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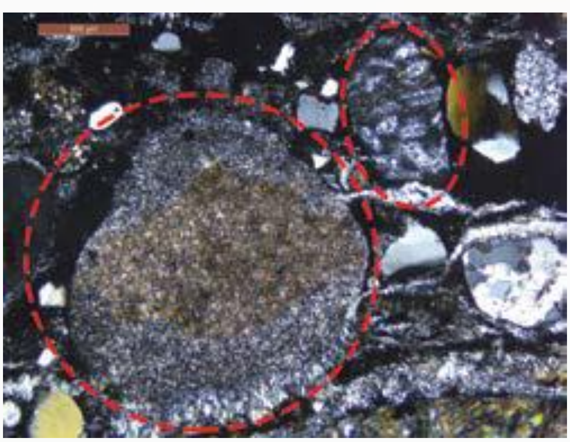
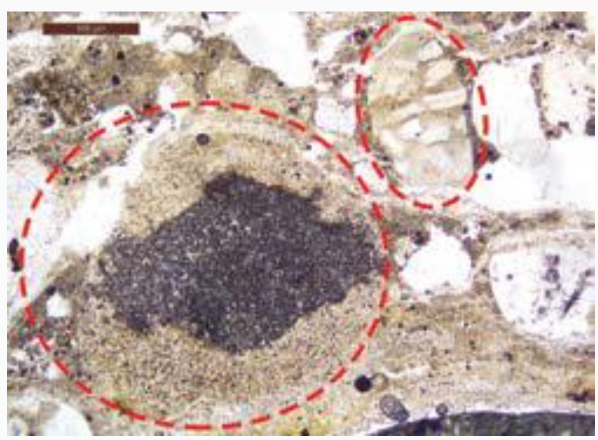
American Concrete Institute Malaysia Chapter

MYCONCRETE

The Bulletin of the American Concrete Institute – Malaysia Chapter (e-Bulletin)



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MyConcrete:
The Bulletin of the American Concrete Institute – Malaysia Chapter

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INTRODUCTION TO ACI MALAYSIA CHAPTER

American Concrete Institute - Malaysia Chapter (ACI-Malaysia) is a non-profit technical and educational society representing ACI Global in Malaysia, which is one of the world's leading authorities on concrete technology. Our members are not confined to just engineers; in fact, our invitation is extended to educators, architects, consultants, corporate, contractors, suppliers, and leading experts in concrete related field. The purpose of this Chapter is to further the chartered objectives for which the ACI was organized; to further education and technical practice, scientific investigation, and research by organizing the efforts of its members for a non-profit, public service in gathering, correlating, and disseminating information for the improvement of the design, construction, manufacture, use and maintenance of concrete products and structures. This Chapter is accordingly organized and shall be operated exclusively for educational and scientific purposes.

Objectives of ACI-Malaysia are:

- ACI is a non-profitable technical and educational society formed with the primary intention of providing more in-depth knowledge and information pertaining to the best possible usage of concrete.

- To be a leader and to be recognized as one of Malaysia's top societies specializing in the field of concrete technology by maintaining a high standard of professional and technical ability supported by committee members comprising of educators, professionals and experts.

- Willingness of each individual member/organization to continually share, train and impart his or her experience and knowledge acquired to the benefit of the public at large.

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UFT STRUCTURE RE-ENGINEERING SDN BHD	No 46, Jalan Impian Emas 7, Taman Impian Emas, 81300 Skudai Johor.	012 - 780 1500 (Mr.Lee)	Structural Repair, Construction Chemical, Carbon Fibre Strengthening, Protective Coating, Industrial Flooring, Soil Settlement Solution, Civil & Structure Consultancy Services, Civil Testing & Site Investigation.
SINCT-LAB SDN BHD	No 46, Jalan Impian Emas 7, Taman Impian Emas, 81300 Skudai Johor.	012 - 780 1500 (Mr.Lee)	Structural Repairing, CFRP Strengthening, Site Investigation, Civil Testing, Soil Settlement Solution, Civil And Structural Design And Submission.
STRUCTURAL REPAIRS (M) SDN BHD	No. 1&3, Jalan 3/118 C, Desa Tun Razak, 56000 Wilayah Persekutuan, Kuala Lumpur	012 - 383 6516 (Mr.Robert Yong)	Carbon Fiber Reinforced Polymer System, Sealing Cracks With Resin Injection, Re-Structure Repairs and Upgrade, Diamond Wire & Diamond Blade Sawing System, Diamond Core Drilling, Non-Explosive Demolition Agent.

Important Notes:

i) ACI Malaysia is only a platform for our members to advertise for interns.
ii) All application to be made direct to companies and would be subject to their terms and conditions.

UP COMING EVENTS

UP COMING EVENTS

PRECEDING EVENTS

PRECEDING EVENTS

**** Please find attached RSVP form in the attachment. Refer Appendix 3.***

ARTICLES

Reprint from: CI Magazine
March 2021, Vol. 43, No 1,
Page 35-40

Pilot-Scale Efforts in Reducing Embodied Carbon Footprints of Concrete in India

by Vijay Kulkarni, Ramesh Joshi, Utsav Biharilal Tayade, and S. Karthikeyan

Pilot-Scale Efforts in Reducing Embodied Carbon Footprints of Concrete in India by Vijay Kulkarni, Ramesh Joshi, Utsav Biharilal Tayade, and S. Karthikeyan activities have already caused a temperature rise of approximately 1°C (1.8°F) above preindustrial levels. A recent report by the United Nations Intergovernmental Panel on Climate Change (IPCC) warns that global temperatures are likely to increase by 1.5°C (2.7°F) between 2030 and 2052, with devastating effects.1

There is an increasing awareness that the construction sector, a main consumer of resources—energy, materials, water, and land—has to play a major role in mitigating the adverse effects of climate change. Among construction materials, concrete uses a lion's share of these resources. It is therefore imperative that concrete be produced and used in the most environmentally friendly manner possible.

Fortunately, there is a growing worldwide trend of making concrete "greener," or more environmentally friendly. This article enumerates the notable initiatives taken by some leading professional and manufacturing organizations in relation to developing criteria for characterizing the "greenness" of concrete. This is followed by a review of the current status of the concrete industry in India and recent pilot-scale efforts toward evolving and implementing green product certification in the country.

A Sampling of Green Initiatives

NRMCA

The National Ready Mixed Concrete Association (NRMCA), jointly with NSF Certification LLC, conducted a survey of approximately 7000 member ready mixed concrete (RMC) plants to arrive at an industry-average environmental product declaration (EPD). A report on this was published in 2019.2 From the immense variety of RMC products (or mixture designs) used by plants surveyed, a conservative approach was adopted to arrive at 72 workable concrete mixtures (48 normal weight and 24 lightweight concrete mixtures) that could pragmatically capture a high proportion of the RMC produced by these plants. The same mixtures were used for arriving at the industry-average EPD. The scope of the EPD is from cradle-to-gate and includes all upstream processes.

NRMCA also describes a methodology for quantifying and reducing the carbon footprints of concrete mixtures with the help of an example of an 18-story building.3 Here, one can use the mixture designs for different concrete structural elements that have significantly lower global warming potential (GWP) than the benchmark mixtures from the EPD data.

