that significant effects in performance from the application of impregnants, providing protection from water penetration through the surface pores. In reference to cubes samples 1-4 on average, concrete grade C40 undergoes a higher rate of water penetration than in C30. As it was earlier identified that, if the graduation of the water level decreases 20% or more within 20 min, it is considered as a failure. Where 20% of the tube is marked at the 1 ml graduation, the results suggest that the C40 concrete control cubes have experienced failure whereas in C30, it can be identified that none of the concrete samples can be considered as failed. The readings from the control samples tested using the RILEM tube test method indicate that, a steady ingress of water down the tube and into the substrate material. It can be observed from Figures 2 and 5, that C40 experiences more water passing through the substrate than in C30, this is shown as the divisions of milliliters along the y-axis of the graph. Also from Figures 3-4 and Figure 5, the effects in performance from solvent-based impregnation are considered more consistent within C30 than C40. It is also found that from the RILEM tube test, the water-based impregnant works just as efficiently as the solvent based over the C30 concrete. In reference to the results and graphs regarding the C40 concrete, the RILEM results show that the impregnant materials improved its performance in protection of water intrusion. However it was seen that the same quantity of impregnants were added in both concrete grades, the cubes from C40 have shown less consistent results and did not perform as well as C30 concrete. In case of control concrete cubes with Grade of concrete C30 as referred from Figure 1, the rate of flow of water at initial time duration (5 min) and longer time duration (30 min) were found to be is in the range of (0.20-0.30 ml) and (0.60-0.80 ml). Thus there is an overall increase in the rate of flow of water of about (75%) as when compared to initial time duration (5 min).

