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3D Crack Profiling Using Real-Time Thermography

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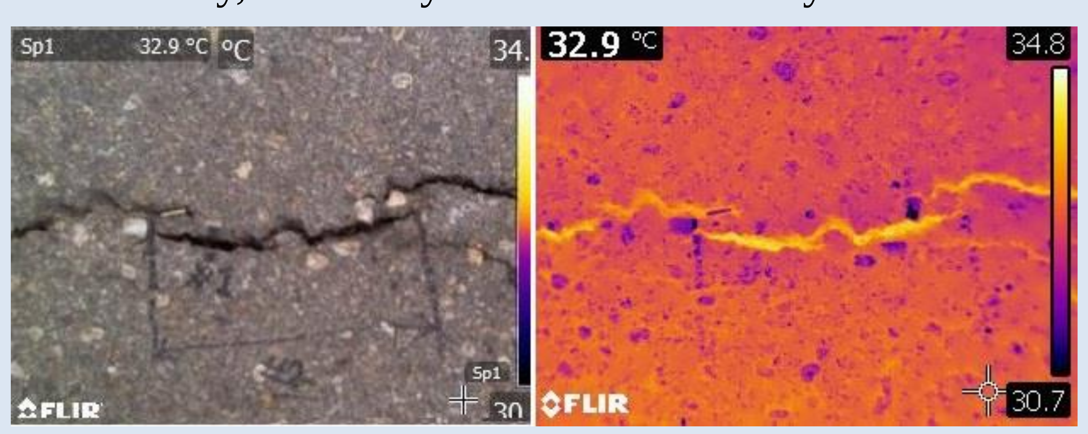
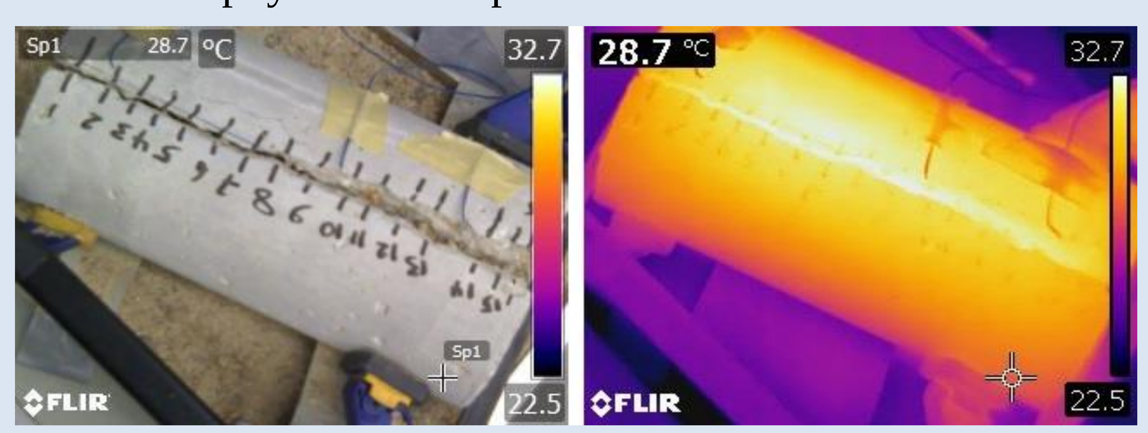
I. Introduction

Non-Destructive Tests (NDT) such as Ground Penetration Radar (GPR), Ultrasonic Test (UT) and Infrared Thermography (IRT) are fast, contact-less, safe and are considered as one of the most useful techniques for detection and evaluation of infrastructure materials defects. These test methods have become a common means of assessment for surface and subsurface defects of asphalt pavement and concrete structure. Among these methods, GPR and UT methods are mostly used for detecting subsurface defects inside materials' domain. On the other hand, IRT has proven to be more effective for investigating close-to-surface delamination and surface cracks based on the difference in thermal signatures in infrared bands. In infrared thermography, infrastructure materials inspection processes are based on interpretation and analysis of visible and infrared spectrum images (Figures below). In this research, IRT is used as a NDT tool to augment the reliability of asphalt and concrete pavements, and a correlation between the temperature variance of the crack and its profile is studied. This will help to predict the severity of the condition of the asphalt and concrete pavement including surface crack and delamination by using the thermal data that are obtained from IRT. The whole test setups are divided into two sections: field test that involved crack inspection on asphalt pavement surfaces and concrete crack inspection in laboratory. Both passive and active employment of heat are utilized in this research. Natural heat source (solar radiation) for passive IRT and artificial heat source (halogen lamp) for active IRT are used for field and laboratory tests respectively. Additionally, laboratory tests are numerically simulated in Comsol Mutiphysics to compare the outcomes.