Concrete Sustainability Council

The Concrete Sustainability Council (CSC) has developed a "Responsible Sourcing Certification" system for cement, aggregate, and concrete companies.4 The certification by CSC includes the complete concrete supply chain: cement manufacturers, aggregate suppliers, and concrete producers. The certification takes place in four categories—namely, environment, economy, social aspect of sustainability, and management. To obtain certification, companies must fulfill certain prerequisites in these categories. CSC is the global system operator supported by regional system operators and certification bodies.

GCCA

During October 2019, the Global Cement and Concrete Association (GCCA) launched the "GCCA Industry EPD Tool" (Version 2.0) to support the publication of EPDs by cement and concrete producers.5 It is reported that GCCA will be making the tool available to all producers and organizations in the cement and concrete industries.

Architecture 2030

Architecture 2030—a nonprofit organization—launched "The 2030 Challenge" in 2006, appealing to the global architecture and building community to adopt targets for reducing GHG emissions.6 The 2030 Challenge sets targets to design new buildings and refurbish existing buildings to become carbon-neutral by 2030 as far as the use of fossil fuel energy is concerned in the operations of buildings. The 2030 Challenge for Products, issued in 2011, specified that manufactured products should meet a carbon footprint of 50% below the industry average by 2030.

Structural Engineers 2050

Structural Engineers 2050 (SE 2050) is a group of professionals who endorse the global vision of net-zero carbon building.7 In December 2019, the group decided to support the development of the SE 2050 Commitment Program.

The goal of this initiative is to inspire structural engineers to contribute to the global vision of zero-carbon buildings by 2050 and to provide measurement of progress toward that vision.

ACI

The American Concrete Institute (ACI) is in the process of creating a "Concrete Sustainability Assessor" certification. Sakai and Buffenbarger report that the program is being developed to endorse the competency of individuals tasked to assess and oversee the sustainability and resilience of concrete construction.8

India's Emissions

India is the third-largest carbon dioxide (CO_2) emitting country in the world, next only to China and the United States. Based on recent data published by India's Ministry of Power, coal—a major contributor to CO_2 emissions—stood at 54.2% in the total power generation (refer to Fig. 1).9 It seems that in spite of the efforts being made by the central and state

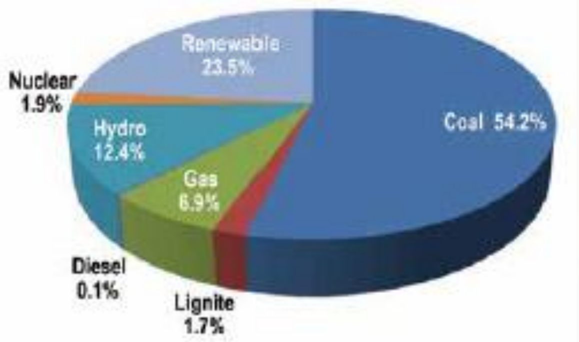

Fig. 1: India's power sector scenario at a glance9

governments to develop alternative sources of energy (for example, solar and wind), India's dependency on coal as a major source of power is not likely to decrease appreciably in the near future. Based on the projections made by The Energy and Resources Institute of India (TERI), coal would account for approximately 45 to 55% of India's commercial energy mix throughout the modeling period up to 2030 in each of the four scenarios studied.10 Incidentally, although India's CO2 emissions are high in quantitative terms, the country's contribution to GHG emissions in per capita terms is not alarming (refer to Fig. 2).11

Yet India has voluntarily pledged to cut GHG emissions by 33 to 35%, relative to 2005 levels, by 2030.12 It has also set a target to achieve approximately 40% cumulative electric power installed capacity from nonfossil fuel energy resources by 2030 by installing 100 GW of solar power and 60 GW of wind power by 2022.

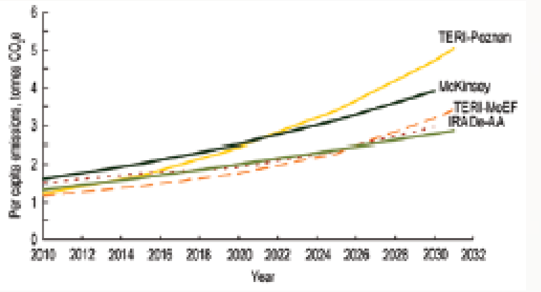

Fig. 2: Per capita GHG emissions by India, projected to 2031 in five model studies (after Reference 11) (Note: 1 tonne = 1.1 tons)

India's Concrete Industry

In India, construction involving concrete has traditionally been a labor-intensive activity. However, concrete construction in India—especially in urban areas—has undergone welcome transformations since the latter half of the 1990s. The demand for rapid construction—for housing, commercial buildings, and transportation systems—has necessitated the adoption of mechanized techniques of construction, including the use of RMC.

Although traditional concrete-making techniques are still in use in semiurban and rural areas, it has been heartening to witness their gradual disappearance from major urban centers.

While many RMC facilities have been developed in metropolitan areas during the past two decades, the exact number of operating RMC plants in the country is unknown. However, according to one rough estimate, 90 to 120 million m3 (118 to 157 million yd3) of concrete is produced annually using modern batch plants in India.13

Green Product Certification for RMC

Ongoing and planned construction activities in India are likely to further increase RMC construction, so the GHG emissions from concrete are bound to increase. Considering this, the Ready Mixed Concrete Manufacturers' Association (RMCMA) partnered with the Green Products and Services Council (GPSC) of India under the Confederation of Indian Industry (CII), and they developed the Green Product Certification for RMC. This initiative was supported by the Quality Council of India (QCI) and the International Finance Corporation (IFC).

For this purpose, an expert team was assembled in late 2017. The team reviewed the international efforts in this sphere. It was concluded that in view of the concurrent existence of modern ready mixed concrete on the one hand and the age-old, labor-intensive, site-mixed concrete on the other, it would be practically difficult to develop a common EPD for concrete in India. It was also observed that in view of the variety of social and economic factors and the lack of robust regulatory mechanisms, adoption of CSC's Responsible Sourcing Certification would not be feasible in India. Therefore, the expert team decided to devise localized criteria for certification. Termed GreenPro certification for RMC, the detailed account of the scheme is enumerated elsewhere.14

Salient features of the scheme include:

- Eight parameters are used for evaluating the green features of RMC: product design, product performance, raw materials, manufacturing process, waste management, life-cycle approach, product stewardship, and innovations;

- The scheme evaluates resource conservation through increased use of recycled content (for example, fly ash and slag cement);
- The scheme uses the well-known 3R (reduce, recycle, and reuse) techniques to assess energy efficiency, water efficiency, and minimization of waste;
- Three simple tools propounded by P.K. Mehta to improve the sustainability of concrete formed one of the main backbones of the certification scheme.15 These tools include: (i) minimize the amount of ordinary portland cement (OPC) in concrete, (ii) consume less concrete through innovative architecture and design, and (iii) consume less clinker in cement;

Credits are awarded based on concrete properties that reduce environmental impact. It was observed that quite a few RMC companies in India promote the use of value-added products, some of which have the potential to become qualified (with appropriate changes) as environmentally friendly products. Certain examples of products listed next are included in the scheme and due credit was given after thorough audits:

- High supplementary cementitious material (SCM) concrete (beyond the maximum permissible percentages permitted by the Indian Standards) used in plain concrete, foundations, mass concrete, and even structural members where 56- or 90-day strength is specified for compliance;
- High-strength concrete, which helps in reducing section sizes, thereby reducing the quantity of concrete required;
- Concretes having low densities, the use of which improves thermal insulation of the building envelope and helps in energy reduction;
- Self-compacting concrete (SCC), which speeds up construction and eliminates the need for vibration during placing of concrete, thereby helping in noise reduction; and
- Durable concrete, which minimizes repair/restoration work and delays reconstruction, thereby saving materials and cost.
- Considering the environmental damage inflicted due to the unrestricted dredging of Indian rivers, the scheme gives credits for the use of crushed stone/gravel sand in place of river sand;
- To achieve the green concrete certification, RMC plants must fulfill certain basic prerequisites with regard to minimum equipment and system requirements, air and water pollution control measures as certified by state pollution control authorities, and occupational health and safety compliances;
- The scheme is based on both plant and product certification. While the maximum achievable credit points are 100, the products and the plant supplying the products will be certified based on certain minimum points earned during the audit-based evaluation; and
- The plant-based audit and conformity evaluation are done by a third-party agency having appropriate experience in such evaluation.

GreenPro Audit of RMC Plants

The GreenPro certification for concrete was launched in the latter half of 2017, with awareness seminars held in some major cities. The actual pilot-scale audit of RMC plants commenced in 2018. A total of 17 plants from reputed companies were offered for certification. Because these plants were in the north, south, east, and west regions of India, the data obtained may be considered representative.

Before commencement of each audit, a joint meeting of the stakeholder teams from the company's plants was held to explain the details of the audit scheme and set the audit schedules for the plants. The plant personnel furnished the required data, including the mandatory prerequisites, to the audit team beforehand. The plant audit was conducted by two experts:

an experienced concrete technologist and a GPSC-certified auditor. The audit data were thoroughly analyzed, and once the nonconformities, if any, were closed, GreenPro certification was awarded.

Critical Observations during GreenPro Evaluation

Here, some critical observations made by the GreenPro evaluation team are worth mentioning:

- All documentary evidence of mandatory prerequisites were duly made available to the auditing team;
- Most of the RMC plants used crushed stone sand (CSS), excepting certain plants in Gujarat state, where river sand was available at a lower price than CSS;
- While the plants from the south, east, and west regions used both fly ash and slag cement, those from the north used only the former as the higher transportation cost of slag cement resulted in uneconomic mixtures. For producing high-strength concrete, microfine materials like silica fume or ultrafine slag cement were used;
- The percentage replacement of OPC with SCMs varied from plant to plant (as evident from Fig. 3). The average replacement of OPC with SCMs from 17 plants was approximately 25%; and
- An overwhelming majority of the city-based RMC plants were found to have strict pollution-control systems, including cover over aggregate bins, sprinkling of water on aggregates to suppress dust, silos fitted with dust-control filters at the top and bottom with pressure release valves,

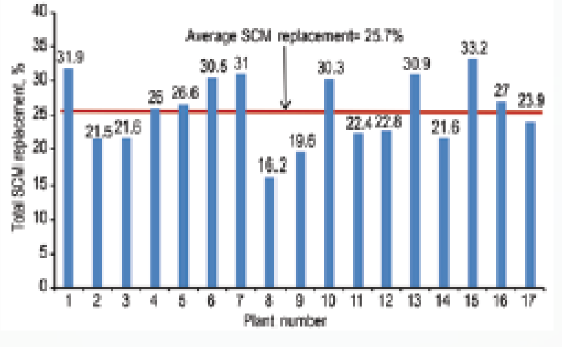

Fig. 3: Plant-wise percentage of the total replacement of OPC by SCMs

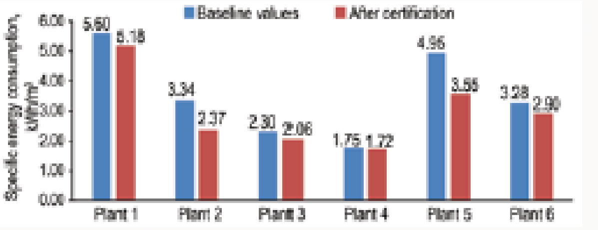

Fig. 4: Comparison of postcertification specific energy consumption with baseline values (Note: 1 kWh/m3 = 0.765 kWh/yd3)

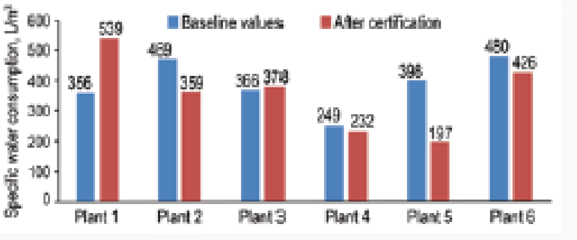

Fig. 5: Comparison of postcertification specific water consumption with baseline values (Note: 1 L/m3 = 0.2 gal./yd3)

and reclaimer systems for treating returned concrete. Some plants even had a working filter press system to effectively reuse the sludge and recycled water.

Postcertification Reduction in Embodied CO2

With a plan to evaluate the outcome of GreenPro certification, RMC plants were requested to share their postcertification data. Out of the 17 certified plants, six plants responded positively. The GreenPro team analyzed the postcertification data of the six plants, and four key parameters were compared with the baseline parameters obtained from certification.

All six plants showed reductions in specific electric energy consumption (refer to Fig. 4). The average consumption came down from 3.40 to 2.80 kWh/m3 (2.6 to 2.2 kWh/yd3). The average specific water requirement for the six plants decreased, from 373 to 335 L/m3 (75 to 68 gal./yd3), although Plants No. 1 and 3 showed an increase (refer to Fig. 5). The average OPC substitution with SCMs from the six plants increased, from 28.6 to 31.14%, although Plant No. 2 showed a 3%

reduction in the substitution (refer to Fig. 6).