Figure 2: RILEM Results on Control Samples with C30

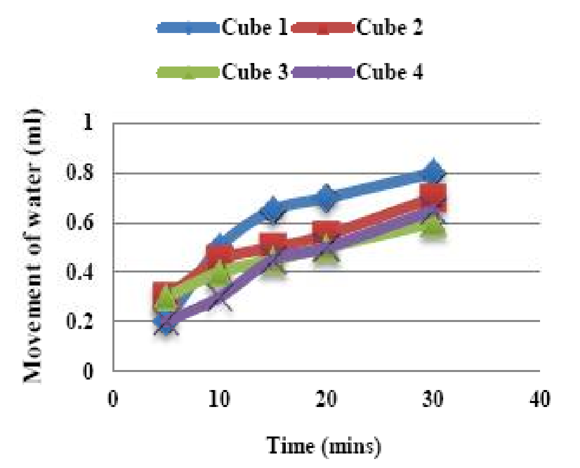


Figure 3: RILEM Results on SB Samples with C30

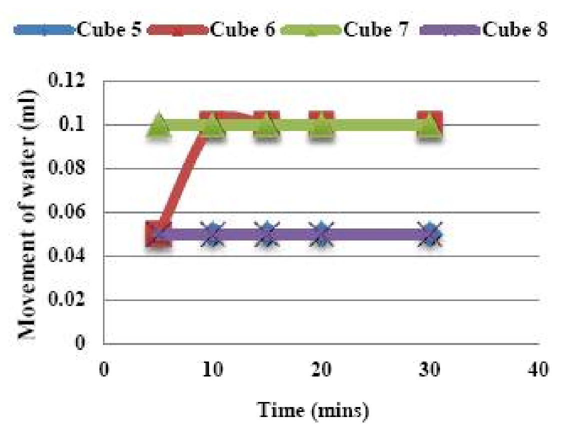


Figure 4: RILEM Results on WB Samples with C30

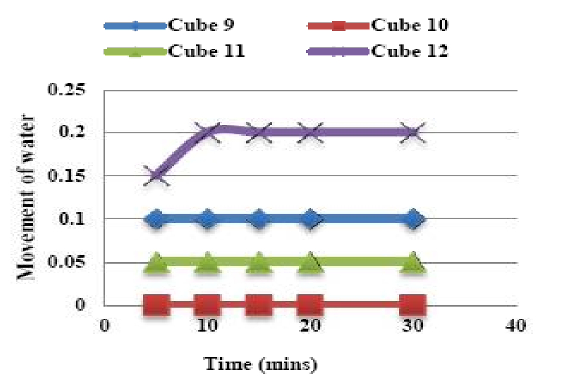
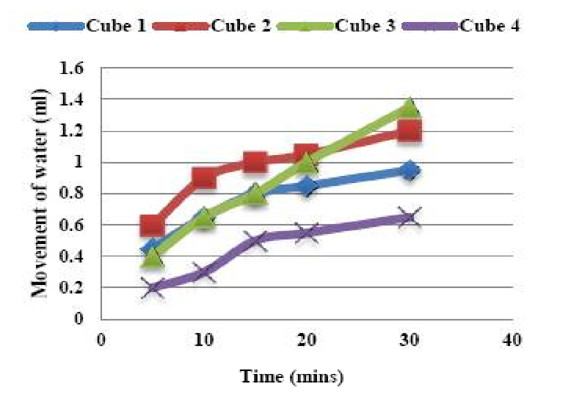


Figure 5: RILEM Results on SB samples with C30



Whereas in the case of control concrete cubes with Grade of concrete C40 as represented in Figure 5, the rate of flow of water at initial time duration (5 min) and longer time duration (30 min) were found to be is in the range of (0.20-0.60 ml) and (0.60-1.30 ml). Thus there is also an overall increase in the rate of flow of water of about (84.61%) at longer time duration (30 min) as when compared to initial time duration (5 min). For in the case of Impregnated concrete cubes (SB) with Grade of concrete C30 as represented in Figure 3, the rate of flow of water at initial time duration (5 min) and longer time duration (30 min) were found to be is in the range of (0.045-0.10 ml) and (0.045-0.10 ml). There is an overall increase in the rate of flow of water of about (55%) at longer time duration (30 min) as when compared to initial time duration (5 min) and attained a constant equilibrium state in the rate of flow of water for longer time duration (30 min). In the case of Impregnated concrete cubes (WB) with Grade of concrete C30 as represented in Figure 4, the rate of flow of water at initial time duration (5 min) and longer time duration (30 min) were found to be is in the range of (0, 0.05, 0.10, and 0.15 ml) and (0, 0.05, 0.1 and 0.20 ml). There is an overall increase in the rate of flow of water of about (50%) at longer time duration (30 min) as when compared to initial time duration (5 min) and attained a constant equilibrium state in the rate of flow of water for longer time duration (30 min). For in the case of Impregnated concrete cubes (SB) with Grade of concrete C40 as represented in Figure 6, the rate of flow of water at initial time duration (5 min) and longer time duration (30 min) were found to be is in the range of (0.1-0.25 ml) and (0.1-0.35 ml). There is an overall increase in the rate of flow of water of about (22.20%) at longer time duration (30 min) as when compared to initial time duration (5 min) and attained a constant equilibrium state in the rate of flow of water for longer time duration (30 min). In the case of Impregnated concrete cubes (WB) with Grade of concrete C40 as represented in Figure 7, the rate of flow of water at initial time duration (5 min) and longer time duration (30 min) were found to be is in the range of (0.2-0.5 ml) and (0.3-0.70 ml). There is an overall increase in the rate of flow of water of about (50%) at longer time duration (30 min)

