SOME ASPECTS OF EVALUATING CRACKING SENSITIVITY OF REPAIR MATERIALS

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Abstract
The most serious deterioration processes that lead to repair failures are caused by cracking of the repair material. Restrained contraction of repair materials, the restraint being provided through bond to the existing concrete substrate, is a major factor leading to cracking and failure of the repair.

The safety and durability of the repaired structures cannot be realized without a comprehensive knowledge of the material’s properties that determine its deformational characteristics and, therefore, its capability to resist cracking. Material manufacturers tend to use different tests and standards to evaluate the performance of their products. Many standard tests used are modified arbitrarily, some modifications are deficient or providing unrealistic results. This situation has resulted in controversy and confusion in the selection and specification of repair materials. Variations of the test methods including size of the specimens, restraint conditions, curing, time of initial readings, temperature and relative humidity limitations, and test duration further complicate the interpretation of comparative results and properties indicated in manufacturer’s data sheets.

This paper presents analysis of the existing test methods for volume changes of cementitious materials and also discusses new methods. It reviews the ongoing research study in which one of the primary objectives is to develop an industry-wide reliable technique for evaluation of sensitivity to cracking of cement-based materials.

Keywords: Compatibility, concrete, cracking, creep, durability, repair, restraint, shrinkage, test method.
1. Introduction

At present, the durability of concrete repairs is controlled almost exclusively by specifying certain requirements for material composition, certain properties, casting, compaction and finishing procedures, curing, and of course materials compressive strength. This approach frequently yields unsatisfactory results, and it is a common objective of concrete researchers and engineers to develop performance criteria that would allow more reliable estimates of the potential durability of a repaired concrete structure.

It is generally accepted that repair durability is to a large extent governed by repair’s resistance to cracking. The ability of cement based materials to resist and to control cracking has been widely and appropriately accepted as fundamental to satisfy the requirements of material and structural serviceability and durability. Therefore, a criterion that is based upon such resistance should be quite a reliable approach. In the same time it must be realized that the durability of concrete repair cannot be achieved by only minimizing cracking in a repair material. Durability equally depends on the design, in-situ installation and quality control. This paper discusses volume change, one of the fundamental causes of cracking in hardened (maturing) repair materials.

Despite the benefits associated with the use of high strength cement-based materials in some applications, significant problems have been observed including increased brittleness, high autogenous shrinkage, low creep relaxation, and therefore the increased cracking [1,2,3].

Cracks reduce durability, decrease service life, and increase maintenance costs. To adequately repair the deteriorated infrastructure, one has to develop means of evaluating the performance of repair materials with regard to its sensitivity to cracking. This will provide engineers with the tools that are necessary to specify materials which will improve the repair durability.

The paper provides a review of ongoing study aimed on developing testing techniques for evaluation of cracking potential of repair materials.

2. Material Properties and Cracking

Volume stability is a paramount characteristic of any cementitious composite. Volume changes govern the mechanical, physical and durability properties of materials. The problems associated with volume changes in concrete repair are triggered by the restraint provided by existing concrete and reinforcement. Volume changes must be controlled in concrete repairs to minimize cracking. Because the repair is a composite system of materials, its performance depends upon interfacial behavior – compatibility of materials combined in a system, and especially dimensional compatibility.
The importance of dimensional compatibility between existing concrete and repair material was addressed previously [4-5]. The dimensional compatibility of cementitious repair materials with existing concrete substrate determines the repair’s ability to resist cracking and depends upon: (1) the degree of restraint; (2) the magnitude of the shrinkage; (3) the stress state; (4) the amount of stress relief due to creep; (5) the tensile strength of the material and (6) the modulus of elasticity.

In order to have good resistance to cracking, the material should have values of shrinkage, thermal coefficient of expansion, and sustained modulus of elasticity as low as possible and a tensile strength and creep as high as possible.

When a freshly placed and hardened repair material is exposed to ambient temperature and humidity, it experiences both drying and thermal strains. The type and magnitude of the related volume changes will depend on the temperature and humidity of the environment, temperature and absorptivity of the existing substrate, the temperature of the repair mixture, the geometry of the repair and the characteristics of the repair materials. The repair will crack when the induced tensile stress exceeds its tensile strength. It is known, however, that due to the creep behavior, some of the stress is relaxed, and it is therefore the residual stress, which determines whether or not cracking would occur. This interplay, this race between tensile stress generated by restrained shrinkage and the stress relief due to the creep determines whether cracking will occur.

