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USING MEDICAL X-RAY MACHINE TO DETERMINE THE SERVICE LIFE OF CONCRETE

Final Report for
NCHRP IDEA Project 199

Prepared by:
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July 2019

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IDEA Program Final Report

NCHRP-IDEA Project 199

Prepared for the IDEA Program

Transportation Research Board

The National Academies

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July 18, 2019

ACKNOWLEDGEMENTS

The researchers on this project would like to first thank Dr. Iman Jawed and the NCHRP IDEA panel for the support and funding of this project. Also, the team would like to thank Dr. Russell Brorsen for his great insights about the development of this dental x-ray prototype, general knowledge about dental x-ray equipment, and the use of his equipment. Also, a big thanks go out to Walter Peters and Matt Romero of the Oklahoma DOT for their valuable insights for this project and how to improve the implementation process of this prototype. Lastly, the team would like to thank Maria Masten of Minnesota DOT for serving as the technical director of this work.

TABLE OF CONTENTS

Acknowledgements ii
Executive Summary 1
Idea Product 2
Measuring Ion Penetration with the CHIP to Determine the Diffusion Coefficient 3
Using the CHIP for measuring effectiveness of silane sealers 3
Using CHIP for measuring impacts of cracks 3
Importance of prototype for industry 3
Concept Innovation 4
Importance of permeability 4
Fundamentals of radiography 4
Service life models of concrete 5
Investigation 5
Preliminary analysis of current dental x-ray equipment 6
Initial design for a potential prototype 6
Sample preparation 7
Potassium iodide solution 9
Constructing a sample stage 9
Obtaining a radiograph image 10
Image calibration 10
Writing imaging analysis software 10
Safeguards of equipment 11
Comparing the CHIP and TXM 12
Case Study Using the CHIP 13
Plans for Implementation 15
Future Work 15
Conclusions 16
References 16
Appendix: Research Results 17

EXECUTIVE SUMMARY

The deterioration of the US transportation infrastructure has become an important focus[1]. The demand for improved durability, lower cost, improved efficiency in construction, and improvement in sustainability have pushed for measures to protect and predict the service life of the concrete[2,4]. However, predicting the service life of concrete has been challenging due to several considerations impact the service life[2,4]. These considerations include mixture design, consolidation, curing, and cracking. One important parameter in the service life modeling of concrete has been the resistance to fluid transport through the concrete. This has often been called the permeability of the concrete as described by the effective diffusion coefficient[4,5]. Only a few current methods to measure fluid penetration exist and have been either not accurate or costly and time-consuming[4-7]. This work focused on developing a new test method that can be used in the lab or the field to determine the service life of the concrete.

The CHIP (**ch**ecking **i**on **p**enetration) is a practical, fast, safe, and inexpensive approach to x-ray image concrete, mortar, or cementitious paste as shown in Figure 1. This prototype was developed by adapting existing dental x-ray equipment and the use of tracers to observe the fluid penetration into paste, mortar, and concrete. The focus of this Type I proposal was to create a functional CHIP prototype. This work focused on developing the conceptual design, obtaining the materials and constructing the prototype, and then completing a case study. Although a lot was accomplished in this work there are still improvements that are needed such as improving the functionality and cost of the equipment, improving the software to make the instrument easier to use, reduce the length of the test, and elicit feedback from the department of transportations (DOTs) by completing more case studies.

This prototype has the potential to give DOTs an inexpensive and powerful tool to help them rapidly investigate the performance of their concrete infrastructure. Furthermore, this could be done while the construction work is being completed or to investigate in-place infrastructure. This method could be completed on cores taken from the field after the concrete has been placed, consolidated, cured, etc. This means that the measured values from the test would be representative of the actual in-place properties of the concrete, warning the owner if a problem was occurring during the construction process. In addition, this method could be used to compare the effectiveness of different repair materials or the use of surface sealers to prolong the service life of the concrete. This would allow DOTs to much more accurately know the quality and expected service life of their concrete infrastructure.

FIGURE 1 CHIP prototype.

IDEA PRODUCT

The CHIP was designed as a practical, fast, safe, and inexpensive approach to measuring the fluid penetration of paste, mortar, and concrete samples. This measurement is completed by taking X-ray images or radiographs of the concrete as a tracer penetrates through the concrete. Figure 2 provides a detailed illustration of the various components and Figure 3 shows pictures of the prototype with chamber doors opened and closed.

The equipment can be used by turning on the computer and the switch on the panel in the equipment chamber. Next, a sample can be loaded into the sample stage. This was done by placing the sample in a adjustable stage and then closing the sample chamber. The x-ray can be energized with the remote and the sensor will capture the radiograph of the sample. The software will process the image. This process was done after obtaining the sample and then after 7 days of exposure to the 0.6 mol/L potassium iodide solution. These two radiographs are used to find the depth of penetration and the concentration of the tracer in the sample. From this information, an effective diffusion coefficient can be obtained and then this can be used to model the service life of the concrete. This is valuable because it can give the permeability of the in-place concrete after mixing, construction, and curing. Further, it could be used to evaluate the effectiveness of a surface sealer, and even appraise the impacts of cracks with regards to fluid penetration.

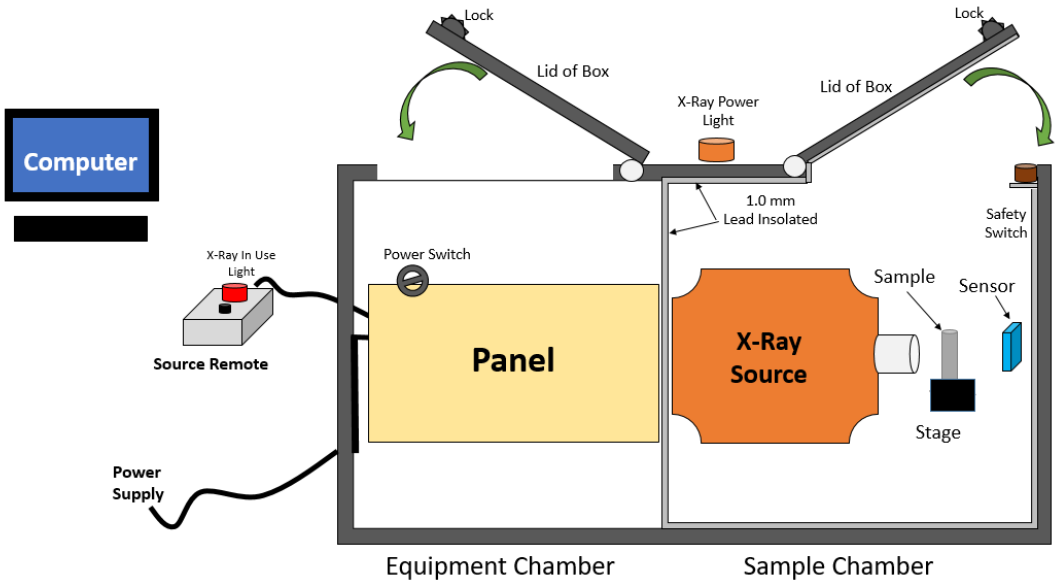


FIGURE 1 Schematic view of CHIP x-ray prototype

FIGURE 3 (a) view of chamber doors closed and (b) view of chamber doors opened.

