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Guidance for the ACI/ICRI Cementitious Repair Material Data Sheet

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Abstract. In practice, cementitious repair material test data are often inaccurately reported or inadequately required in specifications, regularly referencing unclear test method modifications or in-house test methods. Descriptions of material limitations, packaging, storage, label contents, application instructions, material composition, and material properties can be inconsistent, confusing, missing, or misleading. The ACI PRC-364.3-22/ICRI 320.3R-2022 *Cementitious Repair Material Data Sheet—Guide*[1,2] is a first in the industry to propose this information in a standardized, logical, and consistent format so that repair materials can be appropriately selected and specified. The purpose of the guide is to provide a guidance protocol for testing and reporting of data for cementitious repair materials in order to allow objective comparison between alternative products. This reference document is one of the important outcomes of the initiative entitled *Vision 2020: A Vision for the Concrete Repair Protection and Strengthening Industry*, an inter-industry development group which was formed with the intent of supporting the concrete industry's strategic needs to establish a set of goals to improve the efficiency, safety, and quality of concrete repair and protection activities. After the publication of separate initial versions by ACI and ICRI, a joint version harmonizing their content has finally been produced. This paper highlights the various considerations of the data sheet template and provides guidance for its use.

Keywords: Cementitious Repair Material, Characteristics, Data Sheet, Properties, Standard, Test Methods.

1 Introduction

Frequently, cementitious repair material test data are inaccurately reported or improperly required in specifications, often referencing unclear test method modifications or in-house test methods. Descriptions of material limitations, packaging, storage, label contents, application instructions, material composition, and material properties can be inconsistent, confusing, missing, or misleading. ACI PRC-364.3-22/ICRI 320.3R-2022: Cementitious Repair Material Data Sheet—Guide [1,2] is a first in the industry to provide this information in a standardized, logical, and consistent format so that repair materials can be appropriately selected and specified.

The concept of producing a protocol for cementitious repair materials first appeared in "Performance Criteria for Concrete Repair Materials Phase II, Field Studies" [3] in 1998 as the result of a detailed comparison of the published information from 12 proprietary repair materials. A draft document was included in the subsequent report. [4] The document was discussed and refined at the 1999 workshop "Predicting the Performance of Concrete Repair Materials" hosted by the National Institute of Standards and Technology (NIST). [5]

One of the outcomes of the workshop was the formation of a task group that comprised representatives from material suppliers, specifiers, and academics to develop a protocol. Over the next several years, the task group refined and identified the appropriate industry organizations for adoption of the document. This work was included as one of the goals of Vision 2020: A Vision for the Concrete Repair Protection and Strengthening Industry, which was an inter-industry development group to support the concrete industry's strategic needs to establish a set of goals to improve the efficiency, safety, and quality of concrete repair and protection activities. This effort led to a series of focused workshops to define the most important industry issues and needs used to establish the goals in Vision 2020. [6] One of the first goals of Vision 2020 was realized when ICRI published a version of this document as ICRI 03740 Inorganic Repair Material Data Sheet Protocol in 2004. [7,8] It was later renumbered as ICRI 320.3R [9,10] and updated by ICRI in 2012. ACI published a nearly identical version of this document, ACI 364.3R-09: Guide for Cementitious Repair Material Data Sheet, in 2009. [11] Unfortu-

nately, at the time of this publication, it was not possible to have a unified version of the document with both organizations because it had not been developed as a joint committee. Reference to the ICRI document was removed at the request of the ACI Technical Activities Committee (TAC). Now, several years later, the document has been harmonized by merging the content of both versions. The combined document has been balloted by the appropriate technical committees of both organizations and reviewed by both organizations' TACs.

The introduction and scope of the combined document states:

"*The guidance on testing and reporting verifiable properties of mortar, extended mortar, and concrete is primarily intended for the manufacturer, to make sure the repair material data sheets are prepared in a standard way, with reproducible and comparable information. The manufacturer should use it for developing products based on market needs and technology improvements. The information provided in the document is certainly useful to the specifier in choosing verifiable properties consistent with the requirements of a particular repair situation. It provides the general user education on the range of material characteristics and properties that may impact a repair and on the nuances of the various tests available for that matter.*"

"*The purpose of this document is to provide a guiding protocol for testing and reporting of data for cementitious repair materials in order to allow objective comparison between alternative products. It does not address every issue associated with material selection; for further discussion, refer to ACI 546.3R.* [12] *The characteristics and properties described in this document do not necessarily need to be reported depending on the nature of the material and its intended use. Certain tests may not be appropriate for some materials. Materials containing lightweight aggregate or heavyweight aggregate are beyond the scope of this document as typically specialized tests are required for these materials*."

