

## Evaluation of the Bond Performance of Concrete-Epoxy Interface using Segmentation-based Image Processing Techniques

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# 1 Introduction

Background: Concrete/Epoxy bond and the formation of CEI

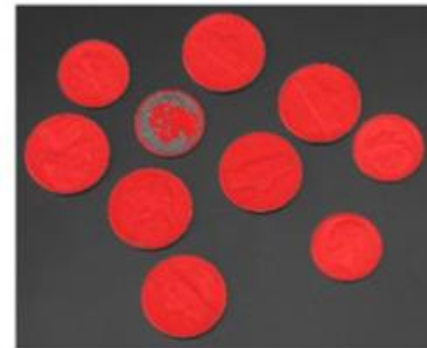
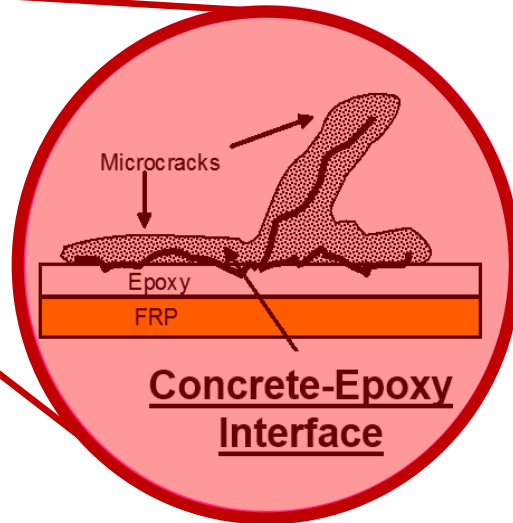
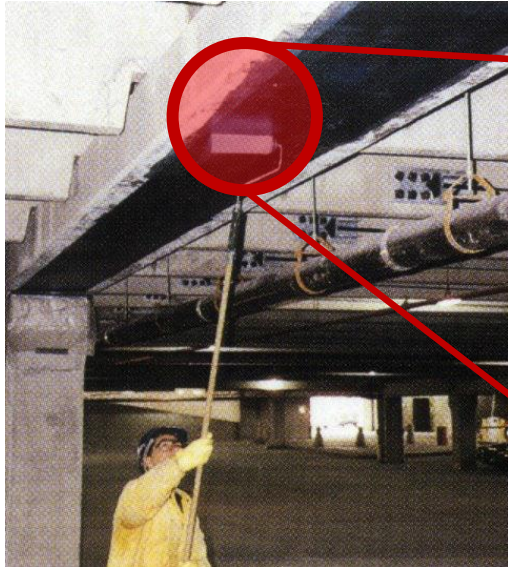