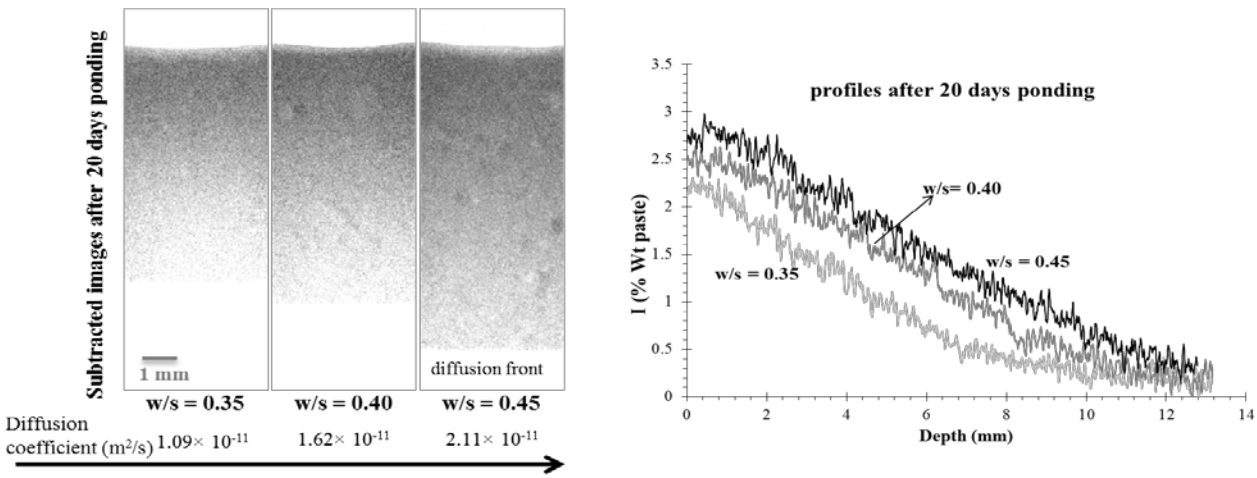
Measuring Ion Penetration with the CHIP to Determine the Diffusion Coefficient

One of the many uses for the CHIP involves the diffusion coefficient. Most life-cycle analysis models place a large focus on the permeability of concrete by measuring the diffusion coefficient of the concrete[4]. The CHIP has the ability to measure the ion penetration of a concrete sample and develop a diffusion coefficient based on the equations below. Then this diffusion coefficient value can be inputted into service life models and the time can be found for the outside chemicals to reach the reinforcing steel. Figure 4 (a) shows three samples with different w/cm and the calculated diffusion coefficient based on the fluid penetration depth as measured by the CHIP as shown in Figure 4 (b).

$$\mathbf{C_{(x,t)} = C_s\,(1\text{-}erf(x/(2(D_c\,t)^{0.5}))} \qquad \mathbf{C_{(x,t)}} = 0 \text{ for } x > 0 \qquad \mathbf{C_{(x,t)}} = C_s \text{ for } t > 0$$

Where,

$\mathbf{C_{(x,t)}}$ = ion concentration at the depth of x from the surface after time t
x = distance from sample surface
t = time
$\mathbf{C_s}$ = surface ion concentration
$\mathbf{D_c}$ = apparent diffusion coefficient



(a) **(b)**

FIGURE 4 Three mixtures with different w/cm and diffusion coefficients. (after Khanzadeh and Ley [5])

Importance of prototype for industry

Concrete is a porous material that will allow materials to move through it[2,3]. The number of pores connected in the concrete, also known as the permeability, influences the ability of fluids to penetration the concrete. And this permeability parameter is an important transport mechanism for freeze-thaw damage, corrosion, alkali silica reaction, and sulfate attack[2]. Corrosion is one of the biggest durability issues with reinforced concrete structures, especially for bridge decks. Once corrosion begins at the surface of the rebar then the surface of the concrete will start to spall and there will be an increase in the corrosion that occurs[2,3]. Therefore, the harder it is for these outside chemicals to penetrate through the concrete the lower the permeability of the concrete and the service life can be improved.

The CHIP can provide state departments of transportation (DOTs) and others with an inexpensive and powerful tool to help them rapidly investigate the performance of their concrete infrastructure. Furthermore, this could be done while the project was under construction. This technique could also be used on in-place infrastructure to determine the quality and predict the remaining service life. This method could be completed on cores taken from the field after the concrete has been placed, consolidated, and cured. This means that the test could give information into the quality of the in-place properties of the concrete. This could warn the owner of a problem during the construction process. In addition, this method could be used to compare the effectiveness of different repair materials or to guide the use of surface sealers to prolong the service life of the concrete. This would allow DOTs to gain new insights into the performance of their structures and better predict the service life of the concrete.

CONCEPT INNOVATION

The CHIP uses X-ray imaging to non-destructively measure the penetration of potassium iodide solution into a concrete, mortar, or paste with a practical, fast, safe, and inexpensive approach. Potassium iodide has a high electron density. This means that it will absorb X-rays and can be imaged as it moves through concrete. Potassium iodide was chosen because it has a similar size and reactivity as chlorides and it is safe for the user, inexpensive, and widely available. Figure 5 compares the rate of penetration for similar-sized chloride and iodide. Also, this 0.6 mol/L concentration gives a good contrast between the paste and solution in the radiograph images.