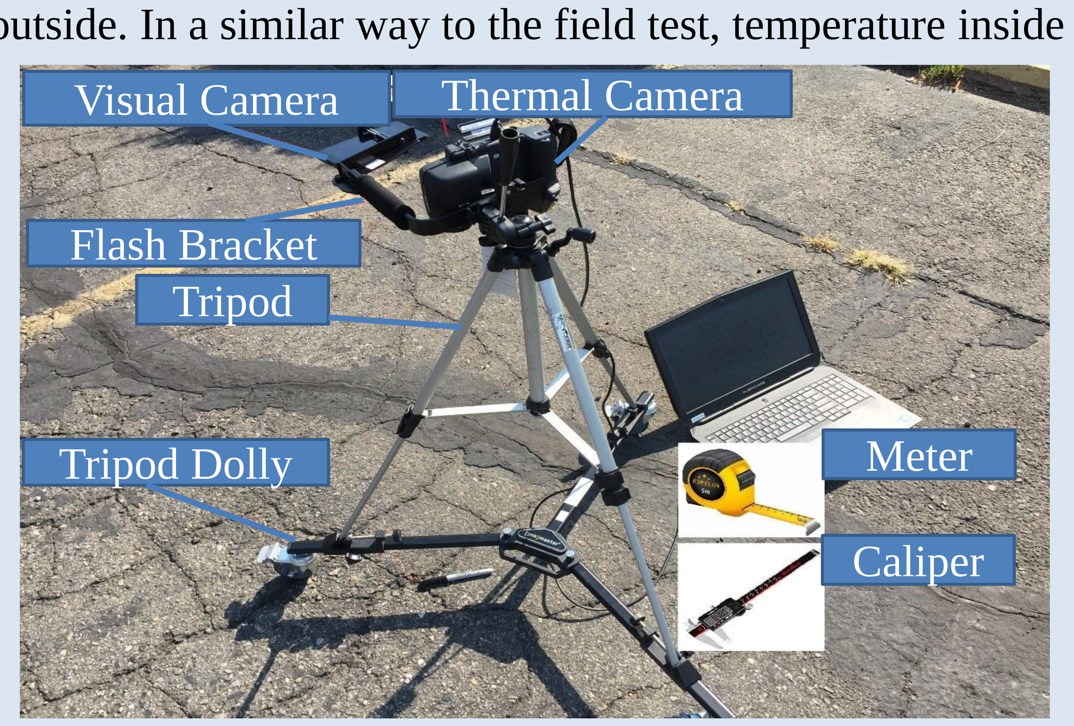
Thermography of asphalt pavement crack



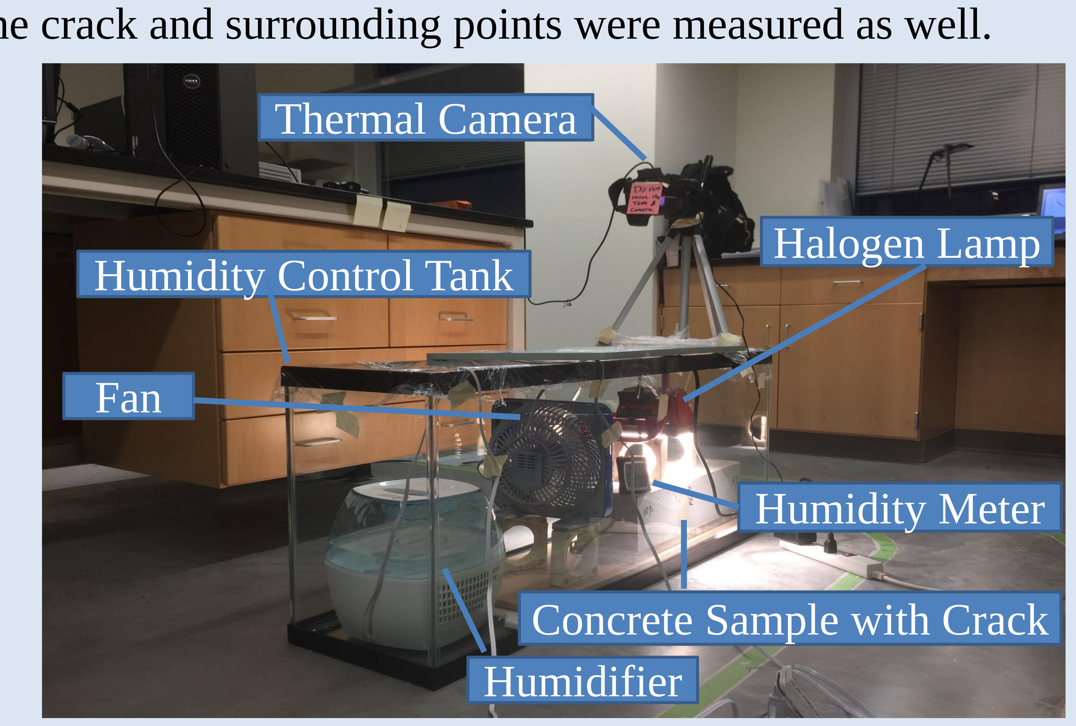
Thermography of cracked concrete sample

II. Methodology

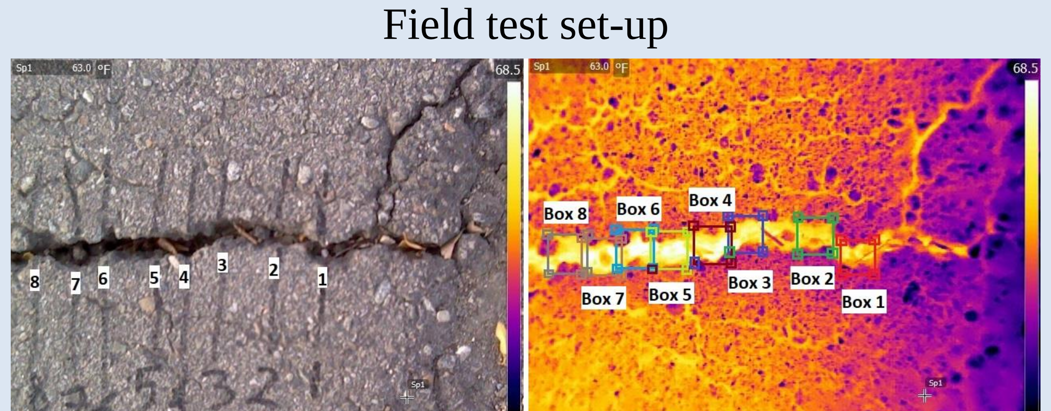
Utilizing apparatus listed in upper-left picture below, the field test was implemented, and four different types of roadway were analyzed: deteriorated roadway, pedestrian sidewalk, parking lot and major roadway. Thermal images were taken 2 hours prior to the sunset period (cooling process). Both temperatures inside the crack and surrounding points were taken to normalize the temperature, so that data can be compared regardless of locations and time of the collected data. At the same time, depth and width were measured and collected. Bottom-left picture shows thermal image taken in the field test. Test setup shown in upper-right picture represents laboratory test with 21'' x 6'' x 6'' concrete sample. Multiple thermal images of modified concrete cracks were taken with infrared thermal camera connected to ResearchIR software after heating up the concrete sample for 2 hours. In addition, humidifier and fan were employed to replicate ambient condition outside. In a similar way to the field test, temperature inside the crack and surrounding points were measured as well.