Tests of various repair materials, performed by the authors, demonstrated that shrinkage is unquestionably one of the major causes of cracking in concrete repair. Unfortunately very little research has been directed toward obtaining reliable shrinkage and creep data for design and selection of materials so as to predict repair performance. The main reason for this is the absence of reliable test methods for evaluation of material’s volume changes, degree of its deformability, its sensitivity to cracking. Number of known accelerated tests is of dubious value, and obtaining data in a real time scale can take a lifetime.

Some of the existing methods have various shortcomings mostly attributed to limitations of individual investigations, and/or a failure to recognize variability. It is, therefore, imperative from the point of durability of repaired concrete structures, not only to study the possibilities of reducing volume changes and resulting cracking but also to control it by a suitable test. Work currently underway in the ad hoc North American workgroup C.R.E.E.P. (Concrete Repair Engineering Experimental Program) is concerned with developing testing method(s) for the prediction of future repair performance.

The actual processes of concrete repair deterioration occurring in practice are both very complex and very diverse. This is due to a very large number of possible combinations of the properties of the components of concrete repair system and time sequence or simultaneity of the effect of the most different external and internal factors of aggressive character. From the scientific point of view every method intended for durability testing
must be based on the specifics of concrete repair and mechanisms of its deterioration, mechanics of its durability, even if the technical arrangement of the test makes one seek the simplest possible ways. These considerations necessarily reveal the fact that every method is subject to development. Forecasting the cracking of concrete in repaired structures should be considered the primary task of laboratory tests of concrete repair durability under various conditions.

This requires the following important relations to be solved at the same time:

- Between cracking of repair in structure and the results of accelerated laboratory tests
- Between cracking of repair in structure and of tests specimens under the same conditions

Quantitative evaluation of laboratory tests, of the accelerated ones especially, in relation to reality and from the point of designing repairs with the required durability under conditions defined in advance, has become a task of first magnitude. Every means – no matter how small – of rendering concrete repair technology more exact has an enormous engineering and economic significance considering the present day volume of concrete and concrete repair production per world inhabitant.

One involved in test research and development work, i.e., in moving along the learning curve, should clearly realize that the application of the results of his labors is in the overall repair project framework – for the production of real repaired structure – and should adjust his efforts accordingly.

Following is a review of some of the known shrinkage test methods with comments on their advantages and limitations.

3. Shrinkage Testing Methods

For simplicity the test methods used can be classified in two categories: standard and nonstandard test methods. From the technical point of view, the test methods can be divided in “free” shrinkage and restrained shrinkage tests. One area given for greater attention in this study than in earlier ones was the use of different restrained shrinkage methods. The information on unrestrained (free) shrinkage test methods is summarized in Table 1.

In the United States the most used method is ASTM C 157, “Standard Test Method for Length Change of Hardened Hydraulic Cement Mortar and Concrete”. This method is not recommended for testing the premixed grouts since the initial reading neglects the volume change during the first 24 hours, which can be very substantial, especially for rapid-hardening repair materials. Another problem with this test is that the specimens are not restrained from movement and the ratio of longitudinal to lateral dimensions is far greater than normally encountered in most repair installations.
Table 1. Unrestrained Shrinkage Standard Test Methods