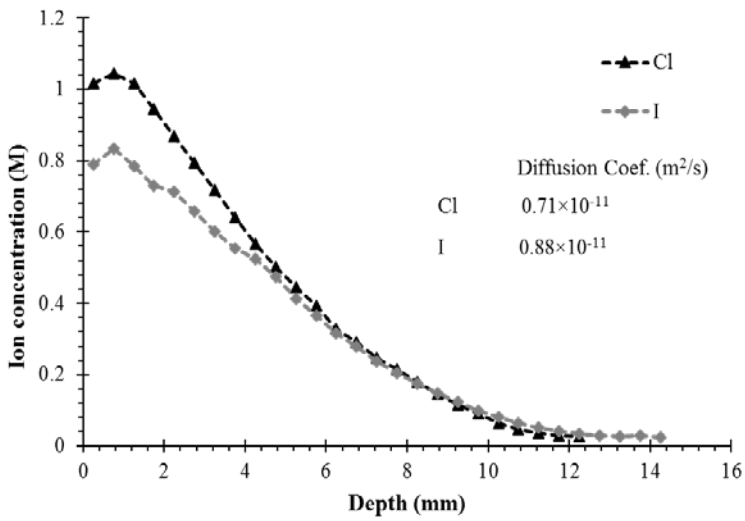


FIGURE 5 Depth of penetration comparison of iodide and chloride. (After Khanzadeh and Ley [5])

The CHIP was designed for X-ray imaging or radiography of concrete, mortar, and cementitious paste samples. A radiograph can be captured by placing a sample between the x-ray tube and the sensor and then using the remote to power the X-ray tube and capture an image with the detector. An overview of this process is shown in Figure 6. The produced radiographs are grayscale images where the shade of the gray changes based on the density, chemistry, or a combination of these. Denser or thicker materials will absorb more x-rays and will appear brighter in the radiograph. Air absorbs a low amount of x-rays and so it is shown as black. As the potassium iodide solution penetrates into the sample the gray value of the different depths becomes brighter as more X-rays are being absorbed.

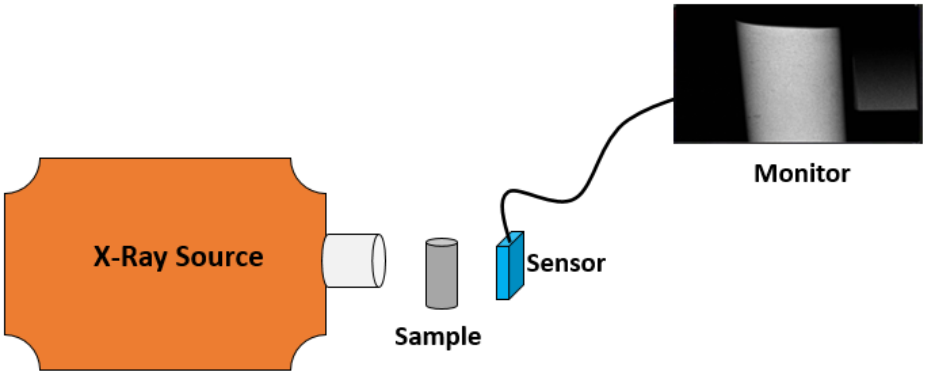


FIGURE 6 General schematic of a dental x-ray imaging setup

By capturing a radiograph before the potassium iodide has been added and then after a known amount of time then the two images can be subtracted and one is able to see the path of penetration into the sample. Further, samples with a known amount of potassium iodide have been created and also scanned with the CHIP. These gray values are used to correlate the gray value from the images to the concentration within the sample at different depths. This information can then be used to find a concentration profile over the depth. This information can then be used to find the effective diffusion coefficient of the material.

The innovation of the CHIP is that this process is non-destructive and can be completed with small samples. The method also uses inexpensive and potentially portable X-ray equipment to image the penetration of the potassium iodide tracer into the sample. These tracers have also been shown to provide a similar diffusion coefficient to chloride ions in concrete. The CHIP is a potential tool for DOTs to use to determine the quality of in-place concrete on either new construction or existing projects.

INVESTIGATION

Prototype Development

The development of the CHIP started by ensuring dental x-ray equipment had the capability to measure the fluid penetration of paste, mortar, and concrete. By working with a local dentist, the research team modified the settings on a dental X-ray machine and calibrated it to obtain equivalent measurements as a laboratory x-ray CT. Figure 7 shows the dental X-ray source and sensor being used to scan a sample at the dental office shown. The work using this equipment and the valuable insights by the dentist helped provide the foundation to develop this x-ray prototype.

FIGURE 7 dental x-ray equipment capturing paste sample image

This testing provided sufficient images and proved the concept of developing a prototype based on this dental x-ray equipment. After the initial proof of concept was proven then the dental x-ray equipment was obtained and assembled. A rough draft of the prototype is shown in Figure 8. It was realized early in the design that a lead-lined enclosure to safely provide a workspace for X-rays to interrogate the sample.

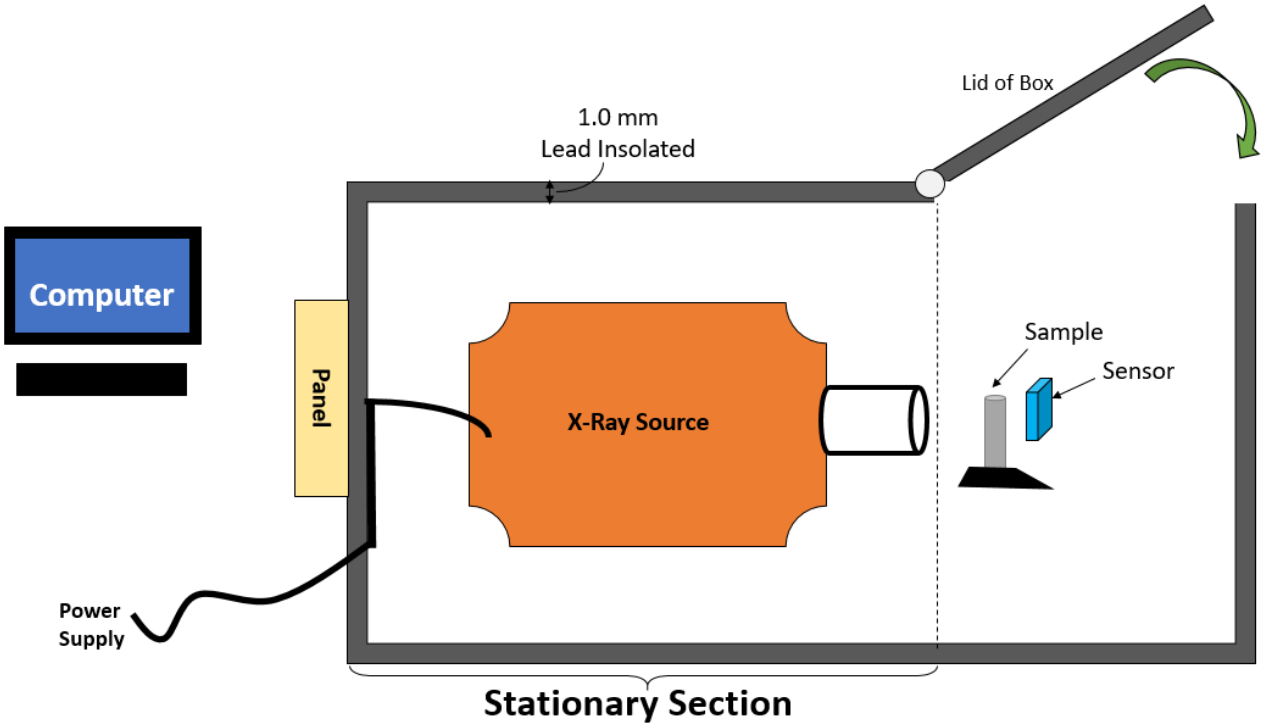


FIGURE 8 original rough draft schematic of the prototype

Several issues were realized with the original design. First, the user would need to get to the X-ray source to change the settings. Also, an easy to adjust stage was needed to control how the sample was being interrogated. The X-ray safety personnel from Oklahoma State University also assisted with some of the safety aspects of the design such as the lead lining, interlocking switches, and doors that can be locked. All of these were incorporated in the final design.

