

Selecting Durable Repair Materials: Performance Criteria – Summary

“An unwise man doth not well consider this: a fool doth not understand it.”— Psalm 92

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The overall objective of any repair project should be to produce a durable repair at a relatively low cost. Some important steps to achieve this objective are outlined in the following:

- assess the condition of the existing structure (degree of deterioration/distress);
- identify the cause(s) of deterioration/distress;
- establish the nature and severity of the interior and exterior environments;
- ascertain the intended service life of the structure;
- evaluate alternative repair systems and select an appropriate system;
- develop repair system design details and specifications;
- select repair material(s) that satisfy specifications; and
- execute the work in accordance with specifications.

To achieve durable repairs, it is necessary to consider the factors affecting the design and selection of repair systems as parts of a composite system. Compatibility (dimensional, chemical, electrochemical, and permeability) between repair material and existing substrate is one of the most critical components in the repair system.

Despite the best efforts of the repair industry, the failure rate for concrete repairs remains unacceptably high. In many cases, cracking of repair materials is the primary problem. Cracks are typically the result of dimensional incompatibility between the repair material and the concrete substrate. Unfortunately, information on material properties that affect dimensional compatibility, how the various properties interrelate, and values that should be specified as performance criteria for individual properties is very limited.

Consequently, a comprehensive, multi-phase research program was initiated to develop performance criteria for the selection and specification of dimensionally compatible cement-based repair materials that will provide durable, crack-free nonstructural (protective) repairs.

In Phase I of the study, preliminary performance criteria for dimensionally compatible repair materials were developed based on a review of the literature. This review¹ concentrated on identifying pertinent material properties, appropriate test methods, and demonstrated field performance. Phase II of the study included concurrent laboratory and field investigations^{2,3} to evaluate the preliminary performance criteria. Results of these investigations were correlated in a summary report⁴ to form a basis for development of the proposed performance criteria.

TABLE 1:
SUMMARY OF LABORATORY AND FIELD TEST RESULTS

Material no.	Field tests results				Laboratory tests results											
	Field perf. rank	German angle	SPS plate defl., in.	Compressive strength, psi	Tensile strength, psi	Flexural strength, psi	Modulus of elasticity, psi x 10 ⁶	Coeff. of thermal expansion, x 10 ⁶ /°F	Drying shrinkage, millionths		Ring test		German angle	SPS Plate Defl., in.	Specific creep @ 1 year Millionths/psi	
									28-days	Peak	Age of 1st crack, days	Implied strain, millionths			Compressive	Tensile
Group 1—Satisfactory field performance																
1	1-3	No crack	0.26	6610	451	289	2.8	5.8	178	366	6	667	No crack	0.06	0.451	0.420
4	1-3	No crack	0.21	11,530	348	779	3.8	8.3	201	703	140	560	No crack	0.08	0.260	0.609
11	1-3	Crack in AZ	0.24	9620	390	503	5.9	7.6	339	641	15	810	No crack	0.24	0.483	0.555
12	4	No crack	0.32	6940	742	805	3.0	9.3	293	634	None	0	No crack	0.16	1.157	0
8	5-6	Crack in AZ	0.20	4060	215	139	2.7	9.2	305	1109	8	1222	No crack	0.43	1.894	3.587
9	5-6	Crack in AZ	0.34	4780	323	415	2.7	6.9	429	877	23	955	No crack	0.32	1.301	1.163
Average			0.26	7260	412	488	3.5	7.8	291	722		701		0.22	0.924	1.267
Group 2—Marginal field performance																
3	7	Crack in AZ	0.43	6360	513	421	3.7	7.1	479	1116	17	685	No crack	0.37	1.913	1.449
2	8	No crack	0.26	7180	399	445	3.2	7.8	391	1032	22	364	No crack	0.33	0.603	0.831
Average			0.35	6770	456	433	3.4	7.4	435	1074		525		0.35	1.258	1.140
Group 3—Unsatisfactory field performance																
10	9	Crack in AZ	0.39	5230	402	495	4.2	9.9	16	678	None	0	No crack	0.21	2.037	0.072
7	10	Crack in AZ	0.54	4330	467	365	2.7	8.5	1779	2682	4	3414	No crack	1.49	3.485	2.835
6	11	Cracked	0.65	9760	323	493	5.3	9.3	301	878	7	1808	No crack	0.06	0.872	0.608
5	12	Cracked	0.13	6940	93	758	4.5	7.8	258	690	10	840	No crack	0	0.562	27.73
Average			0.43	6560	321	528	4.2	8.9	588	1232		1516		0.44	1.739	7.81