"*The test methods used for the determination of the reported data should be selected from those listed in the Table included at the beginning of the document and further explained within the document. The table covers most of the characteristics and properties generally of interest for cementitious materials, although it does not preclude others to be reported. Test data should be reported in the order and sections as listed, with the test method(s) used explicitly mentioned adjacent to it. Variations in the standardized test methods or substitute test methods prevent direct comparison between alternative materials by the specifier. Any additional test methods, non-standardized methods, or deviations from the test methods in this document shall be reported and documented in sufficient detail to allow the specifier to evaluate the likely impact on test results and to allow other laboratories to repeat the testing within acceptable repeatability and reproducibility*."

"*Additional information describing the significance and use of the test methods described herein may be found in ACI 546.3R and ICRI 320.2R.* [13] *In comparison with these documents, ACI 364.3R/ICRI 320.3R serves a very different purpose, that is, guidance on uniformized testing and reporting Material Data Sheet information. While ACI 546.3R lists standardized tests only, without directions, ACI 364.3R/ICRI 320.3R provides guidance on testing and reporting Material Data Sheet information and, where applicable, describes and explains modifications (such as used for drying shrinkage or freezing and thawing of composite specimens). Contrary to ACI 546.3R, no values are suggested in the ACI 364.3R/ICRI 320.3R document as its intent is essentially to provide a basis for testing to allow comparison between materials and to verify compliance with values reported by the supplier or other laboratories*." [1,2]

2 Organization of the Document

The document contains guidelines from both organizations—ICRI and ACI. It is printed in a two-column format, with the test method listed in the left column and commentary in the right. Information from both original versions were combined to create the final document.

The introduction and scope, which were described previously, are presented in the first chapter of the document. The second chapter is devoted to definitions, which is intended to complement what can be found in ACI Concrete Terminology (CT) [14] and ICRI Concrete Repair Terminology (CRT). [15] Chapter 3 contains information suggested to describe the repair material including material type, recommended use, claimed benefits, and stated limitations. Further explanation is included in examples listed by each characteristic. In quantitative terms including detailed methods for determining the characteristic, Chapter 4 covers packaged dry material content characteristics such as total sulfur trioxide (SO_3), total alkali content, chloride content, pH, and characteristics of the aggregate. Chapter 5 addresses the freshly mixed (plastic state) characteristics and properties of the repair material including the referenced test methods. The hardened state characteristics and properties of repair materials that should be reported in the Material Data Sheet are described in Chapter 6. The packaging information and content that should be reported in the Material Data Sheet are described in Chapter 7. Finally, the instructions on how to use the material that should be provided in the Material Data Sheet are described in Chapter 8.

3 Information to be Reported in a Material Data Sheet

3.1 Packaged dry material content characteristics

Due to concern for potential overexpansion or susceptibility to deterioration in some environments, the total SO_3 is to be reported and expressed as a percentage by mass of cementitious materials. Many proprietary materials contain blends of different cements, additives, admixtures, supplementary cementitious materials, and other constituents that contain alkalis or may influence alkali-aggregate reactivity (AAR). Guidance on the risk and mitigation of AAR is provided by referencing ASTM C1778, "Standard Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete." Total water-soluble and acid-soluble chloride contents as a percentage by mass of the mortar or concrete are reported to provide information to avoid exceeding the critical chloride concentration to initiate corrosion of metals in contact with the repair material. Allowable chloride limits are not provided as this threshold depends on the exposure conditions and on the type of structure being considered. The pH of the repair material for both the fresh and hardened states is also to be reported. A test method for determination of these pH values is recommended. The +170 mesh (90 µm) fraction obtained by wet sieving is used to determine the general characteristics, grading, deleterious substances, soundness, and reactivity of aggregates along with the values obtained from specific tests in comparison to the allowable limits for the intended use according to ASTM C33/C33M, "Standard Specification for Concrete Aggregates."

Table 1 lists all characteristics of packaged dry materials to be reported in the Material Data Sheet and applicable test methods.

Table 1. Characteristics of packaged dry materials to be reported in the Material Data Sheet and determined using referenced test methods

Characteristic	Test method(s)
Total sulfur trioxide (SO_3)	ASTM C114
Total alkali content	ASTM C114
Chloride content	ASTM C1152/C1152M, ASTM C1218/C1218M
pH	ACI 364.17T [16]
Characteristics of aggregate	ASTM C33/C33M, ASTM C88/C88M, ASTM C117, ASTM C1778

3.2 Fresh-state characteristics and properties

Chapter 5 describes the freshly mixed (plastic state) characteristics and properties of the repair material including methods for determining consistency, material unit weight, time of setting, air content, and yield using the recommended mixing equipment, duration, and sequence, as well as mixing liquid content. If a range of mixing liquid or consistency is recommended, the most fluid/least stiff workable consistency is to be used and the amount of mixing liquid used and consistency reported. Specific test methods are used for mortar and concrete and for self-consolidating and non-self-consolidating materials. A method for calculating yield of a repair material is provided from the unit weight of the mixed material and the total mass of mixed material and mixed package unit.