The embodied carbon dioxide equivalent (CO2e) was calculated for plant-wise concrete (CO2e signifies the amount of CO2 that would have the equivalent global warming impact). The postcertification CO2e is compared with baseline values in Fig. 7. For such calculations, the embodied CO2e was considered as 0.82 kg CO2e per kg of cement

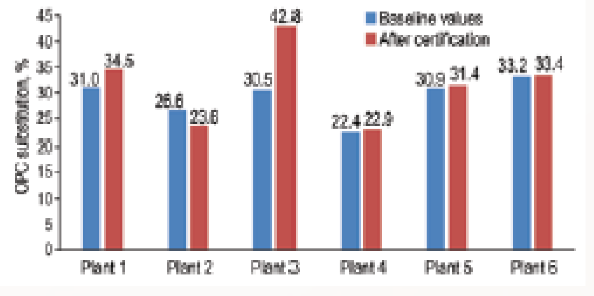

Fig. 6: Postcertification improvement in OPC substitution of six plants

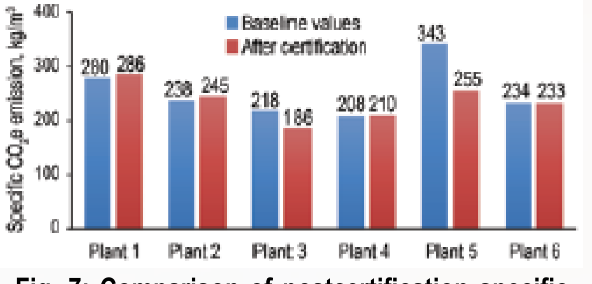

Fig. 7: Comparison of postcertification specific CO2 emission with baseline values measured as kilograms of CO2e per m3 of concrete (Note: 1 kg/m3 = 1.7 lb/yd3)

(0.82 kg CO2e/kg [1.8 lb CO2e/lb]) and was based on the report from CII.16 From the database maintained by CII, the CO2 intensity values for fly ash and slag cement were assumed as 0.004 and 0.071 kg CO2e/kg (0.0088 and 0.156 lb CO2e/lb), respectively. The CO2e values of locally sourced aggregates, being marginal, were neglected. The postcertification average for the six plants decreased from a base value of 0.251 to 0.233 CO2e/m3 (0.192 to 0.178 CO2e/yd3), showing a reduction of 7.2%. Considering that the six plants reported to the evaluation team that they produced 350,215 m3 (458,100 yd3) of concrete, the reduction in embodied CO2e totals 6304 tonnes (6949 tons). This small initial achievement would certainly encourage our team to continue future efforts in this area.

Conclusion

The pilot-scale implementation of an indigenously developed green certification scheme in India not only helped in enhancing general awareness about the need to enforce such measures but also triggered welcome improvements. This was evident from the analysis of the postcertification data from six plants, which showed a reduction in specific electric use and specific water consumption, as well as an improvement in OPC substitution with SCMs. The postcertification reduction of 7.2% in the embodied CO2e of concrete from the six plants can indeed be considered a worthwhile achievement.

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Selected for reader interest by the editors.

ACI member **Vijay Kulkarni** was Vice President of the ACI India Chapter from 2005 to 2007. He was the Principal Consultant to RMCMA and contributed to the development and implementation of the quality scheme for ready mixed concrete in India. He was the President of the Indian Concrete Institute (ICI) from 2009 to 2011 and is currently the Chair of ICI's Durability Committee. He is the Chair of the Technical Committee for GreenPro certification. He is the past Editor of the *Indian Concrete Journal*.

Ramesh Joshi, a civil engineer with a postgraduate diploma in management, has three decades of experience in different facets of the cement industry. He has filled diverse roles across India, developing deep insights into businesses involving ready mixed concrete, gray cement, and white cement. He is currently the President of RMCMA of India and Senior Management Leader for the concrete and cement industry. He is an active committee member of GCCA on concrete guidelines.

Utsav Biharilal Tayade is an Associate Counsellor with CII—Sohrabji Godrej Green Business Centre, Hyderabad, India. He has over 7 years of work experience in ecolabeling and energy efficiency. He has contributed to the implementation of a low-carbon roadmap for the ready mixed concrete industry through the development and implementation of the GreenPro ecolabeling program in India.

S. Karthikeyan is a Principal Counsellor with CII—Sohrabji Godrej Green Business Centre. He has over 20 years of experience in industrial energy efficiency, green buildings, and ecolabeling. He has been instrumental in designing and developing GreenPro, an Indian ecolabel, which aims at facilitating green product market transformation in the country.

TECHNICAL REPORT

Reprint from: CI Magazine
May 2021, Vol. 43, No 2, Page 18-22

Fiber-Reinforced Polymer Reinforcement for Concrete Members

ACI Committee 440 is taking the next step toward building code compliance

by Mahmut Ekenel, Francisco De Caso y Basalo, and Antonio Nanni

Fiber-reinforced polymer (FRP) offers new capabilities for structural and nonstructural applications in building construction. FRP bars and, more recently, meshes (Fig. 1 and 2) for use as concrete reinforcement have gained popularity by offering some distinct advantages such as resistance to corrosion, high stiffness-to-weight ratio, and relatively lower labor and handling costs. FRP bars have been successfully used as structural reinforcement in concrete members in building and bridge projects (for example, slabs and beams) for the past three decades. Figure 3 shows progress on the construction of a residential home in Great Harbour, Berry Island, Bahamas, where glass fiber-reinforced polymer (GFRP) reinforcement was used for all structural concrete elements, including the masonry walls. Figure 4 shows the use of GFRP straight and bent bars for the construction of the bent caps in a bridge replacement project at the 23rd Avenue over Ibis Waterway, Broward County, FL, USA.

Recently, there has also been interest in using FRP bars and meshes as secondary reinforcement for concrete members such as plain concrete footings, slabs-on-ground, and plain concrete walls in lieu of conventional temperature and shrinkage steel reinforcement. Use of basalt fiber-reinforced polymer (BFRP) mesh as secondary reinforcement is shown in Fig. 5. BFRP mesh was used for this project at Florida Keys Marathon International Airport in Marathon, FL. The mesh comprised 3.6 mm (0.14 in.) diameter wire fabricated in a 100 x 100 mm (4 x 4 in.) orthogonal grid. The floor slab constructed on an existing concrete slab (with cracks and gaps) is used for light aircraft hangar. The slab thickness varies from 100 to 150 mm (4 to 6 in.).

The evaluation of FRP bars and meshes used as primary or secondary concrete reinforcement in compliance with the legally adopted building codes in the United States is the topic of this article.

Fig. 1: FRP bar examples with various surface characteristics

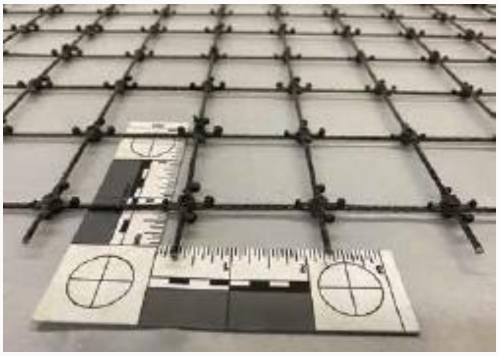

Fig. 2: An FRP mesh example. The intersections are connected with a nonstructural polymer connector

Fig. 5: FRP meshes can be used as secondary reinforcement in slabs-on-ground

Building Codes in the United States

In the United States, where the power to regulate construction is vested in local authorities, a system of model building codes is used. The International Building Code (IBC) and the International Residential Code (IRC) are the two model codes that have been developed to establish the minimum requirements to safeguard the public health and safety. In general, IBC and IRC address structural strength, means of egress, sanitation, adequate lighting and ventilation, accessibility, energy conservation, and life safety regarding new and existing buildings, facilities, and systems. Currently, IBC has been adopted throughout the entire country, as well as the U.S. territories, while IRC has also been adopted by most of the states.