Note: Divide psi by 145 to obtain MPa; Multiply inches by 25.4 to obtain mm

Laboratory investigation

Laboratory tests were conducted to determine the pertinent properties of 12 concrete repair materials, particularly those properties affecting dimensional compatibility. The evaluation included selected standard tests and nonstandard tests developed specifically to provide a basic understanding of restrained shrinkage in repairs. Table 1 summarizes results of selected laboratory tests.

Three restrained shrinkage tests were conducted for comparison with the results of unrestrained drying shrinkage measurements in accordance with ASTM C 157 (Modified).⁵ In the restrained-ring test, material was cast around a section of 254-mm-diameter (10 in.) steel pipe. Following demolding and curing, the specimens were monitored daily under standard laboratory conditions for evidence of cracking. Ten of the 12 materials exhibited cracking in the ring test. Measured crack widths were divided by the circumference of the ring to compute implied strains. There was

only a general correlation between these restrained shrinkage strains and unrestrained shrinkage strains (28-day and peak values). The Structural Preservation System (SPS) plate test specimen was a nominal 51 x 102 x 1321-mm (2 x 4 x 52-in.) cantilever beam. As the material expanded or contracted in response to moisture and temperature changes, deflection of the unrestrained end of the specimen was measured. There was a significant correlation between deflections measured in the restrained SPS plate tests and unrestrained shrinkage strains (Fig. 1). The German angle test consisted of filling 70 x 70-mm-steel (2.8 x 2.8 in.) angles that were 1.0 m (3.3 ft) long with a repair material. Following casting, the test specimens were monitored for cracking under field exposure conditions. None of the materials cracked in the German angle test.

Creep test results did not provide definitive information on the effects of compressive or tensile creep on restrained shrinkage cracking. Results indicate that increased creep alone is insufficient to offset cracking of materials that are also prone to high shrinkage. Additional testing is needed to better understand the effect of creep on restrained cracking of repair materials.

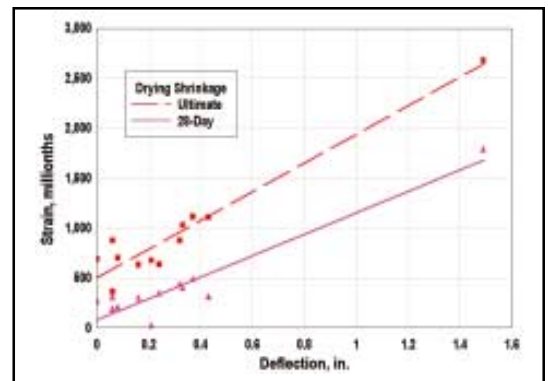


Fig. 1: Correlation between deflections measured in restrained SPS plate test and unrestrained drying shrinkage

Field investigation

Three exposure sites (South Florida, Illinois, and Arizona) were chosen for the field tests to represent a wide range of environmental conditions (high temperature and high humidity, freezing and thawing, high temperature and low humidity). The field evaluation study included repair of simulated spalls in precast concrete slabs and monitoring of material performance. The preformed repair cavities were 0.5 m (1.5 ft) wide by 1.8 m (6 ft) long and 76 mm (3 in.) deep. Each of the 12 selected materials was used to repair three cavities (Fig. 2) at each of three test sites. In addition to the simulated repairs, the field performance of each material was evaluated with two restrained drying shrinkage test methods. The performance of all specimens was monitored for at least 18 months. Table 1 summarizes the results of the field evaluation.

