TESTING AND EVALUATION OF REPAIR MATERIALS

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ABSTRACT

Repair and restoration of deteriorated structures is drawing lot of attention in recent years. A variety of repair materials are available in the market. Therefore, testing, evaluation and selection of a suitable repair material is very important. Various researchers use different evaluation methods, whilst most of the material suppliers quote the property values, but the test standard and method is not reported. It makes difficult to compare the repair materials. Moreover, there is no required specification established so far. Recently research has been carried out throughout the world to address this problem. The paper covers some important parameters regarding the testing and evaluation of repair materials. The need of a unified standard code and to select tests according to the applications is emphasised. Work carried out at CBRI in this direction is also briefly discussed.

Keywords: Concrete; Corrosion; Carbonation; Polymer; Protection; Repair; Mortar; Coating; Testing; Durability.

INTRODUCTION

The concrete structures are deteriorating due to various in-service and the environmental exposure conditions. The deterioration of concrete leads to defects like erosion, cracking, spalling, loss of reinforcement, failure of construction joint, increased porosity and strength reduction (1-3). To restore functioning of the concrete structures and to enhance their lifespan these structures need suitable repairs. There are number of approaches adopted for repair and retrofitting of the deteriorated structures, such as: stitching, strengthening with panels, patch repair, structural repair and protective coatings (1-3). However, the repairs can be broadly classified in two major categories: structural and cosmetic. Structural repair is required to improve the load bearing capacity of structure or to bring it to at least its original load carrying capacity. Cosmetic repair, also called surface or patch repair is necessary to protect the structure from detrimental elements and to improve aesthetics. For different types of repairs the selection of a suitable repair material is vital and needs a through understanding of the behaviour of the repair material under the service conditions.

The required specifications for the repair materials vary according to the condition and properties of the base concrete and form of the repair i.e. structural or cosmetic. In some cases plain cement mortar or concrete can be used. However, due to high shrinkage and low bond strength their application as repair material is not recommended. To overcome these drawbacks and to achieve the desired properties in the repair material polymers are often used (4). However, polymers are relatively costly material and therefore, optimum dose of the polymers is very important. By varying types of polymer or additives and their dose in a cement/polymer mortar a wide range of properties can be achieved. Evaluating the properties of various compositions of the polymer modified repair materials from the end use point of view optimisation of the different formulation is essential. For this purpose various researchers carry different types of tests often following dissimilar test methods. Presently, there is no standard code available specifically for repair materials because of diverse nature of the materials and varying requirements. However, professional societies or institutes like American Concrete Institute (ACI) provide some guidelines, which are quite useful (5). Recently, in Europe standards are being prepared for this purpose (6).

The selection of repair material was traditionally based on high compressive strength and low permeability of the material, but with time properties like shrinkage, creep, elastic modulus and tensile strength are also considered (7-13). Studies have been done to relate performance of a concrete repair with the properties like compressive strength, elastic modulus, shrinkage, thermal expansion and permeability of the repair material (7,8). Despite all these efforts, there are several issues unresolved. For example, it is still not established what properties should be evaluated and what should be the minimum acceptable values to achieve an effective repair for different situations. What are the materials that meet these requirements? Do they perform in the same way in all weathering conditions, such as hot and dry or cold and wet, saline and industrial environment?

This paper reviews the various test methods and requirements for the repair materials suggested by the researchers. Finally, few suggestions are given in the form of recommendations.

REQUISITE PERFORMANCE

This issue has been addressed by various researchers to establish the required properties of the repair material with respect to the substrate concrete (1, 7, 13-15). There seems to be an agreement that the repair material must have the dimensional, structural, permeability, chemical and thermal compatibilities with the substrate and therefore expected to meet the requirements. However, the methods for assessment of these compatibilities and the specification for repair materials are not yet established. The repair materials are being tested for several tests, but all may not be relevant to the repair materials at different situations.