Table 2 lists all properties of fresh state material to be reported in the Material Data Sheet and applicable test methods.

Table 2. Characteristics of packaged dry materials to be reported in the Material Data Sheet and determined using referenced test methods

Property	Test method(s)
Consistency	ASTM C143/C143M, ASTM C1437, ASTM C1611/C1611M
Material unit weight	ASTM C138/C138M, ASTM C185
Time of setting	ASTM C191, ASTM C266, ASTM C403/C403M
Air content	ASTM C231/C231M
Yield	ASTM C138/C138M, ASTM C185

3.3 Hardened state characteristics and properties (chapter 6)

Chapter 6 describes hardened state characteristics and properties of a repair material. These characteristics/properties depend on the curing regimen used for the material with different conditions required if the repair product is normal setting, rapid hardening, or polymer modified. Four regimens are defined and the specific age(s) for testing described for each test. Rapid-hardening materials are either complying with the compressive

strength requirements described in ASTM C928/C928M, "Standard Specification for Packaged, Dry, Rapid-Hardening Cementitious Materials for Concrete," or prepared with a primary binder complying with ASTM C1600/C1600M, "Standard Specification for Rapid Hardening Hydraulic Cement." Polymer modification is left to the claims of the user of the material or determined based on the benefit of polymer modification, if such guidance is not provided by the material manufacturer or specifier. Because the curing regimen and age of the specimens at testing can significantly influence the test results, that information needs to be provided for the various characteristics and properties reported.

Hardened state characteristics/properties that should be reported in the Material Data Sheet include:

- Density, absorption, and voids—to develop the data required for conversions between mass and volume for mortar and concrete and to show inconsistencies within a mass of mortar or concrete;
- Air content—to estimate the likelihood of damage due to cyclic freezing and thawing;
- Compressive strength—to measure maximum resistance of a concrete or mortar specimen to axial compressive loading;
- Splitting tensile strength—to provide a generally satisfactory estimation of the material's tensile strength;
- Flexural strength—to determine the ability of a material to resist failure in bending and to estimate material's tensile strength;
- Direct tensile strength—to assess material's resistance to cracking and to evaluate tensile bond strength;
- Short-term tensile bond—to determine the adhesive bond between the repair material and the substrate concrete;
- Modulus of elasticity—to measure the stiffness of a material;
- Compressive creep—important if stress is induced in the repair material due to the restraint of shrinkage strains or factors such as thermal movement or the application of live loads;
- Coefficient of thermal expansion—to determine the change in linear dimension per unit length or change in volume per unit volume of a material per degree of temperature change;
- Length change—to determine the length changes that are produced by causes other than externally applied forces and temperature changes;
- Restrained expansion—to determine actual time-dependent volume changes the material, described as shrinkage-compensating, undergoes during and after curing;
- Cracking resistance—to evaluate the sensitivity of cement-based materials to cracking when subjected to restrained volume changes;
- Resistance to freezing and thawing—to determine susceptibility to deterioration when exposed to cycles of freezing and thawing;
- Scaling resistance—to evaluate the surface durability of materials in environments involving cycles of freezing and thawing and the use of deicing chemicals;
- Electrical indication of concrete's ability to resist chloride ion penetration—to determine the electrical conductance of concrete and to provide a rapid indication of its resistance to chloride ion penetration;
- Chloride ponding—to establish the correlation between the actual chloride ion penetration and indirect measures of the chloride ion penetration;
- Bulk electrical resistivity or conductivity—to provide a rapid indication of the material resistance to chloride ion penetration or to penetration of other ions;
- Sulfate resistance—to evaluate susceptibility of a material to sulfate attack; and
- Chemical resistance—to determine the material resistance to various chemicals, including inorganic acids, organic acids, alkaline solutions, salt solutions, and solvents.

Table 3 lists all characteristics/properties of hardened state materials to be reported in the Material Data Sheet and relevant test methods.

3.4 Packaging information and content

The packaging information and content that should be reported in the Material Data Sheet includes the following: the brand name; ASTM specification designation (if applicable); lot identification number; net weight in each container; date of manufacture; recommended use expiration date (shelf life); required storage conditions, including minimum and maximum temperature, humidity, and other conditions; conditioning requirements of the material prior to use; usable working time for high and low temperatures within which the product will meet the stated performance parameters; material volume yield in each container; and if the product is formulated for use in horizontal, vertical and/or overhead applications. The intent is to provide a consistent format for what information needs to be present on packaging labels.