The final design of the CHIP uses an X-ray source mounted on a fixed platform and a high definition sensor placed in a lead-lined, box as shown in Figure 1 through 3. The CHIP was powered by a standard 120 V electric outlet. Figure 9 shows the dimensions are roughly 18”x24”x36”. Figure 10 (a) and (b) show the doors open to the control panel and sample area. The sample area of the box was lined with a 1 mm lead sheet with overlapping corners. Multiple modifications and adjustments from the original rough draft were made to improve the prototype.

A door interlock was installed to remove power to the x-ray tube if the door was not closed. Also, the doors have locks that must be engaged with the key removed when the source is energized. A light was also installed to indicate that the X-ray machine was energized. A dynamic sample stage was used to hold the sample at known orientations. The sensor was mounted on the back wall of the sample chamber opposite the X-ray source.

Software code was written to assist in the data analysis of the imaging process. The current version of the software needs more work before this is a finished product; however, the software can capture images and be used to analyze the results. An operations manual and user safety training document was developed to ensure the user of the equipment would understand how to operate and be safe during the use of the instrument. The CHIP was investigated by the Oklahoma State University X-ray safety office three times. In all investigations, the equipment was deemed to be more than satisfactory on the bases of safety.

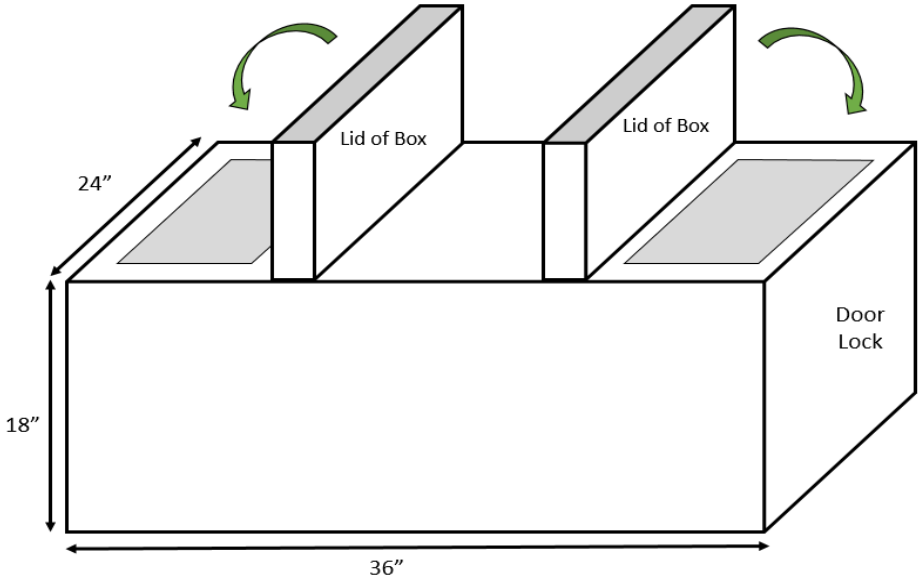


FIGURE 9 Outer schematic of the prototype

(a) **(b)**

FIGURE 10 (a) the inside control panel of the prototype and (b) the sample area inside the prototype

Sample preparation

The CHIP can analyze both laboratory and field samples. The initial preparation for either laboratory or field samples will be different but the ion ponding of these samples will be the same. For the laboratory samples, cylindrical micro vials with an inside dimension of 9.5 mm × 46 mm were used as a mold to cast the samples as shown in Figure 11. Large air voids in each sample mixture were removed from the samples by rodding with a 1.45 mm wire. This allowed potassium iodide solution to only penetrate from the surface of the sample. This surface penetration simplifies the analysis with the CHIP and makes it easier to determine the effective diffusion coefficient of the material.

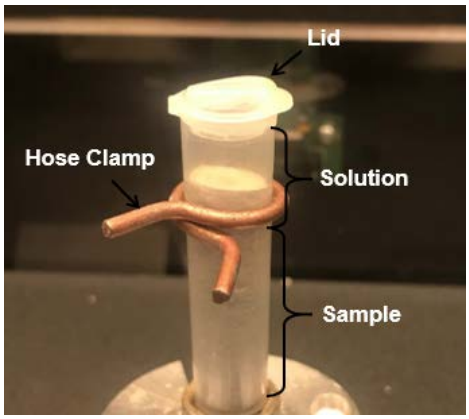


FIGURE 11 Laboratory sample vial

For field samples ¾" diameter cores were taken from the existing concrete structures or were taken from larger cores as shown in Figure 12. A hydrophobic barrier was placed on all faces of the samples except the surface so that the potassium iodide solution will only penetrate from one face as shown in Figure 13. Also, a plastic nut was glued to the bottom of each sample. Figure 14 shows the samples placed in containers to hold the solution.

FIGURE 12 Mini-core was taken from a cored cylinder in the field

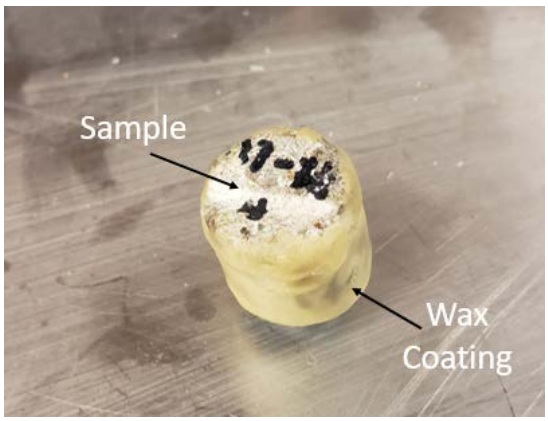


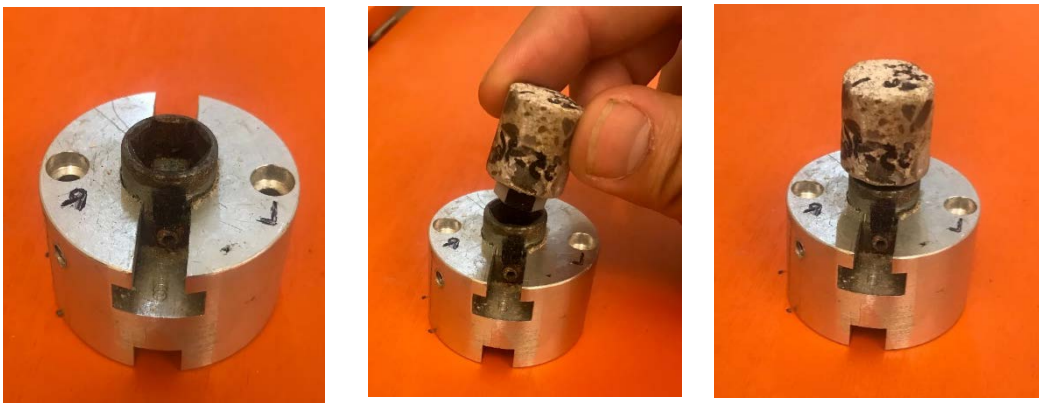
FIGURE 13 field sample with a wax coating