Engineers and architects are usually guided by national and local building codes that are based on the model codes. These model codes become especially important when compliance with the legally adopted building code is mandated by a jurisdiction having the authority to approve construction projects. Compliance can be readily achieved when a design incorporates materials or assemblies covered in the IBC or IRC. However, when a design incorporates materials or assemblies that are not specifically covered in the IBC and IRC, building code compliance may need to be demonstrated. Section 104.11 of IBC provisions1 allows an alternative material, design, or method of construction to be approved, where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, provided the material and method under evaluation is, for the purpose intended, at least the equivalent of that prescribed in quality, strength, effectiveness, fire resistance, durability, and safety. Subsection 104.11.1 of IBC, which refers to research reports, allows such reports to be issued by approved sources where necessary to assist in the approval of materials or assemblies not specifically covered. The more permanent option would be to revise IBC and IRC to allow alternative materials or assemblies, such as FRP bars and mashes to be used as structural and secondary reinforcement; however, such revisions must go through the lengthy, public comment and approval process of t

Fig. 3: A coastal residence under construction. The concrete slabs, concrete columns, and masonry walls included FRP reinforcement

Fig. 4: A coastal bridge under construction. The piers and bent cap were reinforced with FRP reinforcing bars supplied in both straight and pre-bent forms

The International Code Council (ICC). To this end, ACI Committee 440, Fiber-Reinforced Polymer Reinforcement, has commenced the development of a mandatory language design code governing the use of FRP reinforcement. This code will be dependent on the ACI 318 Code[2] and designed to be readily adopted by reference into the model and local building codes.

Creating a code compliance in accordance with Section 104.11 of IBC is the preferred method. This is typically accomplished through product testing in accordance with an Acceptance Criteria (AC), which defines product sampling, testing, and quality requirements to be fulfilled to obtain code-compliance verification. The results of these requirements are summarized in a research report made available to code officials, as set forth in Section 104.11.1 of IBC. The research reports are typically issued by certification bodies that are accredited as complying with ISO/IEC 17065.[3]

All testing must be conducted by a laboratory that complies with ISO/IEC 17025.[4] The certification body (evaluation agency) requires accreditation by a recognized accreditation body, which directly verifies the competence of a laboratory by visiting the facility and observing its personnel during testing. The accreditation body must also determine whether the laboratory has a robust quality system to assure accuracy of reported results and have means to investigate and make corrections when reports are questioned.

To date, IBC and IRC do not include provisions for use of FRP bars and meshes as replacement of steel reinforcement. Chapter 19 of the IBC refers to ACI 318 for design of reinforced concrete buildings; similarly, ACI 318 also does not address use of FRP bars and meshes as replacement for steel reinforcement. Therefore, AC for use of FRP as reinforcement of concrete, AC454[5] and AC521[6], have been developed by ICC-Evaluation Service (ICC-ES) under Section 104.11 of IBC and Section R104.11 of IRC.[7]

Acceptance Criteria for Building Code Compliance

Development of an AC usually starts with an application from an interested party who oversees the invention or production of an alternative construction product, system, or technology. After review of the IBC and IRC to confirm that the proposed alternative is not within the provisions of IBC or IRC, an AC is drafted with the help of producers, academics, and other interested parties. The draft AC is then shared with the public, through an open, online web posting, to solicit comments. Public comments are collected, a response letter by the proponents of the proposed criteria is prepared and shared publicly, and further revisions are implemented if necessary. As a final step, open public hearings are held, with selected independent code officials acting as an evaluation committee that listens to the concerns of the public and the responses of the AC proponents and poses their own questions and comments. The evaluation committee then votes on the proposed AC. A simple majority is required for an AC to be accepted and issued. Because the use of FRP bars and meshes as primary or secondary reinforcement is not within the current code provisions, AC454 and AC521 have been developed under Section 104.11 of IBC and Section R104.11 of IRC, with final approval dates of October 2020 and December 2020, respectively.

AC454 applies to GFRP or BFRP bars, in cut lengths, bent shapes, and continuous closed stirrups and ties (hoops), that are used to reinforce concrete structural members. The AC requires evaluation of physical and mechanical properties, performance under accelerated environmental exposures, performance under exposure to fire conditions, and structural design procedures. AC454 is applicable to FRP bars that are solid and have circular or noncircular cross sections, or hollow and have circular cross sections. Bars meeting AC454 are used as reinforcement in structural concrete members such as columns, beams, walls, shallow foundations, and one-way or two-way slabs, and as shear reinforcement for flexural members. Under AC454, FRP bars are limited to structures constructed in Seismic Design Category A or B using normalweight concrete. AC454 references include ASTM D7957/D7957M-17[8] for most of the required testing and ACI 440.1R-15[9] for design provisions. However, AC454 also describes full-scale structural tests for members reinforced with noncircular solid FRP bars or circular hollow FRP bars.

AC521 applies to glass or basalt FRP bars in cut lengths or meshes produced with solid wires with continuous, uninterrupted circular cross sections. Items evaluated under AC521 include physical and mechanical properties. FRP bars and meshes evaluated under the AC521 are used as alternatives to the shrinkage and temperature reinforcement specified in Section 24.4 of ACI 318-19 for plain concrete footings and for plain concrete slabs-on-ground (as defined by ACI 360R-1010). However, this AC does not eliminate the requirement for joints specified in Section 14.3.4 of ACI 318-19 (and thus IBC and IRC).

FRP bars and meshes under this AC are also used as an alternative to horizontal temperature and shrinkage reinforcement in structural plain concrete walls covered in IBC Section 1906, IRC Sections R404.1.3 and R608.1, and ACI 332-14, Sections 8.2.1 and 8.2.7,11 excluding walls where vertical reinforcement is required. AC521 also provides provisions for shrinkage cracking testing (Fig. 6). The purpose of the shrinkage cracking test is to demonstrate equivalency between a given FRP bar or mesh configuration (that is, FRP cross section size and spacing) and a selected steel reinforcement configuration, in terms of control of shrinkage cracking performance. The intent is to allow the contractor to obtain the building official's approval for the use of an FRP solution as an alternative to a steel solution, without the need for additional testing or engineering calculations.

Besides testing in accordance with the requirements of acceptance criteria, an equally important aspect of product evaluation is the requirement for documentation of quality control measures during the manufacture of the materials. The measures are intended to verify that the produced materials will match the performance as previously demonstrated by testing. As a means of verification, the quality system needs to be inspected by an accredited inspection agency. The inspection agency must be independent and conform to requirements stipulated in ISO/IEC 17020,12 as determined by a recognized accreditation body. The evaluation agency is charged with requiring that the inspection agency inspect each manufacturing location regularly, and not less than once per year, to provide assurance that the FRP materials are produced and conform to critical performance and measurements set forth in quality documentation.

Fig. 6: Formwork, reinforcing bars, and crack initiator for shrinkage cracking test specimen preparation

Summary

ACI Committee 440 is progressing with the development of an ACI 318-dependent, mandatory language design code governing the use of FRP reinforcement. The committee expects the document to be completed by 2022. Once this code is published by ACI, it will be submitted for public review through the ICC process so it can be adopted into IBC and IRC for concrete building construction.

IBC and IRC are the predominant building and residential codes in the United States. To construct buildings using alternative materials that are not covered by the codes, two options exist:

- The building code must incorporate the new technology through the public hearing process of ICC, or
- Building code compliance is shown, based on Section 104.11 of IBC or Section R104.11 of IRC.