The mean mass of packages in any shipment, as shown by weighing 50 packages selected randomly, must not be less than the mass printed on the package. In the USA, package mass must comply with the maximum allow-

able variation requirements specified for packages labeled by weight in the NIST Handbook 133 [17] and in Canada, package mass must comply with the tolerance requirements specified in the Consumer Packaging and Labelling Regulations (C.R.C. c. 417) [18] or local requirements, if superseded by local regulations. In all locations, the mass of an individual package must not vary by more than ±2% from the mass printed on the package.

Table 3. Characteristics of packaged dry materials to be reported in the Material Data Sheet and determined using referenced test methods

Property	Test method(s)*
Density, absorption, and voids	ASTM C642
Air content	ASTM C457/C457M
Compressive strength	ASTM C39/C39M, ASTM C109/C109M
Splitting tensile strength	ASTM C496/C496M
Flexural strength	ASTM C78/C78M, ASTM C348
Direct tensile strength	CRD-C 164 [19]
Short-term tensile bond	ASTM C1583/C1583M, ICRI 210.3R [20]
Modulus of elasticity	ASTM C469/C469M
Compressive creep	ASTM C512/C512M
Coefficient of thermal expansion	CRD-C 39 [21]
Length change	ASTM C157/C157M
Restrained expansion	ASTM C806, ASTM C878/C878M
Cracking resistance	ASTM C1581/C1581M
Resistance to freezing and thawing	ASTM C666/C666M
Scaling resistance	ASTM C672/C672M (*withdrawn*), ICRI No. 320.2R
Electrical indication of concrete's ability to resist chloride ion penetration	ASTM C1202
Chloride ponding	AASHTO T 259 [22]
Bulk electrical resistivity or conductivity	ASTM C1876
Sulfate resistance	ASTM C1012/C1012M
Chemical resistance	ASTM D1308

*Some of the referenced test methods are modified in this document, as stated in the corresponding section

3.5 How to use the material

The instructions that should be provided in the Material Data Sheet on how to use the repair material include concrete substrate preparation prior to repair such as the recommended Concrete Surface Profile (CSP) [23] number or range and the recommended moisture condition for the surface at the time of the repair material placement. When a bonding agent is recommended to bond fresh repair material to the substrate, the type of agent and its open time are to be included. If bonding agents or some types of bonding agents are to be avoided, this also needs to be clearly indicated.

If the product is permitted or required to be aggregate extended, the mass quantity to add per unit of material and, if it depends on the repair thickness or any other parameter, the recommended adjustment criteria, the grading size number per ASTM C33/C33M, the recommended aggregate moisture content, the maximum thickness of repair material beyond which aggregate extension is required, and any other requirement of the aggregate to be used needs to be included in the Material Data Sheet.

The recommended mixing equipment per ICRI 320.5R [24] as well as the amount of mixing water or other designated liquid to be used, or most fluid/least stiff workable consistency or range and the recommended mixing duration or sequence of mixing and resting time periods should also be in the Material Data Sheet. The repair material volume yield for mortar using ASTM C138/C138M with the 13.5 fl. oz. (400 mL) cylindrical measure of ASTM C185 and for concrete according to ASTM C138/C138M as ft^3/package (m^3/package) at the recommended mixing liquid content or most fluid/least stiff workable consistency needs to be reported on the data guide as well, as repeated in the product marking information.

The manufacturer's recommendations for placing, consolidating, and finishing the repair material including the working time of material at minimum and maximum application temperatures and the minimum and maximum application thickness are also information that should appear on the Material Data Sheet.

Curing is beneficial for development of desirable properties with cementitious materials. Adequate curing of repairs can be difficult and is sometimes neglected. For overhead and vertical repairs, curing methods such as the use of water spray or fog may not be practical, and the application of certain membrane-forming curing compounds could affect the appearance, the properties, or both, of the completed repair. The manufacturer's recommendations for curing the repair material, including a list of acceptable methods and materials for curing

of the applied material and guidance on return-to-service time at maximum and minimum curing temperatures needs to be provided in the Material Data Sheet.

Finally, the manufacturer's recommendations for cleanup and disposal of material in accordance with local regulations and requirements and the safety precautions necessary in batching, mixing, and application of the repair material referring to the manufacturer's safety data sheet (SDS) are to be included in the Material Data Sheet.

4 Conclusion

ACI PRC-364.3R-22/ICRI 320.3R-2022 is a new type of document for the concrete repair industry that can help overcome several of the obstacles that exist regarding the development of repair specifications. A multifaceted approach is required in the concrete repair industry where a great number of solutions are needed to solve the unique requirements that arise on repair projects around the world. Using this document, specifiers can select the important material properties and performance characteristics, which can be verified due to the transparency of the test methods used in the reporting of the repair material information.

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Note: Additional information on the ASTM standards discussed in this article can be found at www.astm.org.