Overall, the 12 repair materials exhibited better resistance to cracking than was originally anticipated. Fine surface crazing of Material No. 8 in Florida, minor surface crazing of Material No. 9 in one repair in Florida, and minor surface deterioration of Material No. 12 in one repair in Illinois appears to be unrelated to dimensional compatibility properties. Therefore, results of these tests indicate that one-half of the materials (Nos. 1, 4, 8, 9, 11, and 12) demonstrated satisfactory dimensional compatibility and resistance to cracking under the range of service conditions studied. Two materials (Nos. 2 and 3) were susceptible to cracking only when subjected to high temperature and low humidity conditions, and their performance was rated as marginal. The remaining materials (Nos. 5, 6, 7, and 10) exhibited cracking in each exposure condition, and their performance was rated as unsatisfactory.

Two types of tests were conducted under field exposure conditions to evaluate restrained volume changes and cracking potential of the repair materials. Field test results indicate that both the SPS plate and German

TABLE 2:
PERFORMANCE CRITERIA FOR REPAIR MATERIALS

Property	Test method	Requirement
Tensile strength, minimum 28 days	CRD-C 164 [*]	2.8 MPa (400 psi)
Modulus of elasticity, maximum	ASTM C 469 [†]	24 GPa (3.5 x 10 ⁶ psi)
Coefficient of thermal expansion, maximum	CRD-C 39	12 millionths/deg C (6.7 millionths/deg F)
Drying shrinkage, maximum 28 days 1 year	ASTM C 157 (Modified)	400 millionths 1000 millionths
Restrained shrinkage-cracking, implied strain at 1-year age, maximum	Ring Method [‡]	No cracks within 14 days 1000 millionths

^{*}Standard Test Method for Direct Tensile Strength of Cylindrical Concrete or Mortar Specimens," *Handbook for Concrete and Cement*, U.S. Army Corps of Engineers.

[†]Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression," ASTM.

[‡]Reference 2.



Fig. 2: Repair of simulated spalls in precast concrete slabs

angle tests can be used for a general assessment of the ability of a repair material to resist cracking.

Correlation of results

Results of the laboratory and field investigations were correlated in an attempt to conclude how individual material properties, or their combination, affect the potential for cracking of field repairs.

Strength

It is generally agreed that the potential for cracking of cement-

based repair materials increases with high compressive strengths, despite inherently higher tensile strengths. Increased cracking is usually attributed to the typically higher modulus of elasticity, lower creep, and possibly higher shrinkage of high-strength materials. However, the results of this study indicate that, for the range of materials tested, there was no significant correlation between compressive strength and dimensional stability of the field repairs (Fig. 3). Therefore, a

requirement for compressive strength was not included in the performance criteria for nonstructural or protective repairs, which were the primary focus of this study. Overall, there was no significant correlation between direct tensile strength and field performance of repair materials, although the trend was for improved field performance with increased tensile strength. However, there was a significant correlation between tensile strength and field performance for those materials that exhibited marginal and unsatisfactory performance (Fig. 4). The proposed performance criteria (Table 2) require a minimum direct tensile strength of 2.8 MPa (400 psi). The results of this study indicate that there was no correlation between flexural strength and field performance; in fact, there was no apparent trend between flexural strength and field performance.