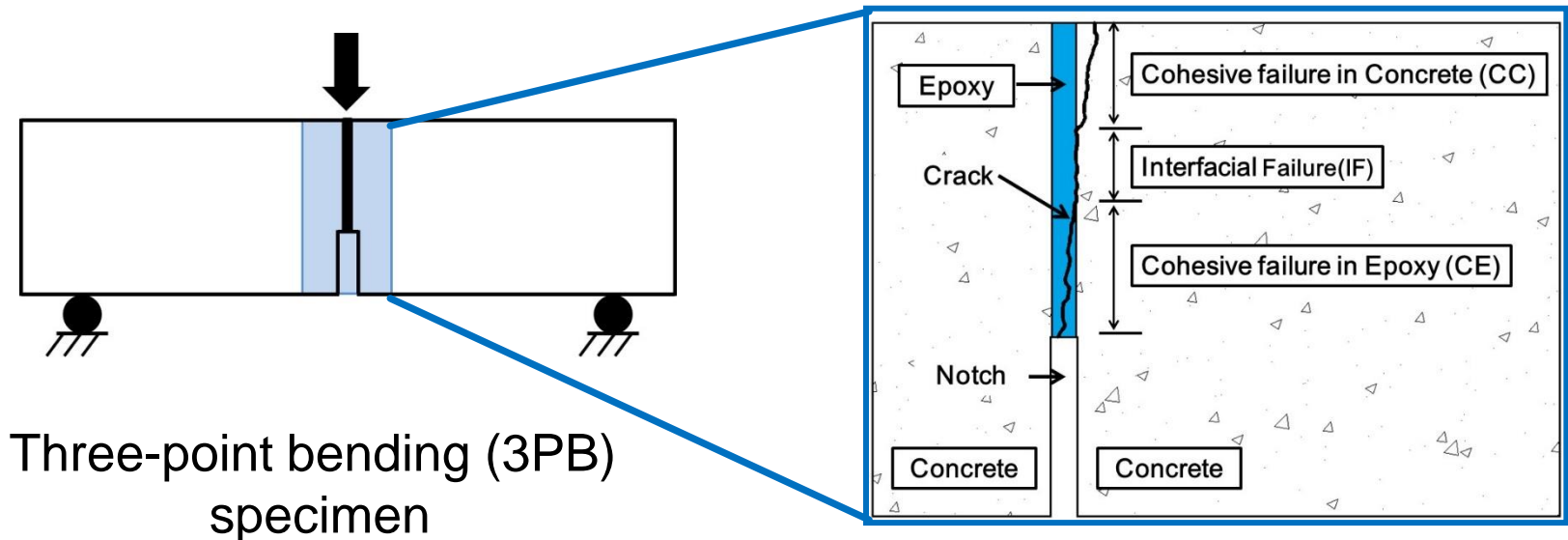
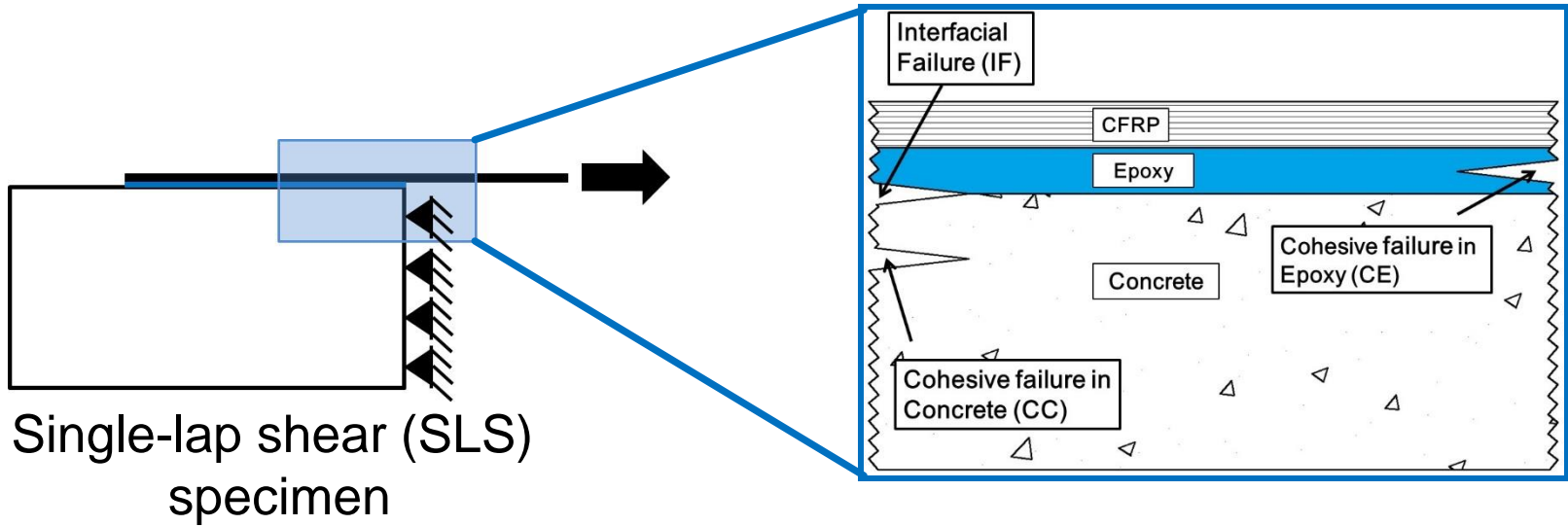
Image-segmentation  
method

sources:  
<https://ch.mathworks.com/discovery/image-segmentation.html>

**This presentation will introduce an image analysis methodology for evaluating Concrete-Epoxy Interface(CEI) based on segmentation-based techniques**