The first case may be accomplished once ACI Committee 440 has successfully developed a design code. The second case requires that the proponent of the alternative materials demonstrates building code compliance via AC454 or AC521, where AC454 applies to structural reinforcement applications and AC521 applies to shrinkage and temperature reinforcement applications.

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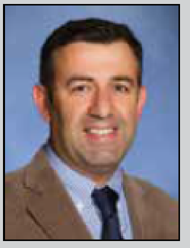

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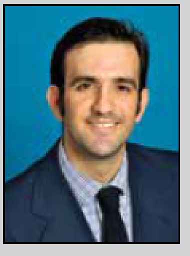

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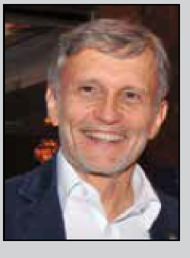

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CASE STUDY

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Biogenic Sulfuric Acid Attack and Case Studies

by Hugh (Xiaoqiang) Hou, Kimberly A. Steiner, John Fraczek, and James A. Mahaney

Biogenic sulfuric acid attack (BSA) is probably the most common and most severe biodegradation mechanism affecting concrete. BSA causes widespread global infrastructure deterioration, and it is reported to be responsible for damages totaling about 10 billion dollars per year in the United States alone.[1,2] Several different names have been attributed to the distress, including microbially or microbiologically induced deterioration (MID), microbially induced corrosion (MIC), biogenic sulfide corrosion, and hydrogen sulfide corrosion. Identifying the characteristics of BSA distress can raise awareness of the distress and its impact. Improved understanding of the mechanisms and rate controlling factors is crucial in designing new, durable concrete structures and mitigating existing concrete against the deterioration.

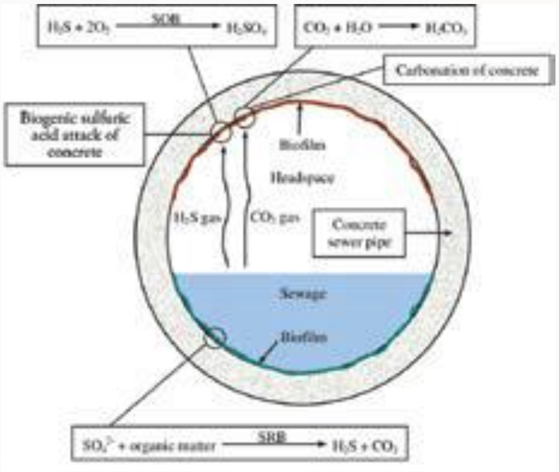

Fig. 1: Schematic representation of biogenic sulfuric acid attack (BSA) mechanism in a concrete sewage pipe (after Reference 2), where SOB is sulfur-oxidizing bacteria and SRB is sulfur-reducing bacteria. Elemental sulfur can be formed via chemical reaction: 2 H_2S (gas) + O_2 (gas) → 2 S (solid) + 2 H_2O (liquid)

BSA involves cycling different sulfur species (of various valence) and eventually concentrating sulfuric acid on the concrete surface of sewer systems, waste digesters, chimneys, or similar structures, under the influence of various bacteria (Fig. 1). Normal sewage effluents have a pH of 5 to 8, which is not low enough to severely degrade concrete in contact.[3] However, anaerobic bacteria (for example, *Desulfovibrio* species) in the sewer system can decompose inorganic and organic sulfur compounds (for example, sulfate), releasing hydrogen sulfide (H_2S) gas to the headspace above the effluent/sludge waste. The hydrogen sulfide is absorbed into a surficial moisture film on inner walls of concrete pipes, which contain aerobic bacteria such as thiobacilli. Hydrogen sulfide is oxidized into sulfur and eventually into sulfuric acid by bacterial metabolism. The sulfuric acid reacts with the cementitious paste of concrete (as well as steel and carbonate aggregate, if present) and cause deterioration.

Research has been devoted to designing and developing new durable concrete with good resistance to BSA.[4] Calcium aluminate cement, calcium sulfoaluminate cement, and geopolymer are reported to exhibit better performance in resisting BSA than portland cement.[5] Concrete mixtures with carbonate aggregates also perform better relative to mixtures with siliceous aggregates,[6] due likely to the sacrificial role or greater acid-neutralizing effect of carbonate aggregates.

Coatings, polymer linings, surface treatments, antimicrobial and mineral admixtures, running the pipes at full capacity, or decreasing the effluent residence time are all measures that reportedly reduce the detrimental effects of BSA.

BSA deterioration is generally manifested as exfoliated surface loss with aggregate exposed, discoloration, and progressively altered zones with varying composition and texture in the existing concrete. This article discusses two case studies:

- A relatively new waste digester; and
- A decades-old sewer tunnel structure.[7] The focus of the discussions is on distinct compositional and textural characteristics and variations from the exposed surface to sound concrete in these BSA-affected structures.

Fig. 2: Fractured concrete roof panel. BSA-caused deterioration manifested as paste color lightening and weakening along the cell perimeter (arrows) as well as corroded and broken prestressing strands

Case Study I: Manure Digester

The concrete roof of a methane production facility failed prematurely because of BSA-caused corrosion. The roof consisted of a topping slab supported on hollow-core precast prestressed concrete planks. The concrete planks were apparently manufactured using an extrusion fabrication method, resulting in large amounts of irregular, interconnected, entrapped air voids in the concrete. Field investigation revealed that the plank concrete suffered severe deterioration throughout the roof area, with up to 5 in. (127 mm) of localized spalling from the underside and with broken or corroded prestressing strands (Fig. 2).

Concrete cores extracted from the top surface to the mid-depth of the planks (that is, the upper half of the planks) were studied using petrographic methods. The plank concrete exhibited distinct deterioration along the perimeter of the empty cells (cores) to a maximum depth of about 20 mm (0.8 in.), shown in Fig. 2 to 6. The deterioration appeared to be progressive, starting from the cell surface and propagating to the interior web and flange concrete to the side and above each cell. No deterioration or alteration of the concrete matrix was observed in the topping concrete.

Material layers or alteration zones from the cell surface to the interior concrete included:

- An elemental sulfur (S) layer, approximately 1 mm (0.04 in. or 40 mils) thick, at the perimeter of the cell (Fig. 3 and 4). The layer comprised many thin sublayers and exhibited an overall banded or lamination texture. Acicular sulfur crystals occurred and aligned perpendicular to the banding or the cell surface. Generally, no cement paste or aggregate particles were present in the sulfur layer. The layer did not appear to have been derived or altered from concrete or exhibit evidence of concrete constituents. The surface of the sulfur layer was smooth and did not appear to have ever been in direct contact with the effluent or waste sludge;
- Large, frequently tabular euhedral gypsum crystals behind the sulfur layer. The thickness of the large gypsum zone was approximately 0.2 mm (8 mils), shown in Fig. 3 and 4. Only a few aggregate particles were present in the gypsum layer. Large euhedral gypsum crystals are presumed to have recrystalized from solution, and the presence of the large crystals (as well as the sulfur layer described previously) would indicate a long period of a stagnant, nonturbulent environment;
- A zone behind the large gypsum layer of intimately mixed microcrystalline gypsum and amorphous silica-alumina gel that encased aggregate particles. The thickness of this