Figure 6: RILEM Results on SB Samples with C40

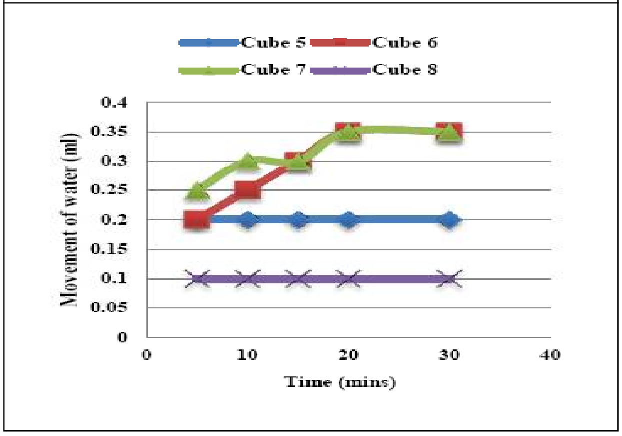
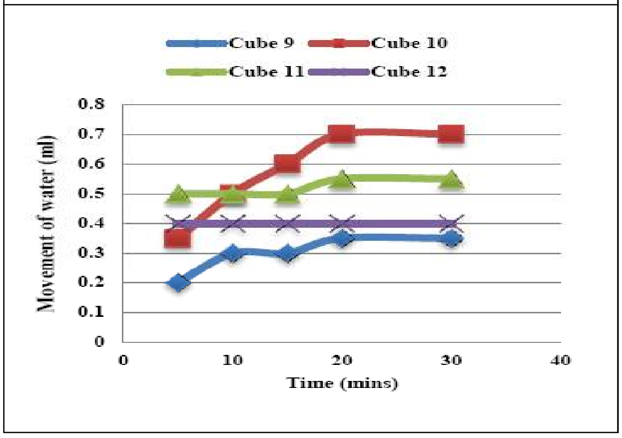


Figure 7: RILEM Results on WB Samples with C40



as when compared to initial time duration (5 min) and attained a constant equilibrium state in the rate of flow of water for longer time duration (30 min).

CONCLUSION

1. The results obtained from experiment by RILEM tube test method, it can be determined that the Solvent-Water based impregnant with C30 performs more effectively in the protection of water penetration than C40, and this is represented by its consistency throughout the testing in both Grades of concrete.
2. In case of control concrete cubes with Grade of concrete C30, the rate of flow of water at initial time duration (5 min) and longer time duration (30 min) were found to be is in the range of (0.20-0.30 ml) and (0.60-0.80 ml). Thus there is an overall increase in the rate of flow of water of about (75%) as when compared to initial time duration (5 min). Whereas in the case of control concrete cubes with Grade of concrete C40, the rate of flow of water at initial time duration (5 min) and longer time duration (30 min) were found to be is in the range of (0.20-0.60 ml) and (0.60-1.30 ml). Thus there is also an overall increase in the rate of flow of water of about (84.61%) at longer time duration (30 min) as when compared to initial time duration (5 min).
3. For in the case of Impregnated concrete cubes (SB) with Grade of concrete C30, the rate of flow of water at initial time duration (5 min) and longer time duration (30 min) were found to be is in the range of (0.045-0.10 ml) and (0.045-0.10 ml). There is an overall increase in the rate of flow of water of about (55%) at longer time duration (30 min) as when compared to initial time duration (5 min) and attained a constant equilibrium state in the rate of flow of water for longer time duration (30 min). In the case of Impregnated concrete cubes (WB) with Grade of concrete C30, the rate of flow of water at initial time duration (5 min) and longer time duration (30 min) were found to be is in the range of (0, 0.05, 0.10, and 0.15 ml) and (0, 0.05, 0.1 and 0.20 ml). There is an overall increase in the rate of flow of water of about (50%) at longer time duration (30 min) as when compared to initial time duration (5 min) and attained a constant equilibrium state in the rate of flow of water for longer time duration (30 min).
4. For in the case of Impregnated concrete cubes (SB) with Grade of concrete C40, the rate of flow of water at initial time duration (5 min) and longer time duration (30 min) were found to be is in the range of (0.1-0.25 ml) and (0.1-0.35 ml). There is an overall increase in the rate of flow of water of about (22.20%) at longer time duration (30 min) as when compared to initial time duration (5 min) and attained a constant equilibrium state in the rate of flow of water for longer time duration (30 min). In the case of Impregnated concrete cubes (WB) with Grade of concrete C40, the rate of flow of water at initial time duration (5 min) and longer time duration (30 min) were found to be is in the range of (0.2-0.5 ml) and (0.3-0.70 ml). There is an overall increase in the rate of flow of water of about (50%) at longer time duration (30 min) as when compared

to initial time duration (5 min) and attained a constant equilibrium state in the rate of flow of water for longer time duration (30 min).