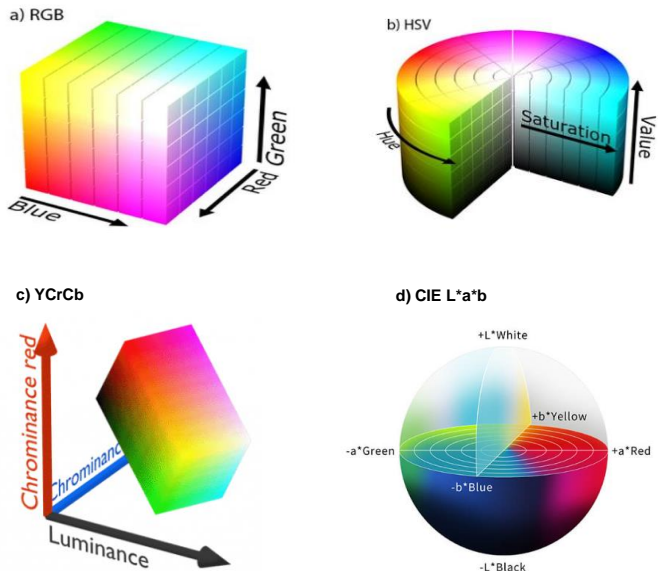
# 1 Introduction

## Background: Failure mechanism of CEI



# 1 Introduction

## Study Purpose



Different Color Spaces

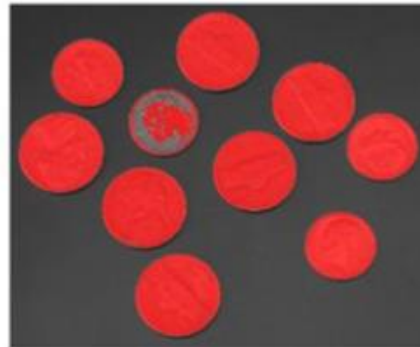
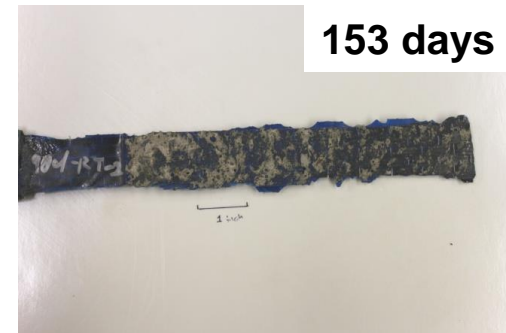
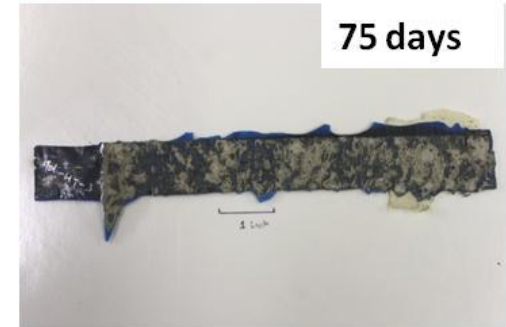


Image-segmentation method

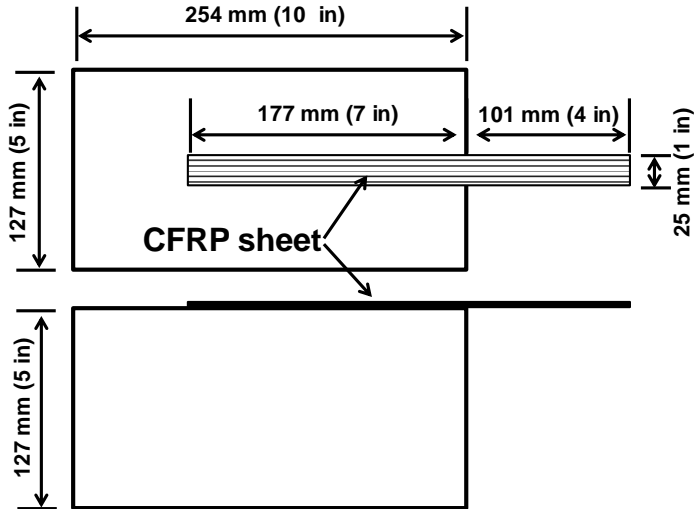


This study uses image segmentation to evaluate the effects of sustained loading and temperature on CEI failure modes.