(a) (b) (c)

FIGURE 14 (a) side of field sample, (b) underneath of field sample, and (c) field samples in the sample containers

Sample stage

To investigate the gray value change in each sample over time, it was necessary to take images at the same orientation at different time intervals. To make this simple, the sample holder was designed to accept the nut that is glued to the bottom of the sample as shown in Figure 15(a). This stage makes it simple to capture radiographs of the samples exactly from the same side and angle at each time intervals. The sample with the stage holder can be loaded onto the stage as shown in Figure 15(a) through (c). Figure 16 shows the sample loaded onto the sample holder on stage in the CHIP.



(a) (b) (c)

FIGURE 15 (a) sample stage holder, (b) loading sample onto holder, and (c) sample loaded on holder

FIGURE 16 close look of the x-ray source, sample, and sensor in the sample chamber of the CHIP

Obtaining a radiograph image

When designing the CHIP, a significant emphasis was placed on making it simple for the user to capture a consistent radiograph. Parameters such as the calibration of the imaging equipment and the horizontal and vertical alignment of the stage must be well understood and controlled as illustrated in Figure 17. The equipment must be calibrated to ensure a consistent image through a uniformed gray value. The horizontal distances between the sensor, sample, and x-ray tube must not change or this can impact the results. This issue can be fixed by using a stationary X-ray source, detector, and fixing the distance to the sample from both of these. The final alignment can be seen in Figure 16.

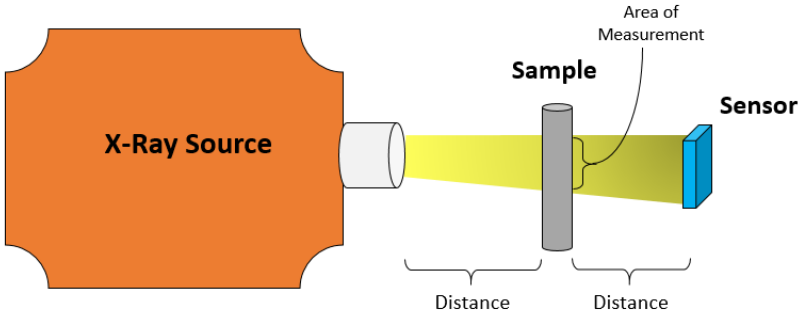


FIGURE 17 illustrates a radiograph being taken

Imaging analysis software

An imaging analysis software program was written to handle all data processing steps from the raw data acquisition to the final calculation of diffusion coefficients with minimal user intervention. After the sensor captures the raw data image as shown in Figure 18(a), the software automatically processes this image. The direct measurement from the image processing gives the profile of the X-ray attenuation coefficient that indicates the ion concentration at different ponding depth from the exposure surface as shown in Figure 18(b). Next, a database of calibrations curves, which has been established experimentally, gives the correlation between the X-ray attenuation coefficient and the percentage of ions concentration. Using a calibration curve, the profile of the X-ray attenuation coefficient can be converted into the percentage of ion concentration as shown in Figure 18(c), which can be used to calculate the diffusion coefficient. Both the raw data and the final image will be saved to the appropriate directory.