During the past two decades several researchers have attempted to evaluate different repair materials. They conducted different tests and followed different methods. Some of them are summarised in Table 1. The test methods followed by the researchers vary, particularly those followed in America and in Europe.

Dimensional compatibility

During selection of a suitable repair material the most important parameter is dimensional compatibility of the repair material with the substrate concrete. It refers to the capacity of the repair system to withstand the stresses generated due to the different volume changes in the applied repair material and the substrate. If the repair material and the substrate concrete are not dimensional compatible, they may debond and cause delamination at the interface. The main elements that cause the dimensional problems are shrinkage (plastic, drying and autogenous) in the repair material, excessive expansion in shrinkage compensating materials and high thermal expansion due to change in temperature. The other parameters are the size, the shape & thickness, modulus of elasticity, strain capacity and creep of repair materials. To ascertain dimensional compatibility different properties, such as shrinkage, thermal expansion and creep are measured and matched with those of the substrate concrete.

Structural compatibility

The mismatch of structural properties of the repair material with the concrete substrate can lead to serious consequences. For structural repair the compressive, flexural and tensile strength of the repair material must be more than that of the substrate concrete. Second requirement is that the repair material should have approximately the same elastic modulus. To find out the structural compatibility few researchers test compressive strength and bond strength only, but others test tensile as well as flexural strength, as can be seen in Table 1. Recently, considerable importance has been given to creep also.

It has also been noted that for resinous material small sized specimens are used, but for cement boned materials containing coarse aggregate bigger size specimens are used. The results obtained on different size and curing conditions cannot be directly compared. To overcome this problem some research work is required. For flexural test of repair materials also great variation in the specimen size and method of testing has been found. Clearly the results obtain from these tests cannot be compared for selecting a material. Therefore, while selecting repair material using flexural properties, these aspects should be considered.

To evaluate repair materials several types of bond tests are being carried out. Although BS and ASTM (BS6319: Part4; ASTM C 882-91) suggest the shear slant test, many researchers (7, 8) are of the view that in this test the material is being tested under combination of shear and compressive stresses. Therefore, they use tests based on pullout methods, which impose more severe stress condition.

Chemical compatibility

The repair material should not have any harmful effect on the repaired structure. The detrimental elements could be chloride ion, which may cause corrosion of reinforcing steel, or sodium/ potassium ions may increase the alkali aggregate reaction rate. Surface repair material with low pH value may not provide sufficient protection against corrosion. Further, the acidic components may degrade the base concrete. Therefore, the repair material should be analysed for these detrimental elements. However, the permissible limits for maximum content of these chemicals are not yet established.

Durability

Durability of repairs materials is ascertained by conducting various tests like permeability, resistance to freeze and thaw, acid resistance, weathering resistance and abrasion resistance. Permeability is measured by using different penetrants and techniques. For example, water permeability and nitrogen gas permeability. Some other methods including capillary water absorption, chloride ion penetration, resistance to carbonation and resistance to seawater & sulphates can be found in literature. Further details can be found in (16).

DISCUSSION

Repair and restoration of deteriorating concrete structures is an important activity, which consumes a large portion of the total budget of the construction industry. Therefore, this activity must be undertaken with utmost care. The success of a concrete repair depends on several factors. Proper testing and evaluation is one of them. However, there are number of test methods available for the repair materials and it is not known which test method is better or whether all the tests are required for a repair material. Besides this it is not clear what should be the acceptable values. Nevertheless, recently some recommendations have been made regarding acceptable values for the repair materials. Some of these values are presented in Table 2. In view of this scattered information, it is important to bring out a unified code covering the test methods and specifications of the repair materials for different exposure conditions. Presently, there is no standard design code available for repairs. It is, therefore, necessary to develop design methods, which can use the test results. Currently, in the absence any standard design code the use of the results depends upon the design engineer's judgement and experience. For designing the repair system, care must be taken while using the short-term properties because in long term these properties may change and need further repair. For example, Shambira and Nounu (19) found that due to comparatively higher time-dependent properties of the repair material the load bearing function of the repair material was lost in few weeks. However, for achieving the long-term properties the moulding or liquid state properties should not be compromised.