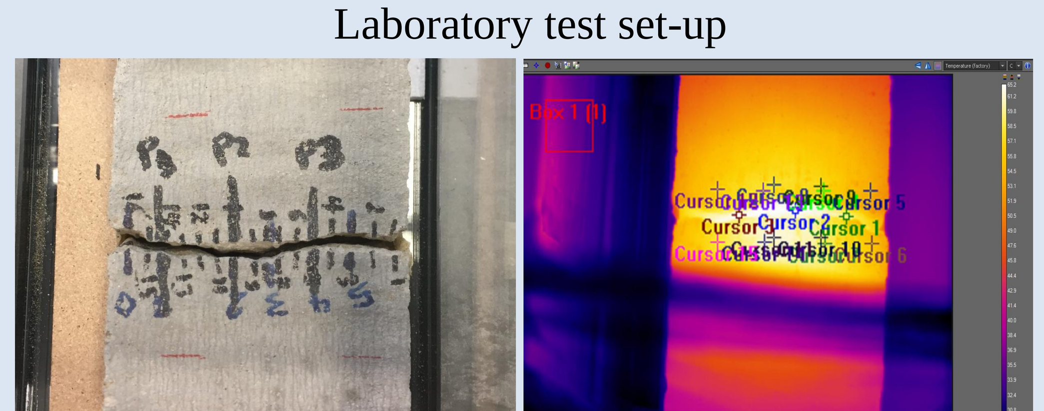


Field test set-up



Laboratory test set-up


Thermal image of asphalt pavement crack

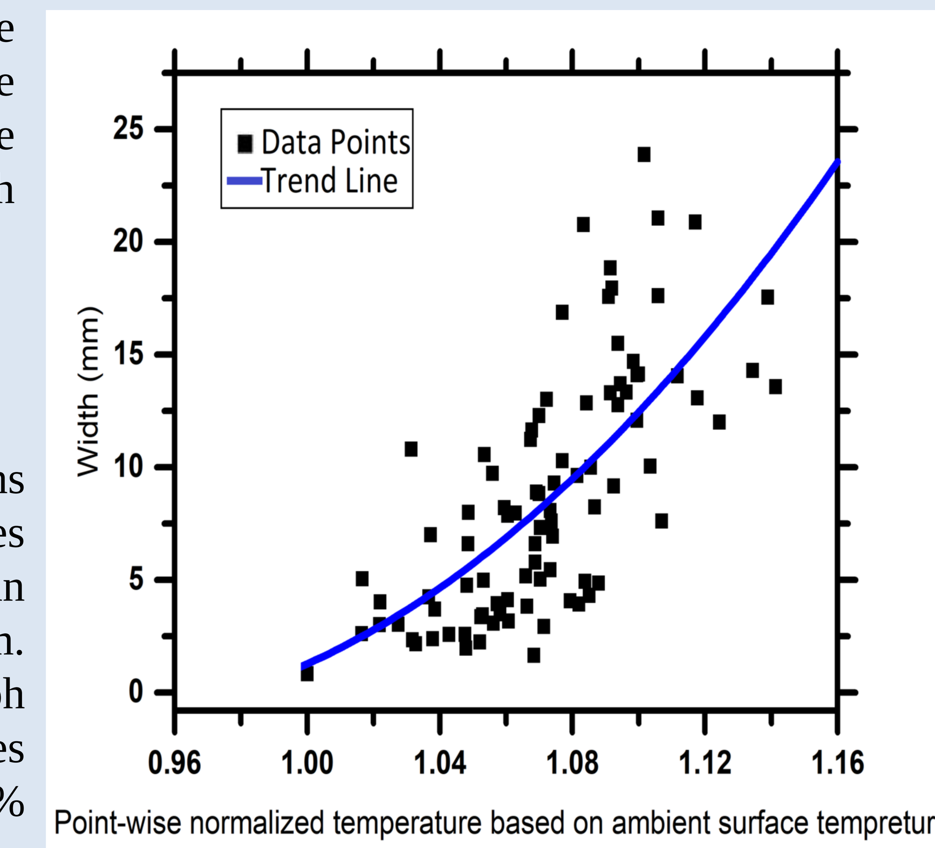

Thermal image of concrete in ResearchIR

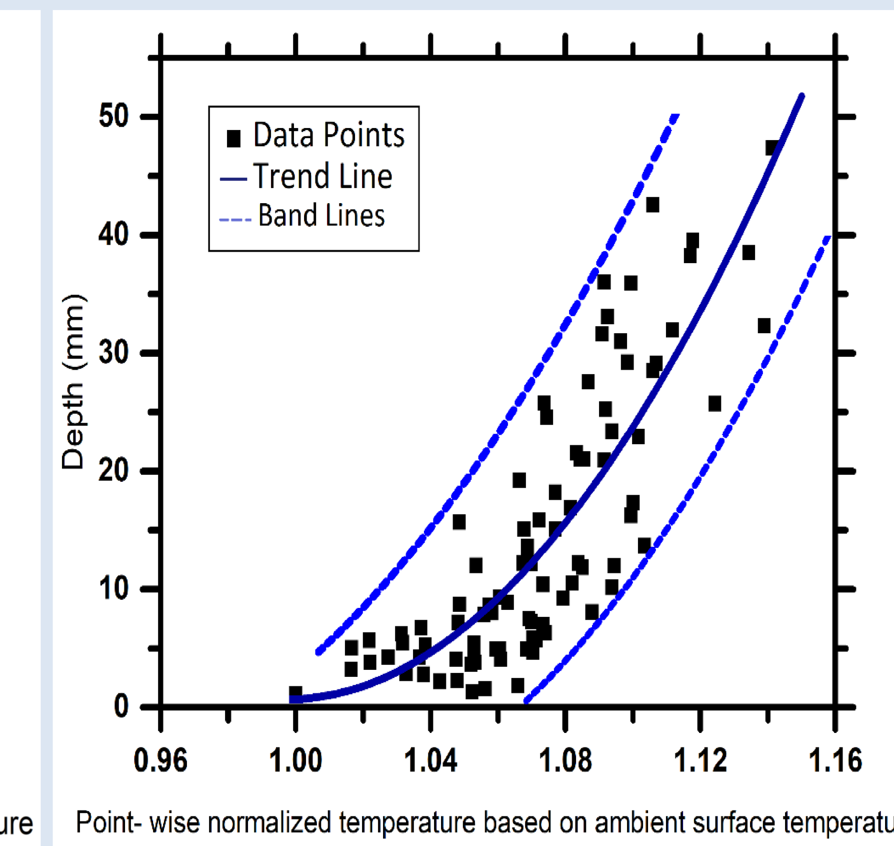