REFERENCES

1. Bunte D and Rostasy F S (1989), “Test methods for on-site durability of structure”, Proceedings of the IABSE Symposium, V.57, No.2. Lisbon, pp. 335-340.
2. Butlin R N *et al*. (1991), “Studies of preservative treatments on historic buildings”, Proceedings of the European Symposium on Science, Technology and European Heritage, Bologne.
3. Gerdes A (1995), “Assessment of water repellent treatments by the application of FT-IR spectroscopy”, First International Symposium on Surface Treatment of Building Materials with Water Repellent Agent. Delft, November,12-1-12-9.
4. Littmann K, Sasse H R, Wagener S and Hocker H (1993), “Development of polymers for the consolidation of natural stone”, Proceedings of the International RILEM/UNESCO Congress on Conservation of Stone and Other Materials. Paris, pp. 681-688.
5. Metz F and Knofel D (1992), “Systematic mercury porosimetry investigations on sandstones”, *Mater Struct*, Vol. 25, pp. 125-136.
6. Nwaubani S O (1999), “Non-destructive assessment of the performance of surface-treated concrete”, *J Prot Coat Linings,* Vol. 16, No. 1, pp. 42-54.
7. Nwaubani S O and Dumbelton J (1997), “ Influence of polymeric surface treatments on the permeability and microstructure of high strength concrete”, Third Southern African Conference on Polymers in Concrete and ICPIC Workshop. Johannesburg, July, pp. 388-402.
8. Pfeifer D W and Scali M J (1981), “Concrete sealers for protection of bridge structures”, NCHRP report 224, TRB Washington, 1981.
9. RILEM Commission 25-PEM (1980), “Recommended tests to measure the deterioration of stone and to assess the effectiveness of treatment methods”, *J Mater Struct,* Vol. 13, No. 75, pp. 175-254.
10. Ross K D, Hart D and Butlin R N (1990), “Durability tests for natural stone. Proceedings of the Fifth International Conference on Durability of Building Materials and Components”, Brighton, pp. 97-111.
11. Sauder M and Rauber D (1995), “Long-term durability of different water repellent agents applied at the protesta memorial church in speyer during the last 40 years”, First International Symposium on Surface Treatment of Building Materials with Water Repellent Agents. Delft, Germany, November.
12. Schaffer R J (1972), “The weathering of natural building stones”, BRE Special Report, Department of Science and Industry Research, Building Research Establishment Special Report, No. 18.
13. Skeater G A (1997), “Stone preservation:

methods of laboratory testing and preliminary performance criteria", National Bureau of standards, Technical Notes 941.

14. Tilly G P, Nwaubani S O, Sasse H R and Bordado J (1996), "Re-treatment and assessment of consolidated stone faces", EC Contract EV5V-CT94-0518, Final Report, Volume II, European Commission, Brussels.

15. Van Hees R P J *et al.* (1995), "Test methods for the evaluation of the in-situ performance of water-repellent treatments", Proceedings of the First International Symposium on Surface Treatment of Building Materials with Water Repellent Agents. Delft, Holland, Vol. 14, No. 1, pp. 14-16.

16. Wendler E, Klemm D D and Snethlage R (1993), "Consolidation and hydrophobic treatment of natural stone", Proceedings of the Twenty-First International RILEM/UNESCO Congress on Conservation of Stone and Other Materials, Paris, pp. 203-212.

17. Whiting W, Ost B and Nagi M (1992), "Condition evaluation of concrete bridges relative to reinforcement corrosion", Vol. 5: Methods for Evaluating the Effectiveness of Penetrating Sealers. SHRP Report, SGRP-S_FR-92-107, NRC, Washington.