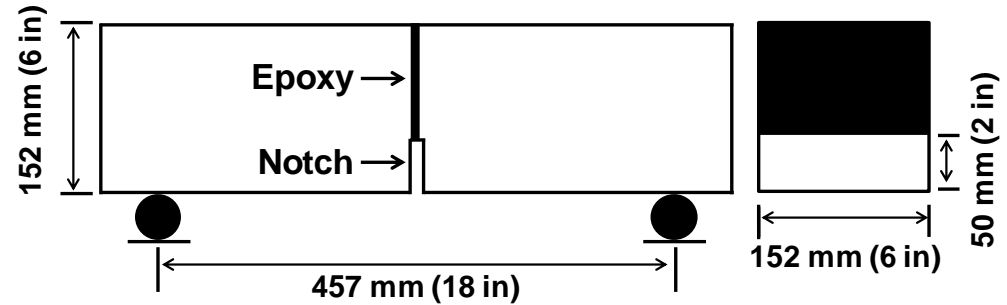
# 2 Mechanical Testing

## Test specimens

SLS specimens, 24



3PB specimens, 30



## Material properties

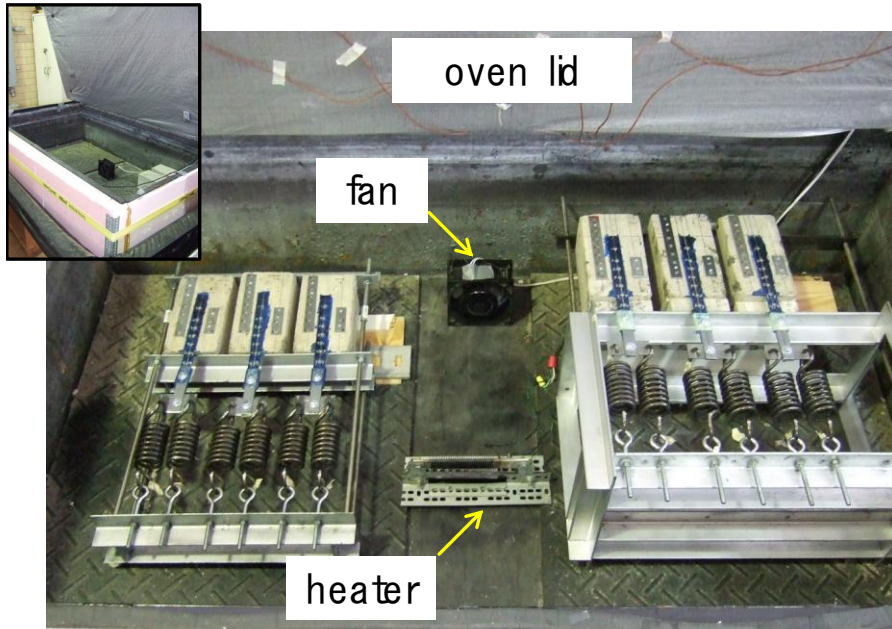
- Concrete: 28 day compressive strength-34MPa
- CFRP:CF-130, Single Ply CFRP sheet
- Epoxy: Two-part saturant