III. Results (Field tests versus laboratory tests)

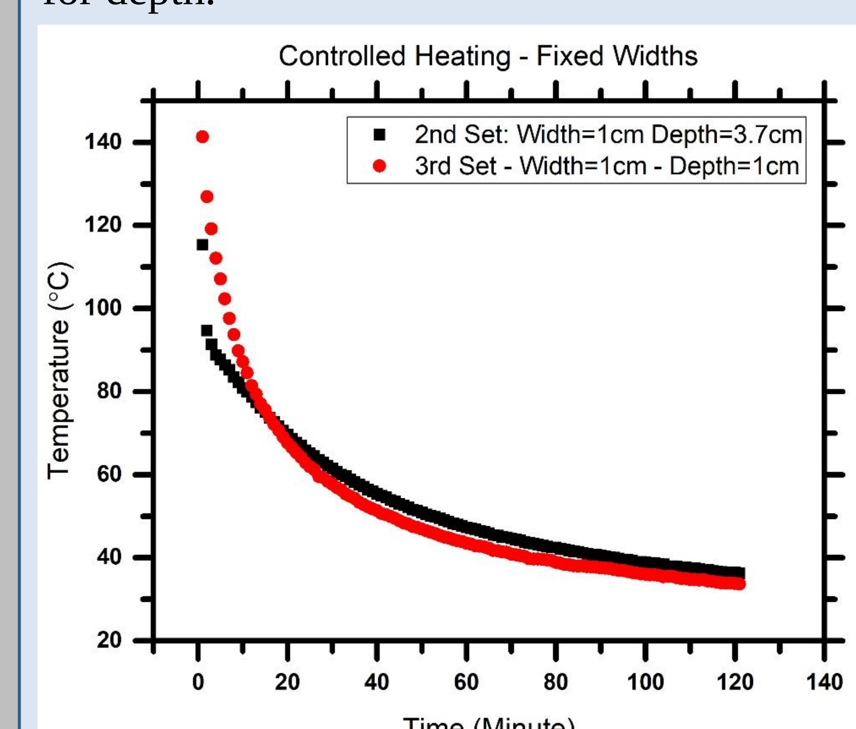
Using an equation listed below, point-wise normalized temperatures for all of the interest points from the field test were compared with their corresponding width and depth.