<table>
<thead>
<tr>
<th>Country</th>
<th>Standard/ Specification</th>
<th>Prism Dimensions</th>
<th>Specified Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>ASTM C 157</td>
<td>25.0x25.0x2.85</td>
<td>1.0x1.0x11.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>23°C (73°F), 50% RH</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>BS 1881, Part 5-1970</td>
<td>75.0x75.0x3.10</td>
<td>3.0x3.0x12.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>This standard does not relate to drying shrinkage. Therefore, test conditions are not included.</td>
</tr>
<tr>
<td>Canada (Alberta Transportation &amp; Utilities)</td>
<td>ATU B-391</td>
<td>25.0x25.0x2.85</td>
<td>1.0x1.0x11.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Initial 24 hr curing per manufacturer’s recommendations. After initial curing; 23°C (73°F), 50% RH</td>
</tr>
<tr>
<td>Australia</td>
<td>AS 1012 Part 3-1970</td>
<td>75.0x75.0x3.10</td>
<td>3.0x3.0x12.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>23°C (73°F), 50% RH</td>
</tr>
<tr>
<td>Germany</td>
<td>DIN 52450-1985</td>
<td>37.5x37.5x1.55</td>
<td>1.5x1.5x6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Various: 20°C (68°F), 65% RH 23°C (73°F), 50% RH 23°C (68°F), 45% RH 20°C (68°F), 95% RH 20°C (68°F), Wet</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>HKHA</td>
<td>25.0x25.0x2.85</td>
<td>1.0x1.0x11.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>25°C (81°F), 55% RH</td>
</tr>
</tbody>
</table>

Techniques to examine restrained shrinkage generally rely on the cracking of the material within a given time period and, therefore more appropriately can be called sensitivity to cracking tests.

There are three basic types of restrained shrinkage tests that have been traditionally used for cement-based materials – linear, plate and ring.

In the linear restrained shrinkage test, restraint of movements of the specimens is provided either internally by axially embedded bars or tubes, or externally by a large steel mold or frame. In the plate type, the restraint is provided only at the bottom of the prismatic specimens. In the ring-test, the cement-based material is cast around a ring of steel, and then it dries while the metallic ring provided the restraint.

The following is an illustration of the several restrained shrinkage tests. It should be noted that the illustration does not fully represent the new developing generation of restraining shrinkage test methods. For instance, interesting and promising quantitative test methods developed by Kovler [6], Springenschmid et al. [7] Bloom and Bentur [8] and by Pigeon et al. [9] are not included in the following review.
3.1 Ring Test
This sensitivity to cracking test has been used for about 60 years. Carlson and Reading conducted restrained shrinkage tests between 1939 and 1942 using a ring specimen [10].

In this test, a thin 25-mm (1-in.) concrete ring was cast around a steel ring (Fig. 1). The top and bottom surfaces of the concrete were sealed so that drying only occurred from the outer circumferential surface. The ring (circular) specimen configuration was chosen because it did not impose stress concentrations into the tested material. It allowed volume changes and stress development, including creep and creep relaxation. The specimen configuration allowed for observation of readily visible cracks developed during the monitoring period.

Figure 1 – Ring Test Specimen
Coutinho [11] studied the rupture strengths of pastes and mortars to resist restrained shrinkage using unrestrained and restrained ring specimens.

The ring concept was used by other researchers for studies of cracking tendency of cement-based materials. The information on different ring tests is summarized in Table 2.
Table 2. Specimen Dimensions Used in Ring Test

<table>
<thead>
<tr>
<th>Ring Dimensions</th>
<th>Researchers and Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter, mm (in.)</td>
<td>External a</td>
</tr>
<tr>
<td>175 (7)</td>
<td>125 (5)</td>
</tr>
<tr>
<td>405 (16)</td>
<td>325 (13)</td>
</tr>
<tr>
<td>125 (5)</td>
<td>100 (4)</td>
</tr>
<tr>
<td>70 (2.8)</td>
<td>50 (2)</td>
</tr>
<tr>
<td>40 (1.6)</td>
<td>30 (1.2)</td>
</tr>
<tr>
<td>57 (2.2)</td>
<td>27 (1.0)</td>
</tr>
<tr>
<td>100 (4)</td>
<td>68 (2.7)</td>
</tr>
<tr>
<td>660 (26.4)</td>
<td>508 (20.3)</td>
</tr>
<tr>
<td>374 (15)</td>
<td>304 (12.1)</td>
</tr>
<tr>
<td>155 (6.2)</td>
<td>115 (4.6)</td>
</tr>
<tr>
<td>175 (7.0)</td>
<td>112.5 (4.5)</td>
</tr>
<tr>
<td>72 (2.9)</td>
<td>37 (1.5)</td>
</tr>
<tr>
<td>190 (7.6)</td>
<td>90 (3.6)</td>
</tr>
<tr>
<td>318 (12.5)</td>
<td>254 (10)</td>
</tr>
</tbody>
</table>