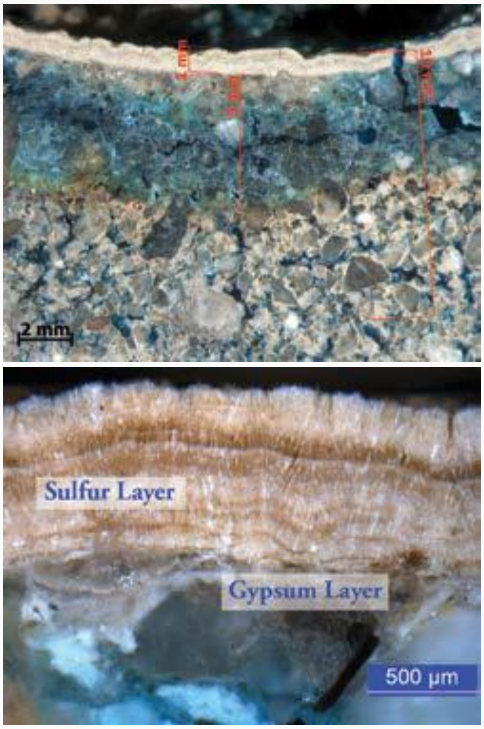

Fig. 3: Close-up views of near-surface concrete subjected to BSA with a banded sulfur layer (buff or pale white); a porous, weak, heavily paste-depleted zone; a brown carbonated front; and sound concrete. Blue epoxy applied in sample preparation readily soaked into the porous altered paste but not much into the dense, unaffected concrete except for large voids (Note: Different lighting condition and greater magnification for the bottom photo)

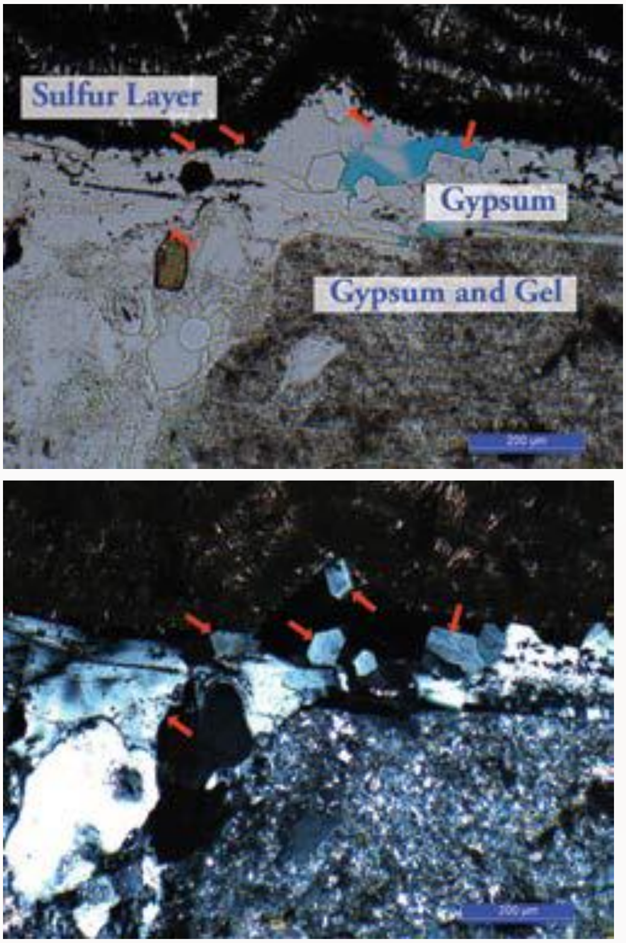

Fig. 4: Thin-section photographs show a sulfur layer (black) backed by large euhedral tabular gypsum (red arrows), and a microcrystalline gypsum and silica gel zone: (a) plane-polarized light; and (b) cross-polarized light

zone ranged from less than 0.1 to 0.6 in. Gypsum and gel materials had almost fully replaced portland cement paste in the zone. No residual cement particles, calcium hydroxide, or normal calcium silicate hydrate (CSH) paste were observed in the zone. Abundant surfaceparallel cracks and microcracks were present. Also, sand particles frequently exhibited cracks that were filled with gypsum. Peripheral/rim cracks surrounding aggregate particles were also frequently lined with gypsum. Materials in this zone were pale white and overall porous, soft, and friable. No carbonation or carbonated products were observed. The alteration in this zone was considered complete or near complete;

- A thin brown-orange discolored layer or line less than 0.05 in. thick, which likely represents the reaction front and signifies the bottom of the severely deteriorated concrete. The discoloration or staining appeared to be mainly related to ferrite in the cement paste that perhaps that was affected by the acidic pore solution;
- An intensely carbonated zone, up to 0.5 in. thick, behind the brown-orange line. Gypsum was occasionally observed in voids or cracks.

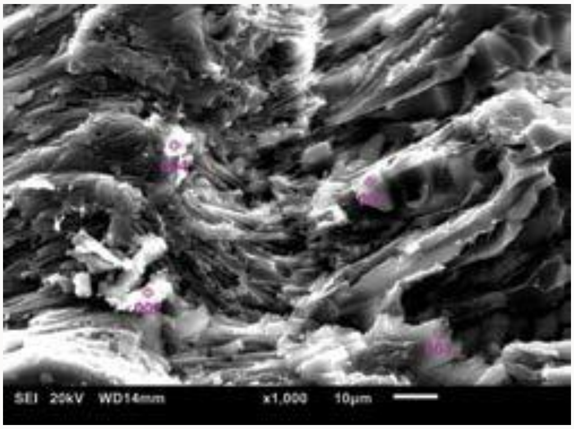

Fig. 5: Secondary electron image (SEI) of sulfur deposit on BSAaffected plank concrete. The composition of the deposit was confirmed using energy dispersive X-ray spectroscopy

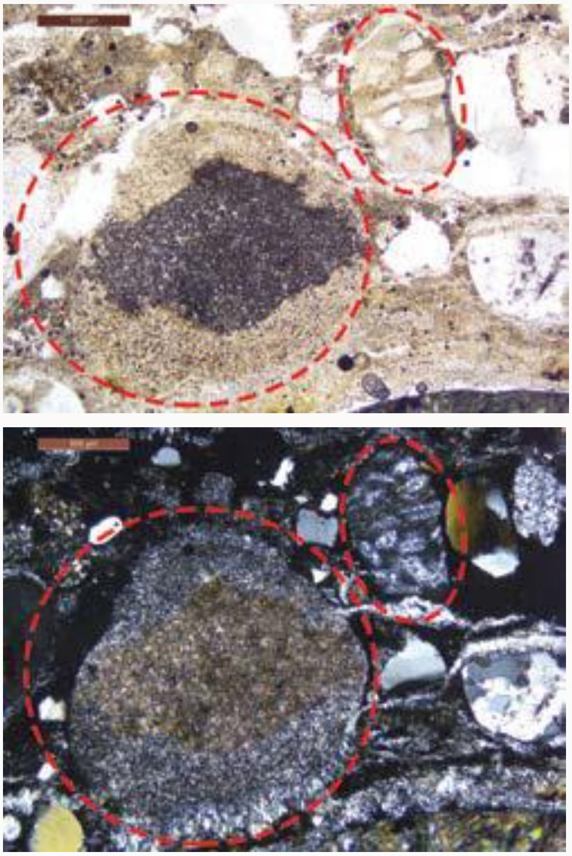

Fig. 6: Thin-section photo shows two carbonate sand particles (circled) partially replaced by gypsum: (a) plane-polarized light; and (b) cross-polarized light. Quartz/quartzite and other siliceous particles were not chemically affected by the acid attack but could frequently exhibit cracks lined with gypsum