Modulus of elasticity

It is generally agreed that the potential for cracking of cement-based repair materials decreases with decreases in modulus of elasticity

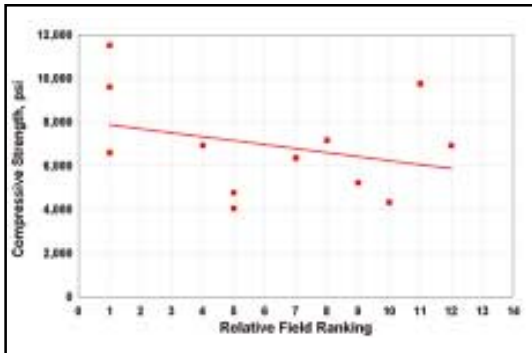


Fig. 3: Correlation between compressive strength and field performance

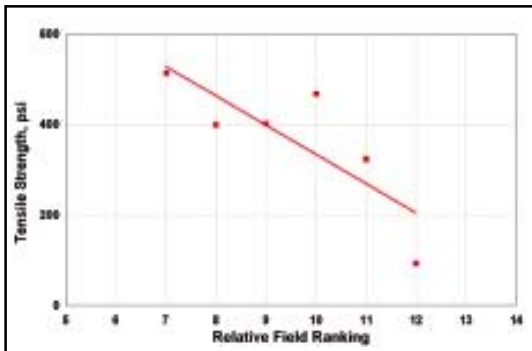


Fig. 4: Correlation between tensile strength and field performance

because creep and stress relaxation of the lower modulus materials reduces the magnitude of stresses induced by drying shrinkage. However, the overall results of this study indicate that, for the range of materials tested, there was no significant correlation between modulus of elasticity and field performance. It should be noted that 10 of the 12 materials exhibited moduli within a relatively narrow range of approximately 19 to 31 GPa (2.7 to 4.5 x 10⁶ psi). Excluding Material No. 11, which exhibited a significantly higher modulus of elasticity compared to the other materials with acceptable field performance, there was a modest correlation between modulus of elasticity and field performance (Fig. 5). The proposed performance criteria limit modulus of elasticity to a maximum value of 24 GPa (3.5 x 10⁶ psi).

Thermal expansion

Overall, there was no significant correlation between coefficient of thermal expansion and field performance. However, the trend was for improvement in field performance with decreasing coefficients of thermal expansion (Fig. 6). Coefficients of thermal expansion, determined in accordance with ASTM C 531,⁶ were higher than anticipated and generally higher than that normally associated with concrete. The proposed performance criteria limit the coefficient of thermal expansion, determined in accordance with CRD-C 39,⁷ to a maximum of 12 millionths/deg C (6.7 millionths/deg F).

Unrestrained shrinkage

Overall, there was no significant correlation

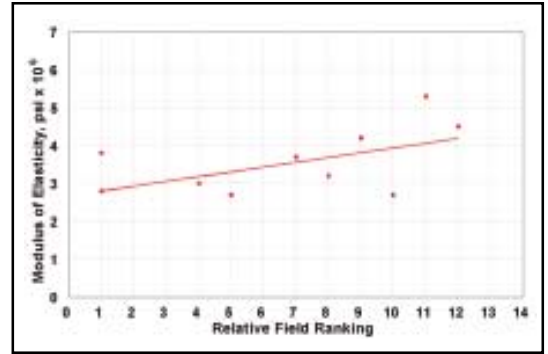


Fig. 5: Correlation between modulus of elasticity and field performance

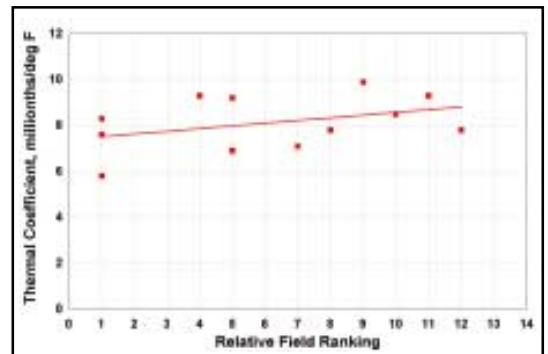


Fig. 6: Correlation between coefficient of expansion and field performance

between unrestrained drying shrinkage at 28 days and field performance, although the trend was for improved field performance with decreasing shrinkage. Attempts to correlate peak drying shrinkage with field performance yielded similar results. However, excluding the materials that demonstrated unsatisfactory field performance, there was a significant correlation between both 28-day and peak drying shrinkage and field performance (Fig. 7). The proposed performance criteria limits drying shrinkage at 28-days age to a maximum of 400 millionths. In addition, the criteria limits the peak (ultimate) drying shrinkage to a maximum of 1000 millionths at 1 year.