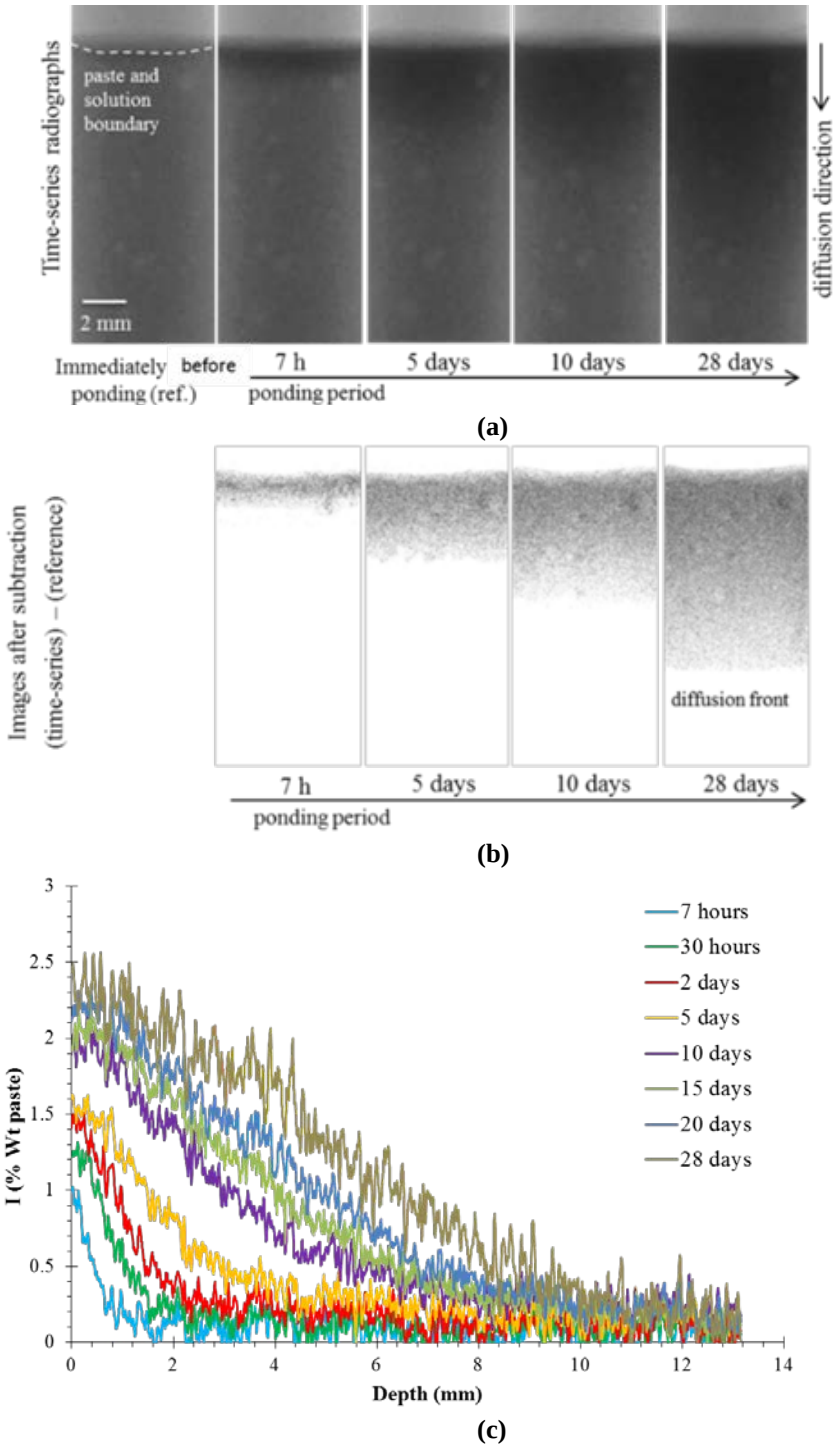


FIGURE 18 (a) raw x-ray, (b) corrected x-ray image of ion penetration, and (c) ion concentration throughout the depth. (After Khanzadeh and Ley [5])

Safety features

X-rays machines produce radiation and safety is imperative. While there have not been any known US laws requiring licenses to operate x-ray equipment, it should be recommended for operators of the CHIP to go through radiation safety training provided by the operators employer. Multiple safeguards have been incorporated into the CHIP as shown in Figure 19. A lock on the lid of the box controls access to the sample area. Also, as shown in Figure 19(b) the door interlock cuts off power to the x-ray source whenever the door was open. Further, the door for the sample area and X-ray

control panel remains locked with the key removed when the source is energized. There was also an external light on the CHIP to warn the user that the X-ray panel was energized. The user also uses a remote to operate the machine that is external to the box and away from the chamber where the X-rays are emitted. Also, radiation safety personnel from Oklahoma State University used an ion chamber meter to measure for potential leakage on the outside of the CHIP and was not able to measure any leakage.

(a) **(b)**

FIGURE 19 (a) power switch on panel in equipment chamber and (b) safety switch located on sample chamber

Comparing the CHIP and Skyscan

The CHIP was compared to a laboratory Skyscan 1172 µCT scanner. This equipment is similar to the CHIP but the X-ray settings can be adjusted to a much larger range. This machine was an inspiration for the CHIP and therefore the results from both machines were compared. Both machines are shown in Figure 20.

(a) **(b)**

FIGURE 20 (a) Skyscan 1172 µCT scanner and (b) CHIP

Figure 21 compares the ion concentration measured between the two machines. This comparison was completed for twenty different samples and the results were similar for both instruments when the sample was aligned correctly. This means that the CHIP and the much more expensive Skyscan 1172 instrument give equivalent results.

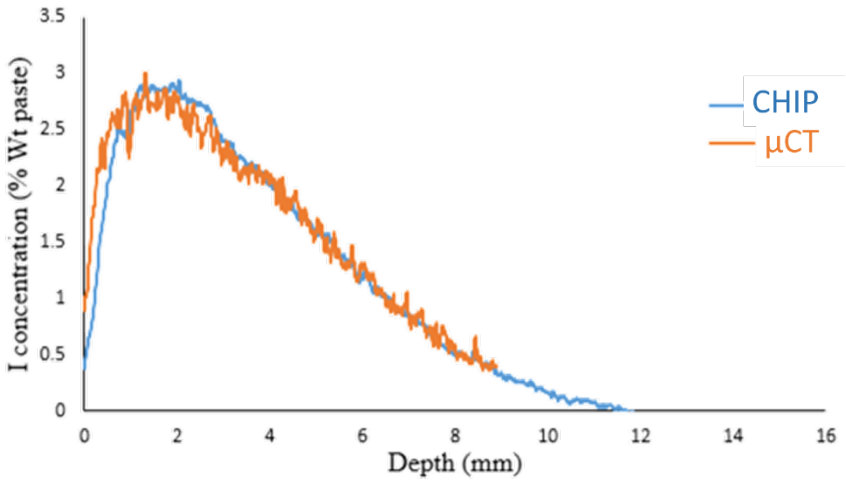


FIGURE 21 Compares concentration profiles of both X-ray methods

Bridge Deck Investigation for the Oklahoma DOT

Cores from 14 different bridge decks were provided from the Oklahoma DOT (ODOT). ODOT wanted to compare the permeability of the different concretes and also evaluate the effectiveness of silane sealers used on the surface of the concrete. These were all recently completed bridge decks.

The results from the permeability testing were shown in Figure 22. The detected iodide concentration was shown for each of the 14 bridges at 2 mm from the surface. This method will also be used to compare the results to the samples with silane sealers. Four 1" diameter cores were taken from the larger 4" cores provided. The smaller cores were coated with wax on all sides but the surface. Two cores were taken from the side of the core to determine the permeability of the concrete and two cores were taken from the surface of the core to determine the performance of the silane sealer. All samples were ponded with potassium iodide for 5 days.

In this case the smaller cores were taken from larger ones; however, these cores could have been taken directly from the surface of the bridge concrete in question. These cores can be taken quickly with a hand drill and can also be quickly patched with rapid hardening mortar.

The results have been organized to show the lowest permeability first and the highest permeability last. Notice that the mean iodine concentration was 2.7% at 2 mm and there is a wide range in the detected iodide concentration. The broad range consists of a 5x difference between the samples with the lowest permeability to the highest.