3.2 Plate Test

Padron and Zolla at the University of Miami [12] used 300-mm (12-in.) square plate specimens with various thicknesses [12]. A wind chamber capable of providing a steady flow in a designated test section was provided. Samples for crack resistance testing were placed in the chamber immediately after casting. After the 16-hr. wind chamber exposure, the samples were polished to improve the visibility of cracks. Two measurements were targeted: a measure of the overall shrinkage of the sample and a measure of the total crack area on the exposed surface of the specimen. Kraai proposed a test method for evaluating the cracking potential of a material [13]. For the test, 2- by 3-ft (61 by 91 cm), ¾-in. (19 mm) thick specimens were used. The cracking potential was determined by comparing the cracking of the two test panels exposed simultaneously to a set of severe conditions designed to cause cracking. One panel was the control panel, the other was a similar panel except that a single material was altered to study its effect. The second panel could also be made identical in materials but then be subjected to different environmental conditions (temperature or drying conditions).
For the control panel, only those influences that were thought to maximize the amount of cracks were chosen. Movement of free water was only in an upward direction. The bottom of the form was covered with polyethylene film to prevent absorption of water at the bottom. This film also prevented the bottom surface from restraining the volume change of the concrete.

Immediately after casting, the two panels were exposed to a wind of 10 to 12 mph (16 to 19 km/h) for 4 to 5 hrs. Panel evaluation started at 24 hrs. At that time cracks were likely to be slightly wider and possibly more numerous than after 4 hrs. Panels reevaluated at 3 and 6 months showed no significant further change in cracking patterns. Crack lengths and average widths were measured and recorded for each panel.

3.3 Linear Restraint Method
A linear restrained shrinkage method using a steel angle mold is being used in Germany [14] (Fig. 2). This method was developed by the Technical Academy, Aachen, Germany and adopted as the Technical Test Regulations (TP BE-PCC) for concrete substitution systems made of cement mortar/concrete with a plastic additive by the Highway Construction Department of the Federal Ministry for Transport.

After pouring mortar or concrete into the shrinkage channels, these are kept uncovered in standard atmosphere, and continually monitored for crack formation. After 90 days, observable cracks having occurred are measured precisely to within 0.02 mm.

![Figure 2 – German Angle Specimen](image)

The number of cracks, the average and maximum crack width and, where applicable, the time of cracking, and large areas of detachment from the steel are all monitored and recorded.

Materials tested by this method with cracks wider than 0.1-mm (0.004-in.) are not accepted. Also, no bonding failure in large areas is allowed.
An entirely new concept was developed by Structural Preservation Systems, Inc. – restrained volume change strain/stress indicator. This test reflects the dimensional behavior of repair systems and allows for simulation of the various effects responsible for distress of in-situ repairs. The specimen is a nominal 51- by 102- by 1,321-mm (2- by 4- by 52-in.) beam. The repair material is cast against a thin steel plate on the bottom of the form. The plate has a layer of epoxy with sand grit applied to improve bond to the repair material. The test involves the measurement of upward tip deflection at the unrestrained end of the specimen over time under standard laboratory and/or in-situ conditions. The specimen is supported by a rigid steel channel. The free end curling experienced by the beam is monitored. The maximum tip curling indicates the maximum volume change related strain of the material under particular exposure. Based on this strain, the stress in the material can be calculated. Fig. 3 shows the test specimen.

A similar technique was developed recently at Laval University. The beam curling test (BC test) is performed by measuring the evolution of the midspan deflection of a concrete or mortar beam exposed to drying on only one of its four longitudinal faces, the remaining surfaces being sealed. Figure 4 is a schematic representation of the test.

The measurement of the beam deflection is carried out using a measuring device that consists in an aluminum angle shape member equipped with a dial gauge and two cone-shaped sitting pins. The samples used in the BC test are sealed on all faces except one longitudinal surface. The specimens used are 50- by 100- by 1000-mm beams and two types of experiments are actually conducted. In the first case, the specimens are cast integrally with the material to be tested and the results of the test reflect its true free curling tendency. In the second type of experiment, a first layer of a reference concrete is placed into the mold and matured prior to the placement of the material to test, in order to obtain a composite specimen simulating a real repair. The results obtained with the latter reflect the capacity of adaptation of the material and, depending on the thickness of the
repair layer relative to that of the support, its sensitivity to cracking. Different other aspects can be addressed with this test that is still under development, for instance the effect of water suction by the substrate.