Restrained shrinkage

Three restrained shrinkage tests were conducted as previously described. All materials except Nos. 10 and 12, exhibited cracking in the ring test, because shrinkage strains induced during drying exceeded the tensile strain capacity at the time. In contrast to its good performance in

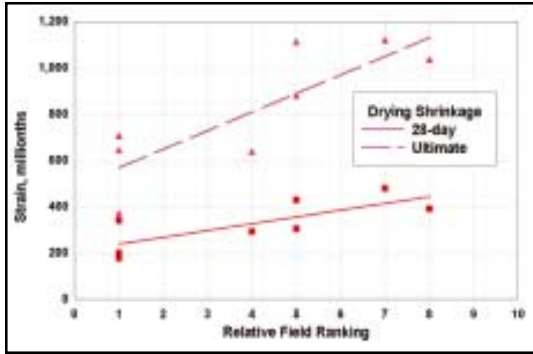


Fig. 7: Correlation between unrestrained drying shrinkage and field performance

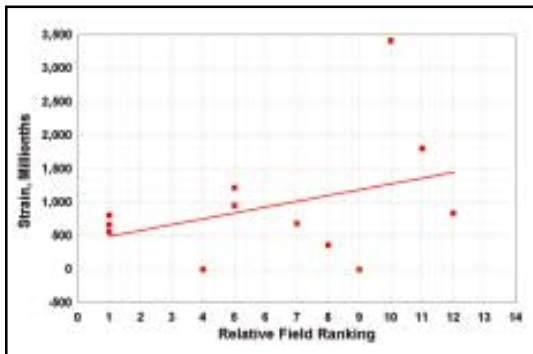


Fig. 8: Correlation between restrained drying shrinkage and field performance

the laboratory, Material No. 10 exhibited unsatisfactory crack resistance in the field tests. This poor performance is attributed in part to the highest coefficient of thermal expansion of all materials, a property that would be much more significant under widely varying field temperatures compared to controlled laboratory conditions. Material No. 12 exhibited good crack resistance in field tests.

The remaining materials exhibited first cracks in the ring test at ages ranging from 4 to 140 days. The average age at first crack of materials with acceptable field performance was 33 days. However, excluding Material No. 4, the ages at first crack ranged from 8 to 23 days with an average age of 15 days. In comparison, the average age at first crack of materials with unsatisfactory field performance was only 7 days. The proposed performance criteria require that repair materials exhibit no cracking after 14 days of restrained shrinkage. Crack widths were measured periodically and

implied shrinkage strains were computed by dividing the sum of the crack widths by the circumference of the ring. Overall, there was a significant correlation between restrained shrinkage strains and both 28-day and peak values of unrestrained drying shrinkage. Also, the trend was for poorer field performance with higher calculated strains (Fig. 8). Implied strains for those materials with acceptable field performance ranged from 364 to 1222 millionths with an average of 752 millionths. In contrast, implied strains for those materials with unsatisfactory field performance ranged from 840 to 3414 millionths with an average of 2021 millionths. The proposed performance criteria limit implied strain to a maximum of 1000

millionths at 1 year.

In the German angle test, restrained shrinkage specimens were monitored for crack formation under laboratory and field exposure conditions. Field test results indicate that the German angle test can provide a general assessment of a material's resistance to cracking when the test specimens are exposed to varying exposure conditions. Eight of the 12 materials exhibited cracks in field tests with this method. In contrast to the field tests, none of the materials cracked when German angle test specimens were exposed in a controlled laboratory environment. Consequently, 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.