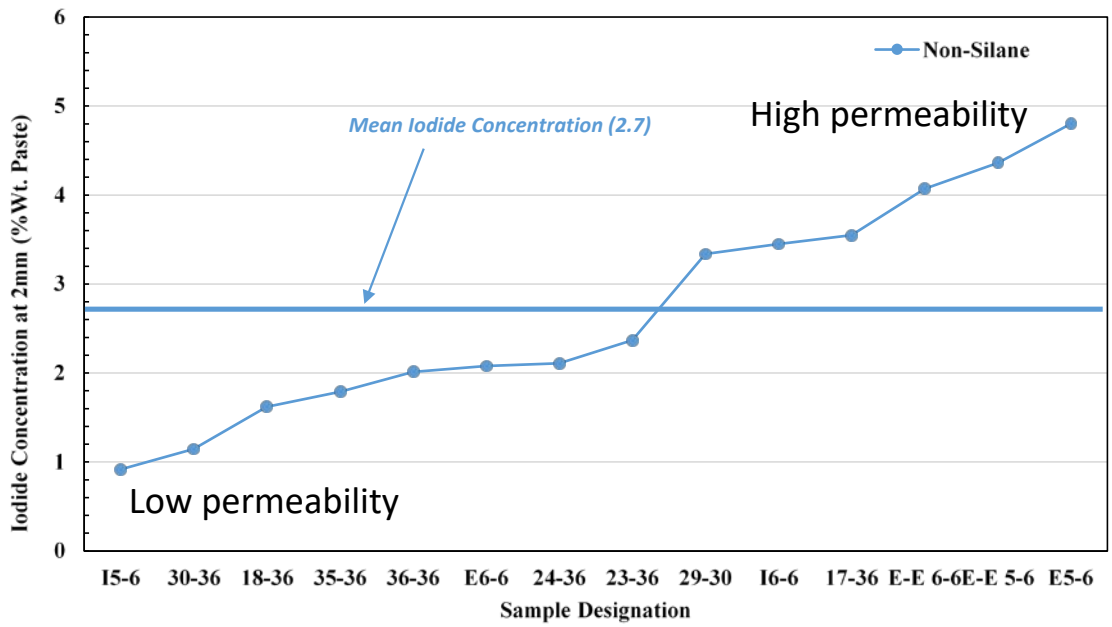


FIGURE 22 The iodide concentration at 2 mm from the surface in percent for the 14 different bridges investigated[9].

Next, the effectiveness of silane sealers was investigated by completing the same ponding test but this time it was with concrete from the bridge deck that had been coated with silane [8,9]. The results were shown in Figure 23. In this case, the permeability of the concrete has been greatly reduced in all samples except in sample 30-36. From closer inspection of this sample, there was a crack on the surface that allowed the iodide to penetrate the concrete. Despite this one sample, the other 13 showed a reduction in the permeability and a much lower variation. In fact, the mean permeability level has been dropped by 6x. This shows the great value of using silane sealers to extend the life of a bridge deck. It also shows that the CHIP can accurately show the difference in performance between field concrete with different levels of permeability and concrete with and without silane sealers [8,9].

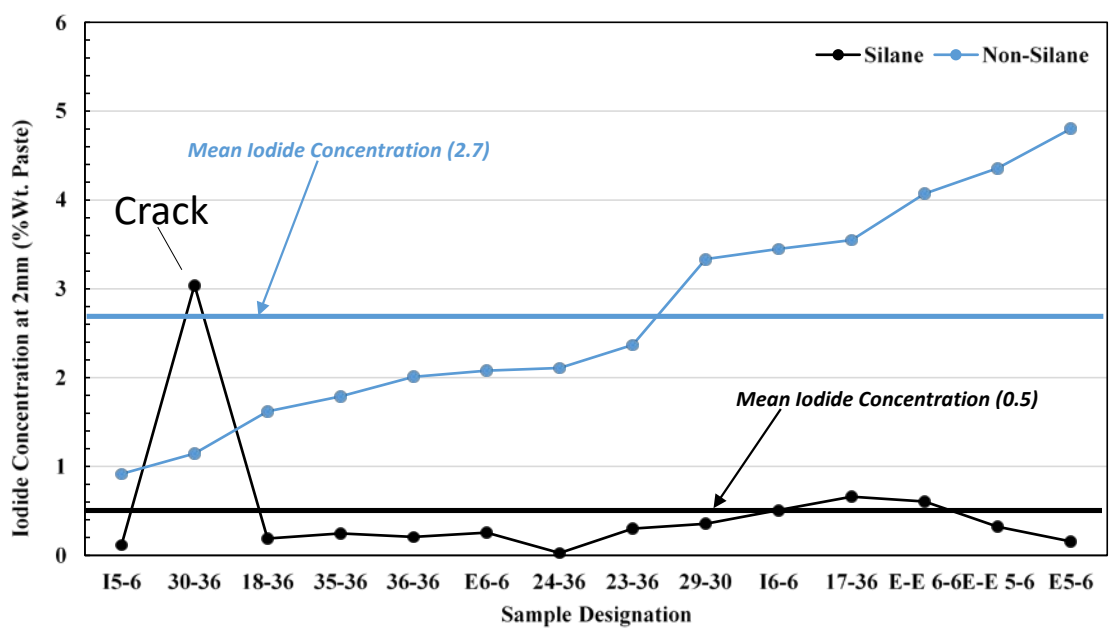


Figure 23 The iodide concentration at 2 mm from the surface in percent for the 14 different bridges investigated comparing concrete with and without silane sealers[9].

PLANS FOR IMPLEMENTATION

The results from the testing have been shared with the FHWA mobile concrete lab, Oklahoma DOT, Minnesota DOT, and Illinois DOT. All of these partners are interested in providing additional case studies to evaluate the performance of the CHIP; however, it is not clear how these case studies will be performed as there is no more funding available for this work.

For these case studies the team would like to obtain samples from concrete during the mixture design, construction, and then after the placement and curing of the concrete. This would allow important insights into how these different processes change the permeability of the concrete. Also, the CHIP could be used on different repair methods and surface sealers to determine their effectiveness. This will be a great opportunity to show the potential for the CHIP and help these states justify obtaining this equipment in the future.

FUTURE WORK

This report presents a single case study of using the CHIP. For a more confident application of the CHIP for concrete permeability and durability, it is critical that a wider range of concrete materials and concrete mixes with a variety of cementitious materials and admixtures be investigated. This would also help sort out and address issues that might arise before a commercialized version of the device is developed.

While the CHIP shows promise to be a very useful tool to help state DOTs evaluate the quality of their concrete infrastructure, the instrument needs to be made more rugged, practical and user-friendly in order to be easily usable by the state DOTs. The present instrument is the initial prototype developed to show the feasibility of using X-rays to determine the concrete permeability and durability. However, much still needs to be accomplished to make it viable equipment that can be implemented and commercialized.

To make the CHIP more economical and more portable, it is important to optimize, both in terms of cost and performance, the X-ray source and the detector as they are the most expensive items needed to fabricate the equipment. The X-ray source used in the initial prototype was rather large and heavy and therefore some lighter options need to be investigated. Also, other less expensive detectors should be explored to see if they could be used with the CHIP and provide the needed accuracy. These two improvements should significantly reduce the cost and the weight of the instrument. The instrument also needs to be made rugged and robust. The current housing is made of wood and needs to be redesigned using a stronger, weather-resistant material such as fiberglass. The instrument also needs to be made more shockproof and damage resistant in case it is dropped or impacted by some external objects. While these loads/impacts may be accidental, the instrument should be able to withstand such impacts and keep operating properly. It would also be useful to develop a stage that could capture the location of the sample from the previous scan. The stage should be such that it can be moved to the exact same location when users want to scan the instrument at later times and make sure that the alignment is correct.