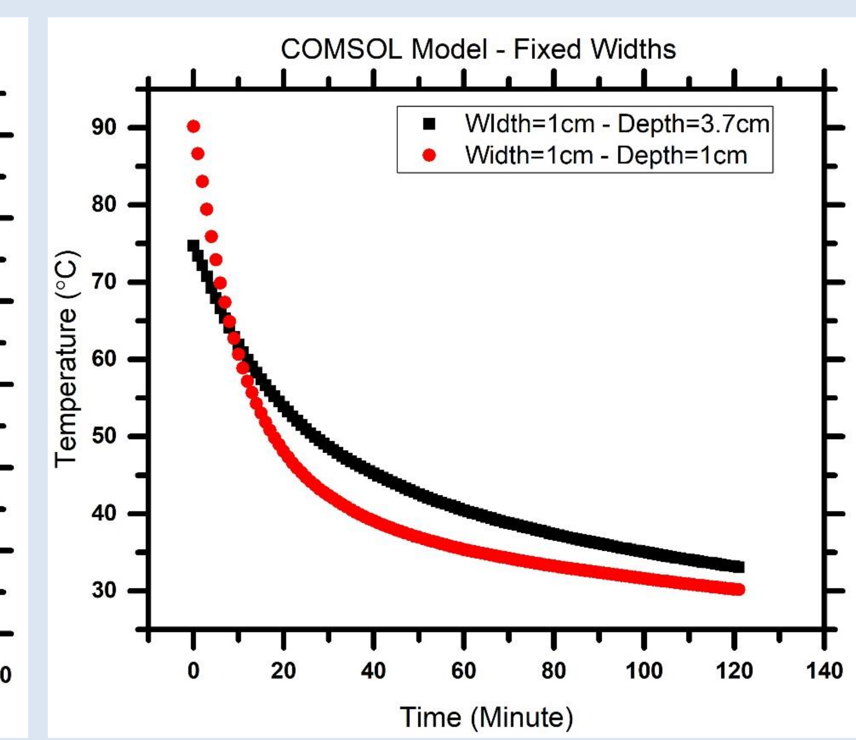
$$\frac{\textit{Temp Inside Crack}}{\textit{Average Temp of sound area.}}$$

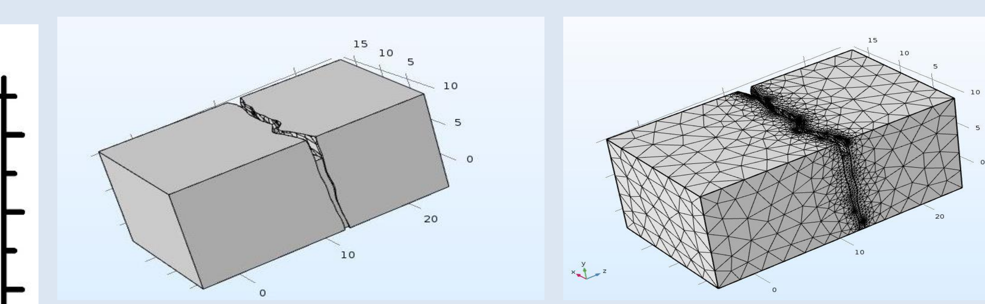
The normalized temperatures never went below 1.00 as clearly shown in the graphs on the right, meaning that temperatures inside the cracks were always higher than or equal to the sound areas around them. Also, trend line was drawn for each graph and the R^2 values for the these trend lines were found to be 50% for width and 70% for depth.