Overall, there was no significant correlation between SPS plate test deflections measured in controlled laboratory conditions and field performance, although the trend was for improved field performance with decreasing deflection. However, excluding the materials that exhibited unsatisfactory performance in field repairs, there was a significant correlation between laboratory test results and field performance (Fig. 9). Overall, there was a modest correlation between the results of plate tests conducted in the field and performance of field repairs. Excluding Material No. 5, which exhibited some cracking attributed to plastic shrinkage and thermal gradients, there was a significant correlation between field test results and performance of field repairs. Test results indicate that the plate test can be used for a general assessment of a material's dimensional compatibility, or resistance to cracking; however, modifications to

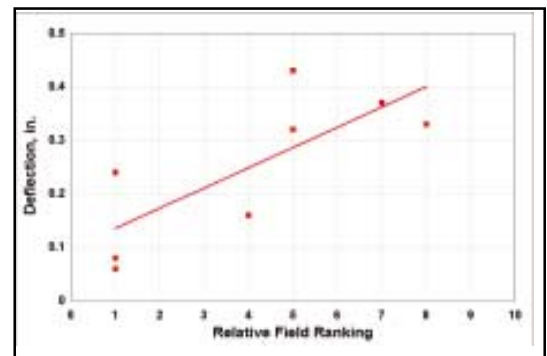


Fig. 9: Correlation between results of laboratory SPS plate test results and field performance

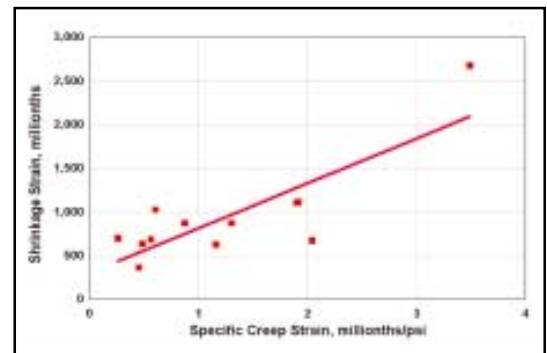


Fig. 10: Correlation between ultimate unrestrained drying shrinkage and compressive creep

specimen details and instrumentation are necessary to improve the precision of this promising test.

Creep

Results of this study appear to contradict the generally accepted theory that higher creep aids in relaxation of stresses and strains induced by restrained shrinkage in concrete repairs, thus reducing the potential for cracking. Although there was no significant correlation between either compressive or tensile creep and field performance, the trend in each case was for improved field performance with decreased creep. These unexpected results are attributed in part to the generally higher drying shrinkage associated with the materials that exhibited high creep characteristics (Fig. 10). Apparently, the higher strains induced by increased drying shrinkage more than offset any additional strain relaxation because of increased creep. Additional research is necessary to improve procedures for conducting tensile creep tests and to better understand the interrelationship between tensile creep and the potential for restrained shrinkage cracking.

Performance criteria

Laboratory and field exposure tests were conducted and results correlated to provide a basis for the development of performance criteria for the selection and specification of dimensionally compatible cement-based repair materials (Table 2). While there was a general lack of significant correlation between individual material properties and field performance, these studies indicate that it is possible to predict the field performance of repair materials based on a combination of material properties determined in laboratory tests. The performance criteria proposed for nonstructural repairs should be considered as a general profile of desired material properties. The relative importance of individual properties will vary depending on the anticipated application and service conditions for a given repair. Therefore, the

requirements should be modified as appropriate for a specific repair.