It is practically not possible to conduct all the tests on a repair material. The number of tests to be carried out can be reduced if correlations can be developed between various properties. In this direction some efforts have been made, but no significant correlation was found between compressive strength and dimensional stability of the repair materials (18). Depending upon the severity of the tests Mirza *et al.* (13) recommended the following order of the lab tests: thermal compatibility with base concrete, freeze and thaw test, drying shrinkage, bond strength, permeability, abrasion-erosion resistance. Prior to selection of a repair material the purpose and location of the repair should be clearly known, so that the relevant material properties could be identified and matched with the requirements.

WORK DONE AT CBRI

At Central Building Research Institute (CBRI), Roorkee, India a number of projects on development of repair and protection materials for various exposure conditions and for the restoration of heritage buildings have been undertaken. The materials developed so far are patching materials, reinforcement coatings and grouting materials, repair mortar and coatings for steel and concrete structures (16, 20-24). The coatings developed by CBRI are epoxy-cardanol coating system for concrete and steel structures and for reinforcing bars used in RCC and an acrylic based coating for concrete structures. An epoxy latex is also developed to use as a bonding agent and for repair mortar for concrete structures. Besides these, number of testing and evaluation of repair materials are undertaken. The institute has facilities available for testing of different materials like grouts, sealants, coatings, mortars, concrete and composites.

CONCLUSIONS & RECOMMENDATIONS

The number of deteriorating concrete structures is increasing day by day. As a result, large quantity of repair materials is requited. To evaluate compatibility of these repair materials with concrete substrate several types of tests are available. For a repair material conducting all these tests for each repair material is not viable. Furthermore, the test methods also vary, which make it difficult to choose a suitable material. Therefore, there is a need to identify the critical properties and test methods, and to develop correlation between various properties of the repair material. This will help in reducing the number of tests required and the criteria to be met. Furthermore, there is an urgent need to develop a unified code for testing and required specifications for different exposure conditions. In addition, there should be a standard code for design of structural repairs.

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Table 1 Test conducted by researchers to evaluate repair materials

Property	Emberson and Mays (7)	Plum (8)	Mangat & Limbachiya (9)	Hasan *et al*. (11)	Postan *et al*. (12)	Mirza *et al*. (13)
Compressive strength	√	√	√	√	√	√
Flexural strength	√	√	√	—	√	—
Tensile strength	√	—	—	√	√	—
Modulus of Elasticity	√	√	√	√	√	—
Poisson's ratio	√	—	—	—	√	—
Shrinkage	√		√	√	√	√
Creep in compression	√	√	√	—	√	—
Creep in tension	—	—	—	—	√	—
Thermal expansion	√	—	—	—	√	√
Adhesion or Bond strength	√	√	—	—	—	√
Permeability	—	—	√	√	—	√
Abrasion resistance	—	—	—	—	—	√
Resistance to freeze and thaw	—	—	—	—	—	√

Table 2. Some recommended performance criteria for repair materials

Property	Dector and Keeley (17)	Postan *et al.* (12)	McDonald *et al.* (18)
Compressive strength, minimum			
3 days	Similar to substrate	17.2 MPa	–
28 days		27.6 MPa	–
Tensile strength, minimum 28 days	Similar to substrate	10% of the compressive strength	2.8 MPa
Modulus of elasticity,	Similar to substrate	–	24 GPa (Max.)
Bond strength	> 0.8 MPa	–	–
Coefficient of Thermal expansion	Similar to substrate	–	12 millionths/ºC (Max.)
Drying shrinkage, maximum			
7 days	<300 microstrain	–	–
28 days	<500 microstrain	400 millionths	400 millionths
1 year		–	1000 millionths
Restrained shrinkage		Tip curling from the SPS plate should be less than 0.25 mm at 28 days.	No cracks within 14 days, 1000 millionths (1 year)