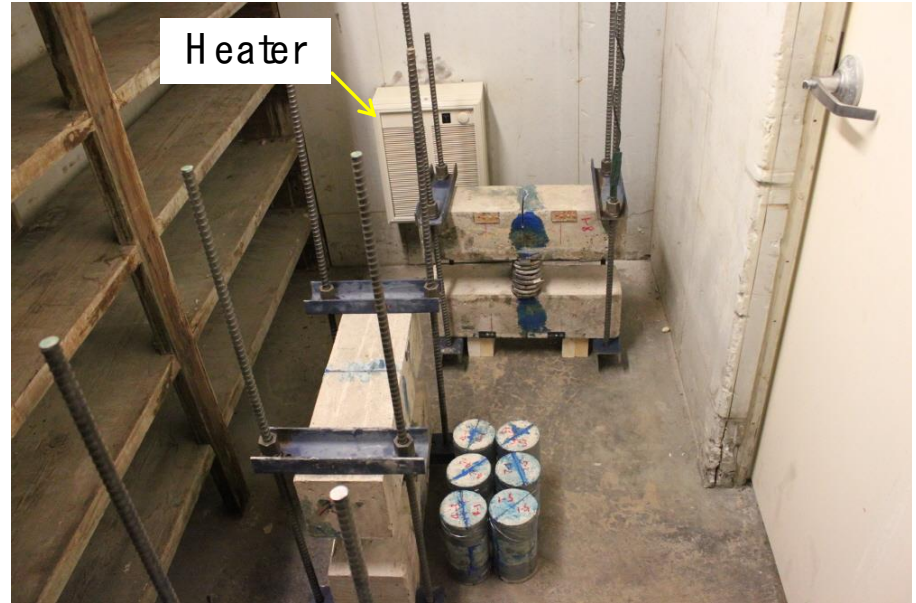
# 2 Mechanical Testing

## Sustained loading tests

### SLS specimens



### 3PB specimens

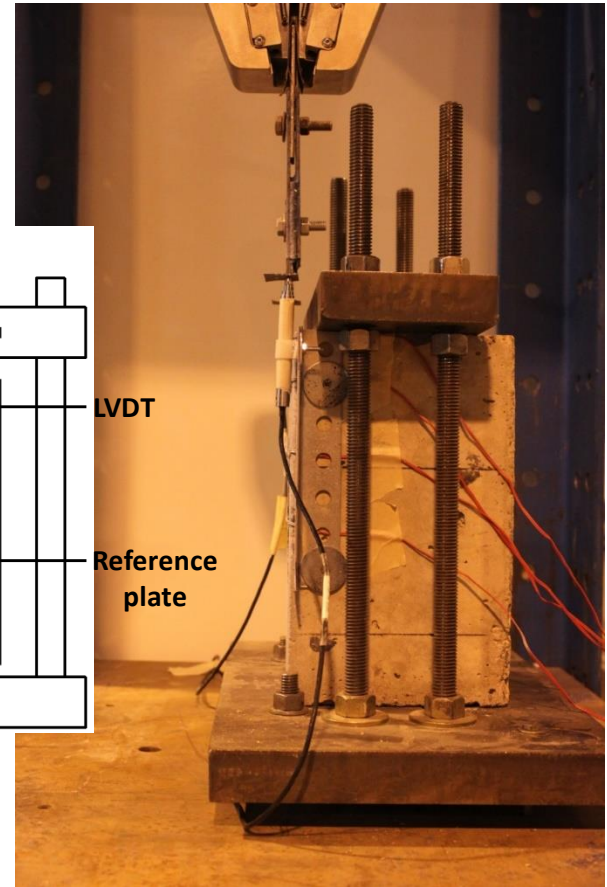
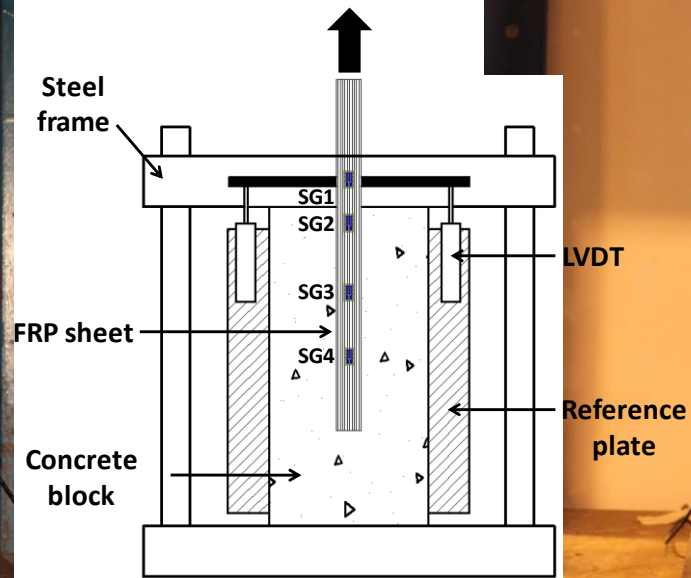
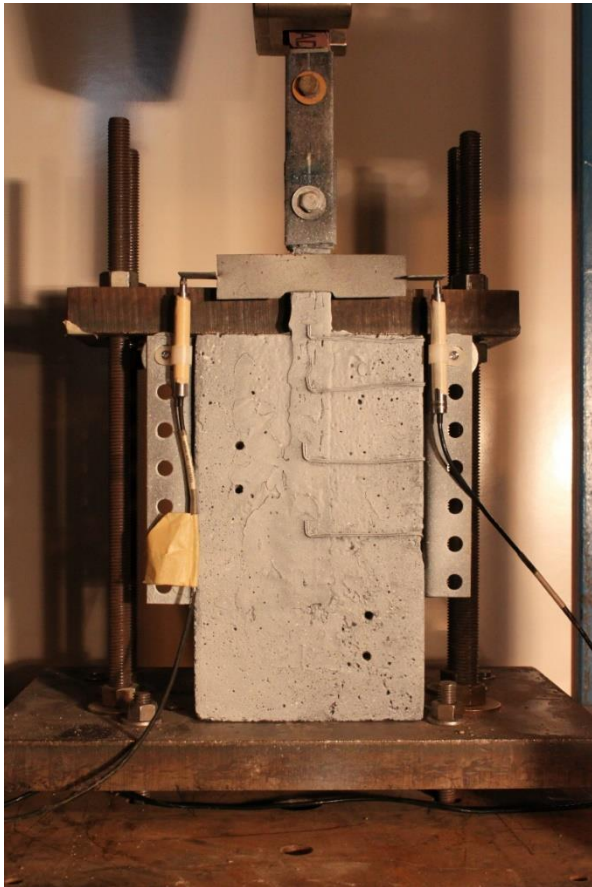