However, no significant reduction in paste hardness was observed; and

- Sound, partially carbonated bulk concrete at a depth of up to 0.8 in. from the exterior surface of the sulfur layer. There was no apparent depletion of calcium hydroxide associated with the carbonation, probably due to an overall low calcium hydroxide content

Fig. 7: Sewer tunnel with exposed second mat of steel reinforcement. Top concrete and the first mat of steel reinforcement were reportedly lost to the existing surface (from Reference 7)

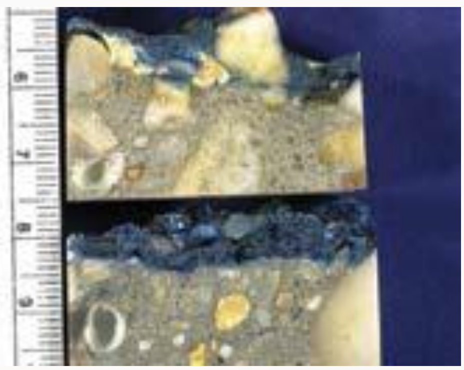

Fig. 8: Close-up views of the near-surface region of the tunnel concrete. The depth of affected paste is well defined by the visible change in color and appearance of the degraded cement paste. Blue epoxy readily soaked into the porous off-white or paleyellow altered paste but not into the dense, unaffected body concrete. Scale is in millimeters

that would be associated with a low water-cement ratio (*w*/*c*) concrete mixture.

The described characteristics are generally consistent with widespread distress caused by BSA. BSA deterioration is generally more severe for concrete exposed to closed gas/air headspace (that is, the "crown" of a sewer pipe or, in this case, the roof soffit of the subject digester, which was not submerged) compared to concrete that remains submerged in the effluent/waste, due to accumulation of H_2S gas in the atmosphere. This differential deterioration can be used to distinguish general acid attack from BSA-caused acid attack.

A third concrete core from the project exhibited no deterioration to a minimal deterioration layer that was typically less than 2 mm (0.08 in.) thick in the cell concrete, based on the visual examination. The exposure condition for this concrete core is not known. Localized variations in depths of deterioration around a specific cell were noted and were mainly related to localized variations in microporosity, void content and connectivity, and paste volume. No soffit portions of the planks were provided for comparison.

Case Study II: 100-Year-Old Tunnel

Concrete from a 100-year-old buried tunnel structure exhibited severe discoloration, spalling, and steel reinforcement corrosion. The interior surface of the tunnel showed a severely corroded reinforcement mat, reportedly the second layer of reinforcement (Fig. 7). Cored concrete studied in the laboratory exhibited overall compositional and textural characteristics similar to those discussed in Case Study I (Fig. 11 and 12 from Reference 7), except that the elemental sulfur layer was not observed. The BSA-affected layers were thin, typically about 0.2 in. in total thickness. Concrete in the exterior of the structure appeared to be in good condition and did not exhibit BSA-related or other distress. The tunnel concrete appeared to have been batched with a low *w*/*c* that resulted in hard and dense paste (Fig. 8).

BSA: Conventional Sulfate Attack or Not?

The two case studies and other publications indicate that BSA deterioration rates may vary substantially. The rate of deterioration in the waste digester was high, while that in the tunnel was quite low. Major contributing factor for the rapid deterioration noted in Case I may include the frequently interconnected voids associated with the extrusion production process, failed or defected protective coating layers, relatively high average temperatures within the digester, possible high sulfur content in the waste, or long residence time of the waste in the facility.

In describing BSA, De Belie[8] and others[1] state that sulfuric acid reacts first with calcium hydroxide in concrete to form gypsum. The gypsum then reacts with monosulfate to form ettringite, resulting in a large volume expansion that causes internal pressure and deterioration of the concrete matrix.[1,8]

Formation of ettringite through the reaction between gypsum and calcium aluminate hydrate (monosulfate) is also a major reaction of "conventional" or "classical" sulfate attack.[3,9,10] However, ettringite or thaumasite, observed in other forms of sulfate attacks,[11,12] were not detected in the deteriorated zones in our BSA case studies. These phases are considered unstable at pH levels below 10.[9,10,13] Values of pH lower than 4 were confirmed in the BSA-affected zones using litmus tests. Measured pH values were approximately 2 after concrete coupons were exposed to sewer environments for 100 days and longer.[14] Concrete suffering from BSA often did not exhibit evidence of expansion.

BSA appears to be mainly an acid attack with involvement of microbiological activities, resulting in a progressive sectional loss and severe reinforcement corrosion.

Superimposition with the conventional sulfate attack due to formation of ettringite did not appear to have taken place based on observations from the two case studies and other similar projects. Gypsum appears to be a stable end product resulting from BSA, instead of a reactant or an intermediate material to produce ettringite as in classical sulfate attack, based on the case studies reported here and many of our other similar projects. Gypsum and silica gel layers formed on the exterior surface of concrete are anticipated to slow down the deterioration.

Summary

BSA is an acid attack caused or promoted by involvement of microbiological metabolism. BSA can cause significant physical, chemical, and mechanical changes that may result in huge maintenance and rehabilitation costs, compromise serviceability, and reduce the service life of affected structures. The distress is manifested as paste discoloration, softening, and progressive sectional loss and accelerated corrosion of embedded steel reinforcement. Affected concrete exhibits altered zones with distinct compositional and textural characteristics. These altered zones can be effectively assessed by petrographic studies in accordance with ASTM C856, "Standard Practice for Petrographic Examination of Hardened Concrete."

Laboratory studies can reveal or confirm the distress mechanism and determine the maximum depth of affected concrete. Furthermore, field and laboratory studies may also help assess deterioration rates and test the resistance of materials to the distress.

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Note: Additional information on the ASTM standard discussed in this

article can be found at **www.astm.org**.

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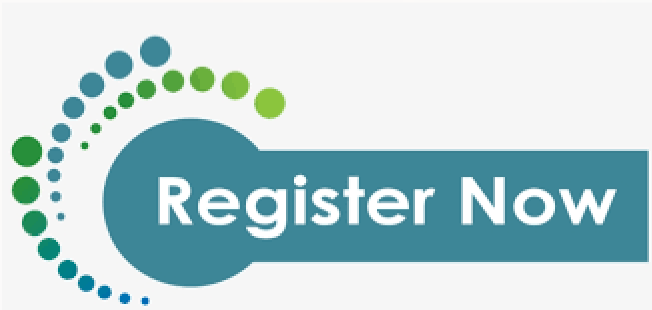

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