Material data sheet protocol

Material data sheets from numerous manufacturers and suppliers in North America were evaluated during the selection of the 12 repair materials for this study. It was obvious from this evaluation that the engineer has very limited, and sometimes misleading, information on which to base selection and specification of materials for a particular repair project. Typically, only data on properties favorable to the particular material are reported. Also, test procedures used to determine material properties vary widely and modifications are often poorly documented. Such information does not provide user confidence in the given properties, and is not a credible basis for selection of materials that will result in durable repairs. Consequently, as part of the overall study, a standard data-sheet protocol was developed for cement-based repair materials.

The proposed data-sheet protocol (Table 3) includes requirements for data on basic material composition and limitations of the material under specific application and service conditions. Material properties pertinent to dimensional compatibility between repair and existing substrate are also required. These properties must be determined in accordance with standardized fabrication, curing, and testing procedures to allow meaningful comparisons between candidate materials for a specific application. Since the selection of the best repair material for given application and exposure conditions is, of necessity, based on an optimum combination of several material properties, material data sheets must become reliable sources for standardized information on these properties.

What we now know, and need to know

One approach to ensure that repaired concrete structures perform their intended function for the

designed service life is to minimize cracking in the repairs. This and three previous articles⁸⁻¹⁰ describe the results of a study in which we developed performance criteria for selection of repair materials that are dimensionally compatible with existing concrete, and are thus less likely to crack. Results of this study provided guidance for selection of repair materials that would reduce the risk of premature failures. The guidance includes a standard protocol for repair material data sheets, and performance criteria for evaluation of alternative materials and specification of those materials with optimum properties. A better understanding of the fundamental nature of dimensional compatibility in concrete repair, along with the proposed performance criteria and standard protocol for material data sheets, should lead to fewer premature failures, greater composite durability and, therefore, more cost-effective use, and possibly more innovative materials.

Although there was a lack of significant correlation between individual material properties and field performance, results of this study indicate that it is possible to predict the field performance of repair materials based on a combination of material properties determined in laboratory tests. The relative importance of individual properties will vary depending on application and service conditions for a given repair; therefore, the requirements should be modified as appropriate for a specific repair.

Results of this study illustrate the significant effects of volume changes and drying shrinkage, in particular, on the performance of restrained repair phase of the composite repair system. While there was a general correlation between the results of laboratory tests on unrestrained shrinkage specimens and field performance, there is a need for new or improved restrained shrinkage tests to evaluate the cracking resistance of repair materials.

Obviously, all repair problems cannot be resolved by improvements in repair materials only. The evaluation

of existing concrete condition, design input, and the quality of workmanship are also of fundamental importance in ensuring the durability of repaired structures. Also, application and service conditions can have a significant effect on ultimate properties of the repair material. Therefore, it should be determined that the material properties required by the performance criteria can actually be achieved under the prevailing site conditions. Such a determination emphasizes the need for adoption of the standard protocol for material data sheets as a basis to evaluate the relevance and reliability of test methods and data. Although adoption of the proposed material data sheet protocol will provide some necessary solutions to current problems, the ultimate goal is to establish formalized and authoritative codes of practice and accepted standards for performance criteria.

Results of this study demonstrate that the formation and severity of cracking in repairs depends not only

on the repair material but also on such factors as mixture proportions and construction operations—mixing, placing, consolidation, finishing, curing, and quality control. The choice of material cannot be made independently of the choice of the process by which the material is to be placed, finished, and cured. The selection and application of the best material for a particular project is no substitute for using good-quality workmanship.

Research in the concrete repair field, unfortunately, is inadequate considering the needs. Both the public and private sectors have been lax in support of the research necessary to resolve current problems. Real progress cannot be made on the basis of “three graduate students – four years.” It is necessary to initiate adequately funded programs that include balanced practical and theoretical approaches.

There is a hope that adoption of the proposed performance criteria and a standard protocol for repair material data sheets may provide a springboard for other positive

activities in the concrete repair field. Over the centuries, concrete has served us well. Let’s never forget the ancient words: “This which our Fathers bequeathed to us, we must earn to possess.”