## Test parameters

- curing duration: 7 days, 90 days at 21°C
- sustained loading: 2.69 kN for SLS, 4.67 kN for 3PB
- creep test temperature: 21°C, 30°C
- Sustained loading period: 31~182 days

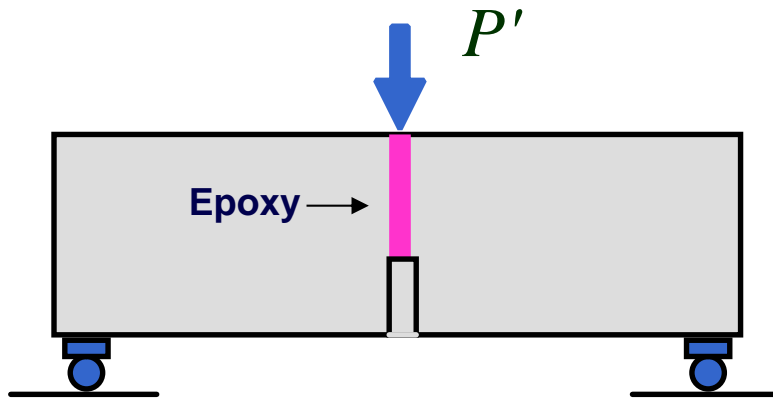
# 2 Mechanical Testing

## Single Lap Shear Tests

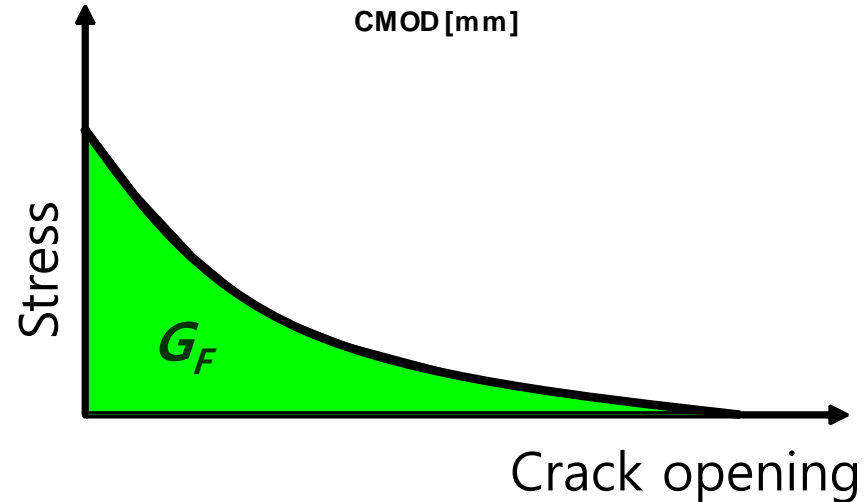
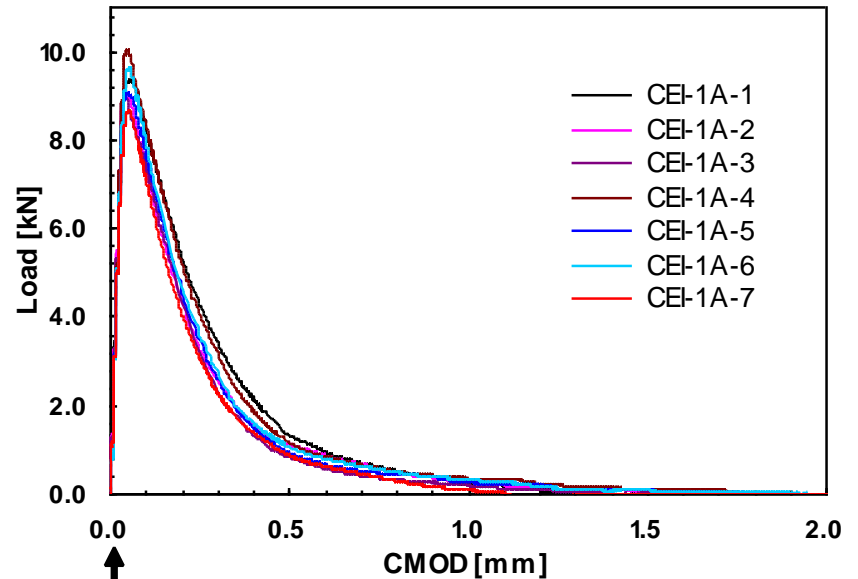
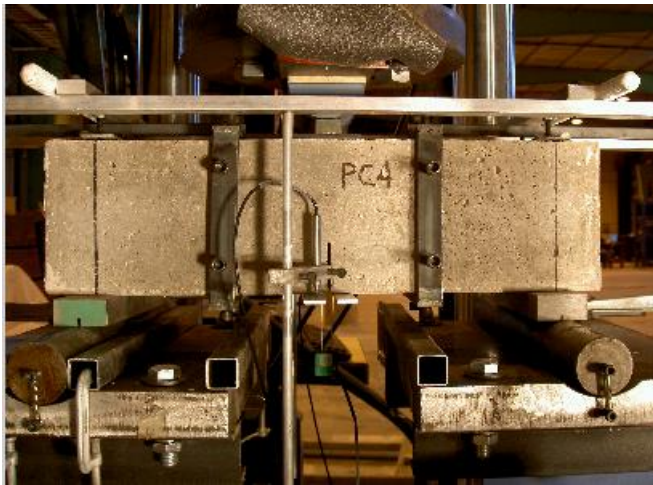