Figure 4 – Laval University Beam Curling Test

Analysis of various test methods for evaluation of shrinkage of cement-based materials allowed for the following conclusions:

- The test methods in different codes of practice promote a narrow view of the complex problem – cracking caused by restrained volume changes. They do not allow to make a prognosis of repair performance.
- Various standard and non-standard test methods have been developed to evaluate the drying shrinkage and deformability of repair materials. Some of such methods raise questions about what is really being measured.
There are no standardized or widely accepted reliable test method to evaluate drying shrinkage in repairs exposed to real-life environment. Existing test methods are unsatisfactory for predicting the field performance of repairs. Many test results have been reported without reference to performance requirements or criteria. Interpretation of such tests is often controversial.

4. Results of A Comprehensive Experimental Program

The objective of an exhaustive experimental program conducted recently and funded by the U.S. Army Waterways Experiment Station was to evaluate, under field and laboratory conditions, the proposed performance criteria in order to establish guidelines for selection of repair materials based on their dimensional compatibility with existing concrete. The critically important part of this objective was to fill the predictability gap. The ultimate goal was practical application of testing methods.

Testing of twelve repair materials manufactured in North America and representing a wide range of drying shrinkage properties was included in the program [15-17]. The laboratory testing included the following standard and non-standard test:

- Compressive strength at 7 and 28 days
- Tensile strength at 7 and 28 days
- Modulus of elasticity
- Compressive creep
- Tensile creep
- Coefficient of thermal expansion
- Unrestrained shrinkage tests
- Restrained shrinkage (cracking potential) tests:
  1. Ring test
  2. German Angle test
  3. SPS Strain/Stress Indicator

The field testing program proposed included three exposure condition areas: Illinois, Arizona, and South Florida. Consideration of these locations was given to such variables as temperature, humidity, wet-dry and freezing and thawing cycles.

The field testing program included the following:

- German Angle test
- SPS Strain/Stress Indicator
- Composite repair system test – installation of 6 x 18 x 0.25 ft repairs in cavities of prefabricated concrete slabs (Fig. 5)

The results of the study, as testing is concerned, allows for the following considerations.

Test results appear to contradict the generally accepted viewpoint that higher tensile creep aids in relaxation of stresses and strains induced by restrained shrinkage in concrete.
repairs, thus reducing the potential for cracking. Apparently, this phenomenon can be attributed in part to the generally higher drying shrinkage exhibited by materials with high creep characteristics. But, primarily, the results were significantly affected by complications in performing the tensile creep test. Creep measurements in pure tension are more difficult than in compression, primarily because of the relatively low strength of material and hence the low stress levels that can be applied, and the consequent low creep strains. Creep being obtained by subtracting shrinkage from the total observed deformation under load, the magnitude and intrinsic variability of shrinkage can thus significantly influence the computed results.

Based on the results of the study, one can suggest that since the ultimate objective of all performance testing is the prediction of how the material will function in the field through evaluation of how it functions under test, the net deformation is the only parameter or information of practical importance as far as the behavior of the repaired structure is concerned. In fact, fundamentally speaking, the total deformation of a drying specimen under load cannot be subdivided into creep and shrinkage components as they are not strictly independent. From an engineering standpoint, however, such an assumption is obviously attractive and convenient for the design of repair works. Unfortunately, the actual state of knowledge on the phenomenon of tensile creep remains insufficient to rely on it safely. For instance, the relationship between drying shrinkage and tensile (drying) creep must be explored, as it has been previously for compression [18], and the relationship between tensile creep and the level of stress has to be characterized up to failure in order to evaluate the maximum potential extension of the material. A fine characterization is essential to evaluate and, most important, quantify the sensitivity of the cracking response of concrete repair materials to the parallel evolution
of shrinkage and creep as deduced from the principle of superposition. Meanwhile, the total deformation is the only one well defined and directly observable quantity that can safely be relied upon [17].