The software developed for use with the current machine needs to be made user-friendly to make it easier for the operators to use. Currently, the software uses several different programs to scan, analyze, and predict the service life of the concrete. It is rather cumbersome to change between programs, which can also be confusing. Further, the software was designed to analyze one sample at a time. The instrument would be more efficient if it could be programmed to run in a batch mode. The state DOTs would certainly prefer to scan multiple samples at a time and have them immediately analyzed. All of this will need more programming work.

Currently, the potassium iodide solution is being used to investigate the permeability of concrete because it gives results similar to those using chloride. However, there are many other tracers available that might be able to be used and give results closer to those with chloride and in less time. The current method requires the samples to be ponded for about 7 days before determining the diffusion coefficient. It may be possible to shorten this time by using a different tracer or by storing the samples at an elevated temperature to facilitate diffusion.

While the CHIP has been used to investigate some field concrete, it would be beneficial to investigate it on a wider number of projects and also for other materials such as asphalt, wood, soils, stone, coatings, etc. The CHIP has the potential to work on all these materials with some changes in the settings. The user will need guidance for finding the optimum settings for various different materials.

A draft test method for the CHIP should be prepared for consideration by relevant AASHTO committees. If approved, it will allow state DOTs to specify and use the CHIP to evaluate concrete on their projects. The research team is experienced in writing AASHTO test methods.

The research team hopes to address all of these needs with future funding.

CONCLUSIONS

This project developed an x-ray prototype that uses dental x-ray equipment with the capability to safely measure the fluid penetration of paste, mortar, and concrete that could be used in the laboratory or the field. This prototype can obtain similar measurements compared to other much more expensive devices with a significantly lower cost and also with a portable unit. A sampling method was determined to obtain samples from the field and software code was written to assist in the data analysis of the imaging process. Multiple modifications and adjustments were made to create an easy to use sample stage. A case study was completed for the Oklahoma DOT that showed the value in the equipment to examine the permeability of different bridge decks the efficiency of silane sealers.

Also, the CHIP can provide DOTs with an inexpensive and powerful tool to help them rapidly investigate the performance of their concrete infrastructure. Furthermore, this could be done while the work is being constructed and also investigate in-place infrastructure. This method could be completed on cores taken from the field after the concrete has been placed, consolidated, and cured. This means that the measured values from the test would be representative of the actual in-place properties of the concrete. This information could be used to warn the owner if a problem was occurring during the construction process. In addition, this method could be used to compare the effectiveness of different repair materials or the use of surface sealers to prolong the service life of the concrete. This would allow DOTs to better predict the service life of their concrete infrastructure. Although good progress has been made on this device there is more work that is needed before it can be a useful and widely used test method. The research team will continue to look for funding to support this work.

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APPENDIX: RESEARCH RESULTS

Sidebar info

Program Steering Committee: NCHRP IDEA Program Committee
Title: USING MEDICAL X-RAY MACHINE TO DETERMINE THE SERVICE LIFE OF CONCRETE
Project Number: 199
Start Date: June 4, 2017
Completion Date: June 28, 2019
Product Category:
Principal Investigator: Tyler Ley and Qinang Hu
Oklahoma State University
Email: tyler.ley@okstate.edu
Phone: 405 744 5752

TITLE:
Using X-rays to Determining Concrete Permeability

SUBHEAD:
This work developed a medical X-ray machine to image the penetration of fluids containing a tracer within concrete.

WHAT WAS NEED?
One of the factors contributing to the duration of the service life for concrete has been the durability of concrete, which can be defined as the ability of concrete to maintain serviceability within a specific environment due to issues such as corrosion, freeze-thaw, sulfate attack, physical abrasion, carbonation, and alkali-silica reaction (ASR). The topics of concrete durability and concrete service life have drawn the attention of many. Because of the complicated inharmonious microstructure of concrete, predicting the service life of concrete has been a major hurdle due to the specific environmental conditions of the concrete in that area such as the local material used in the concrete, the mixture design of the concrete, and the construction practices. The mechanism for many of these durability issues has been due to ion diffusion into concrete such as water penetrating into the concrete as a key component to corrode the steel reinforcement. For this reason, the x-ray prototype was developed as non-destructive testing (NDT) technique to focus on the fluids transport in the concrete which potentially contain deleterious ion species. In other words, this assists in measuring parameters connected to the serviceability of concrete.

WHAT WAS OUR GOAL?
Create an economical tool to determine the durability of concrete infrastructure.

WHAT DID WE DO?
This project developed an x-ray prototype that uses dental x-ray equipment with the capability to safely measure the fluid penetration of paste, mortar, and concrete that could be used in the laboratory or the field. A sampling method was determined to obtain samples from the field and software code was written to assist in the data analysis of the imaging process. Multiple modifications and adjustments were made to create an easy to use sample stage. A case study was completed for the Oklahoma DOT.

WHAT WAS THE OUTCOME?
An X-ray prototype was successfully created in a practical, time-efficient, safe, and inexpensive approach to measure the permeability of concrete. A case study was completed for the Oklahoma DOT that showed the value in the equipment to examine the permeability of different bridge decks the efficiency of silane sealers.

WHAT IS THE BENEFIT?
This research is the first step in establishing a product to give state departments of transportation (DOTs) an inexpensive and powerful tool to rapidly determine the permeability of their concrete infrastructure. This device could be used to compare different mixture designs as well as different construction practices from the field. This method can be used on

cores taken from the field after the concrete has been placed, consolidated, cured, etc. This means that the measured values from the test would be representative of the actual in-place properties of the concrete. This could warn the owner if a problem was occurring during the construction process. In addition, this method could be used to compare the effectiveness of different repair materials or the use of surface sealers to prolong the service life of the concrete. This would allow DOTs to know how the repair methods were performing and update the prediction of the service life of the concrete.

LEARN MORE
To learn more contact:

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IMAGES

FIGURE A1 - *X-ray prototype.*

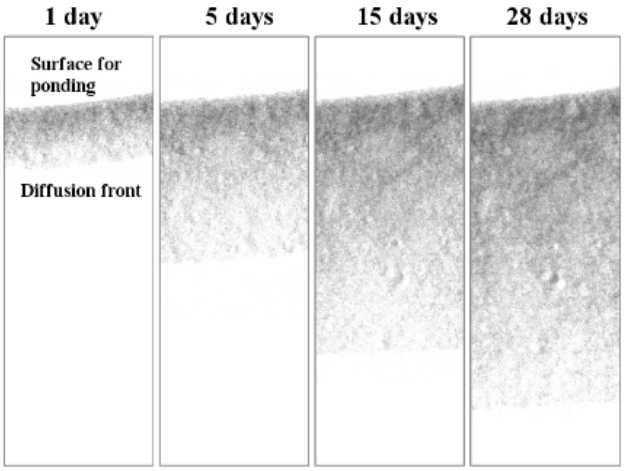

FIGURE A2 - *X-ray images of ions penetrating from 1 day to 28 days.*