# 2 Mechanical Testing

3PB RILEM tests



Three Point Bending Test

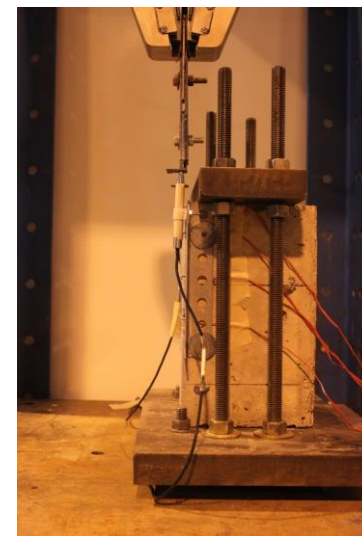
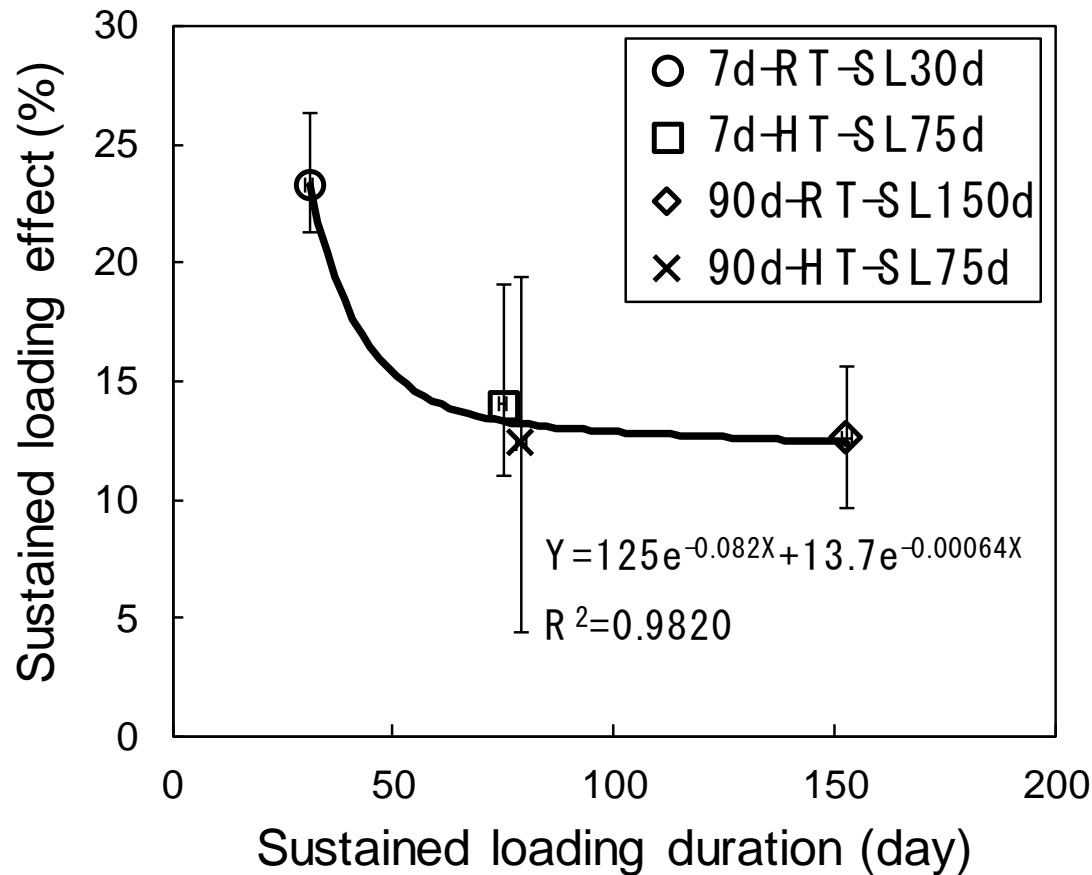