The German angle field test results indicate that this test can provide information on a material’s resistance to cracking when the test specimens are exposed to varying exposure conditions. However this test appears to offer minimal potential for prediction of field performance based on laboratory tests unless the anticipated service conditions can be simulated in the laboratory.

There was a modest correlation between results of the SPS plate test conducted in the field and performance of the field repairs. Test results indicate that this test can be used in field and laboratory for a general assessment of a materials deformability; however, modifications to the test are necessary.

The composite repair test (box test) is considered to be the most reliable test. This test can be used to generate both laboratory and field data, under known conditions of exposure, which could then be correlated to observed field performance. One of the interesting possibilities with such test would be to evaluate the performance of a reference material under various types of exposure conditions, and then correlate the results obtained with the observed field performance.

5. Development of Reliable Test Methods

The urgent need for standard test methods specifically designed to assess the performance of repair materials is obvious. Efforts are actually spent by the C.R.E.E.P. workgroup towards the development of a repair material performance test that would be representative of field conditions, but still using specimens sufficiently small to make it a laboratory tool as well. The so-called box test used in the Waterways Experiment Station program (see Figure 2) is considered to be the type of test needed. As seen in the Figure 2, it simply consists of a concrete slab having a surface cavity in which a layer of repair material is cast. After casting, the slab can be placed under various types of exposure conditions, and cracking arising in the repair layer as a function of time is monitored. In addition to the size of the box, it is particularly necessary to define details of the experimental procedure such as the preparation of the substrate, since absorption of water by the substrate can certainly influence to a large extent the characteristics of the interface and the performance of the repair material. Besides, it is also necessary to define standards for the evaluation of performance (type and intensity of cracking as a function of time of appearance), including the possibility of the use of destructive type measurements (e.g. pull-out tests).

The box test or cavity slab test could be used to generate laboratory and field data, under known conditions of exposure, which could then be correlated to observed field performance. On the long term, such a standardized test will allow the construction of a
database from both laboratory and field tests under standardized conditions, including when available the relationships with observed field performance (Figure 6).

Figure 6 – Box test under development by the C.R.E.E.P. workgroup: (a) molds for 1.0, 1.5 and 2.0 m long specimens; (b) 1.0 m long cavity slab after casting; (c) 2.0 m long slabs filled with repair material

In the past, as stated earlier, various other nonstandard testing techniques have been experimented in different laboratories to ultimately better characterize the cracking tendency of repair materials in restrained conditions. Among these, there are the ring test,
the German angle test, the SPS plate test and the beam curling (BC) test. They all show some interesting promise as indicators of the cracking tendency of repair materials, but further research has to be focused on factors such as specimen geometry, test instrumentation and exposure conditions. In addition, the data obtained in such tests must be interpreted in view of representative data, generated for instance in tests such as the box test, in order to define sound performance criteria. All these methods will thus be investigated along with the development of the box test.

Beyond the performance tests, it is still important to try to better characterize the significant individual properties of the repair materials in view of their overall compatibility, especially the tensile creep characteristics. For that matter, reliable and simple experimental techniques are required. Sophisticated testing devices such as those used by Kovler [19] or by Pigeon and Bissonnette [20] are necessary to carry on fundamental studies, but they are much too expensive and complicated for the intended purpose. A potential answer lies in the development of a flexural creep test procedure. An investigation in that regard is actually under way.

6. Conclusions

1. The industry urgently needs to test (to evaluate) the cementitious repair materials in such reproducible ways to be confident, when specifying and using them. In the same time our scientific understanding should enlarge so that practical exploitation is soundly based. If this task is reached we will be better able to make intelligent adjustments when deviations in performance are experienced.
2. The acceptable test methods should be developed to model the material’s response in every environment in which it is to be used so that performance predictions become more accurate. To ensure the accuracy of these predictions the step of considering the material as part of repaired structure (component) must be taken fully into account.
3. Site testing has to be given serious consideration. The relevance of test results to “real life” behavior must always be taken into account. The advantages of site testing are that measurements made are specific to the test environment, the level of confidence is high and the test results can be used to set up accelerated tests.

7. References