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- Vaysburd, A. M.; Emmons, P. H.; McDonald, J. E.; Poston, R. W.; and Kesner, K. E., “Performance Criteria for Concrete Repair

TABLE 3:
REPAIR MATERIAL DATA SHEET PROTOCOL

1. Repair material description					
<ul style="list-style-type: none"> Recommended use Benefits Limitations 					
2. Composition data					
<ul style="list-style-type: none"> Base material(s) Sulfur trioxide (SO₂), % - ASTM C 563 Alkali content, lbs/yd³ pH Air content 					
3. Physical properties					
<ul style="list-style-type: none"> Material's unit weight, lbs/ft³ Fresh wet density – ASTM C 138 Strengths 					
Property and test method		Age, days			
		1	3	7	28
Compressive strength					
- Mortar – ASTM C 109					
51 mm (2-in.) cubes					
- Concrete; mortar expanded with aggregate – ASTM C 39					
76 x 152 mm (3 x 6-in.)					
Flexural strength					
- Mortar - ASTM C 348					
- Concrete; mortar expanded with aggregate - ASTM C 78					
Splitting tensile strength – ASTM C 496					
- Mortar					
- Concrete; mortar expanded with aggregate					
<ul style="list-style-type: none"> Modulus of elasticity – ASTM C 469 - Mortar - Concrete; mortar expanded with aggregate 					

Table 3 (Concluded)				
4. Performance properties				
<ul style="list-style-type: none"> Drying shrinkage - ASTM C 157 (Modified¹) <ul style="list-style-type: none"> -Mortar -Concrete; mortar expanded with aggregate Coefficient of thermal expansion – CRD C 39-81 <ul style="list-style-type: none"> -Mortar -Concrete; mortar expanded with aggregate Freezing and thawing resistance – ASTM C 666A Compressive creep – ASTM C 512 <ul style="list-style-type: none"> -Mortar -Concrete; mortar expanded with aggregate Rapid chloride permeability – ASTM C 1202 <ul style="list-style-type: none"> -Mortar -Concrete; mortar expanded with aggregate Sulfate resistance – ASTM C 1012 Cracking resistance – Ring Test¹ <ul style="list-style-type: none"> -Age of first crack -Implied strain (Sum of crack widths at the end of test divided by the ring circumference) -Age at the end of the test Cracking resistance – German Angle¹ 				
5. Packaging, storage				
<ul style="list-style-type: none"> Packaging Volume yield Shelf life Storage requirements 				
6. How the material works				
7. How to use the material				
<ul style="list-style-type: none"> Concrete surface preparation Mixing Application and finish Curing Cleanup Safety 				
¹ See Reference 4 for commentaries to the Material Data Sheet Protocol.				

Materials, Summary Report," *Technical Report REMR-CS-62*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., 1998, 56 pp.

5. ASTM C 157, "Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete," ASTM, West Conshohocken, Pa.

6. ASTM C 531, "Standard Test Method for Linear Shrinkage and Coefficient of Thermal Expansion of Chemical-Resistant Mortars, Grouts, and Monolithic Surfacing," ASTM, West Conshohocken, Pa.

7. CRD-C 39, "Test Method for Coefficient of Linear Thermal Expansion of Concrete," *Handbook for Concrete and Cement*, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Miss.

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SPECIFICATION FOR CAST-IN-PLACE CONCRETE PIPE

This specification covers cast-in-place concrete pipe (CIPCP) and isn't valid for pipe with a diameter more than 120 in. (3050 mm). CIPCP is an underground continuous concrete conduit with no reinforcing steel, joints, or seams except as necessitated by construction requirements. CIPCP is used to convey irrigation water, storm water, or industrial waste under a maximum internal operating head of 15 ft. (4.5 m) and external loads as described in the specification.

aci international

SPECIFICATION FOR CAST-IN-PLACE CONCRETE PIPE
Order Code: 034601CI01
\$10.00



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