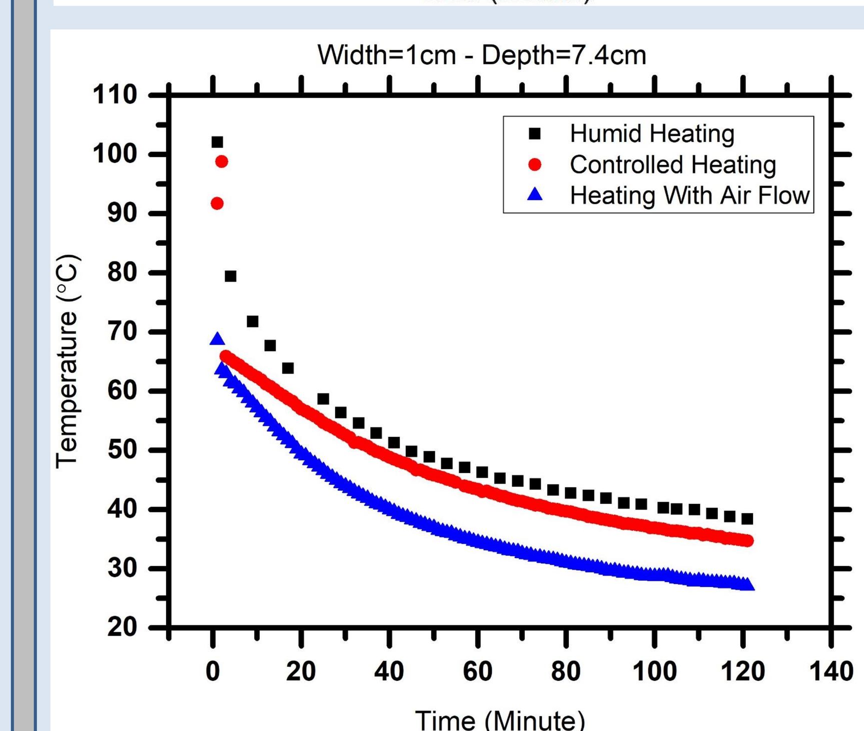


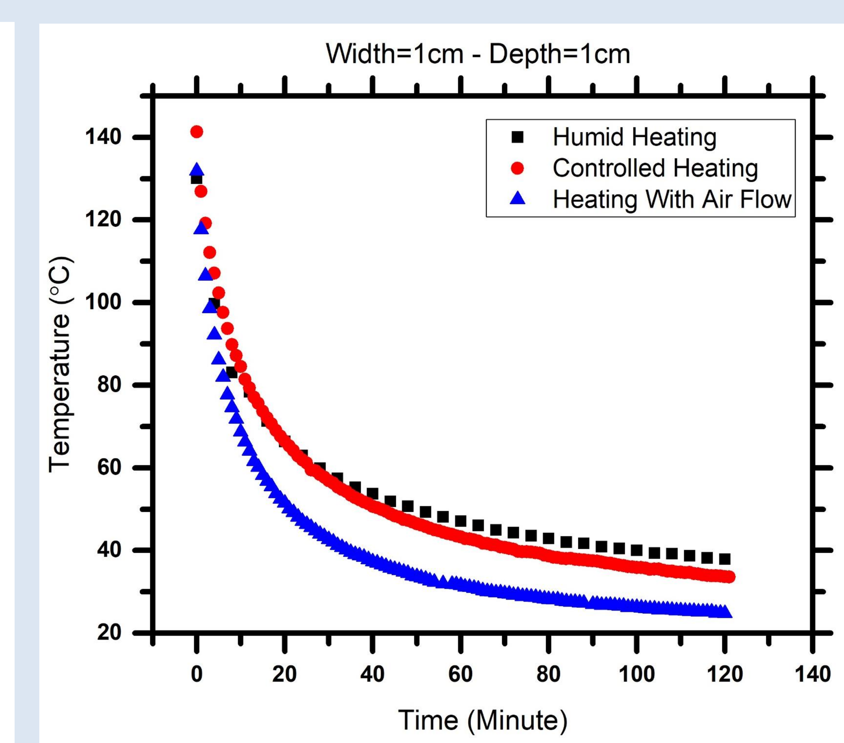






Heat dissipation in concrete crack was analyzed and recorded by varying width & depth in the laboratory test. Additionally, concrete sample was modeled in the Comsol (Figures above) using 3D scanning and Catia software, and simulated with same condition as the laboratory tests to verify outcomes. Graphs on the left side show the heat dissipation behavior of concrete crack for constant width and varying depth.





Influences of different ambient conditions on both heat dissipation of the concrete cracks in different sizes and readings from the thermal camera were also observed and studied. For the variation in ambient conditions, humidifier and fan were employed to the test set-up to see the effects of humidity and air flow in the heat dissipation behavior. By varying one ambient condition at a time for each test, heat dissipations for cracks with constant width and different depths were measured. The left two graphs show the dissipation behavior of two different cracks with varying depths.

IV. Conclusion & Future Study

- Based on the point-wise normalized temperatures, the areas inside the cracks always have higher temperatures than their surrounding areas.
- Graphs plotted from the field tests show that wider and deeper cracks have higher temperatures than narrow and shallow cracks. In addition, it is concluded that depth has more effect on the temperature than the width based on the calculated R^2 values.
- Graphs for the effects of crack depth on heat dissipation demonstrate that deeper cracks absorb heat more during the heating process and reach peak temperatures faster compared to the cracks that have shallow depth.
- Comparing graphs for the effects of crack depth, deeper crack has higher slope throughout the test period meaning that deeper cracks dissipate heat faster and reach their normal temperatures faster than shallow cracks.
- Cracks heat up more and lose heat slower in humid condition. Also, deep cracks are more prone to the effects of humidity than shallow cracks.
- The study on concrete specimen will continue using passive IRT to see the effect of sun on concrete sidewalk cracks.
- In future studies, Pundit Ultrasonic test device will be employed to measure and analyze the depth and characteristics of subsurface anomalies.