Fracture energy( $G_F$ ) of 3BP specimen is determined using the work-of-fracture.



# 2 Mechanical Testing

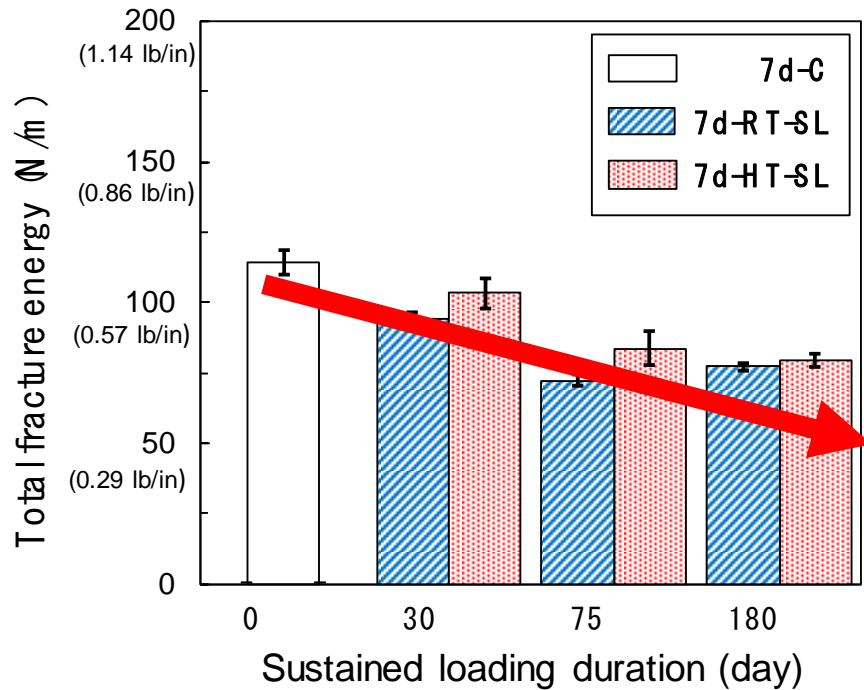
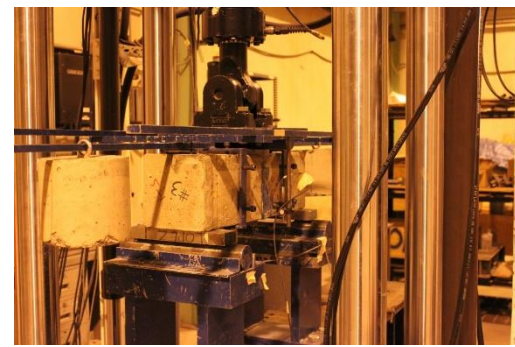
## Sustained loading effects $P_u$ of SLS specimens



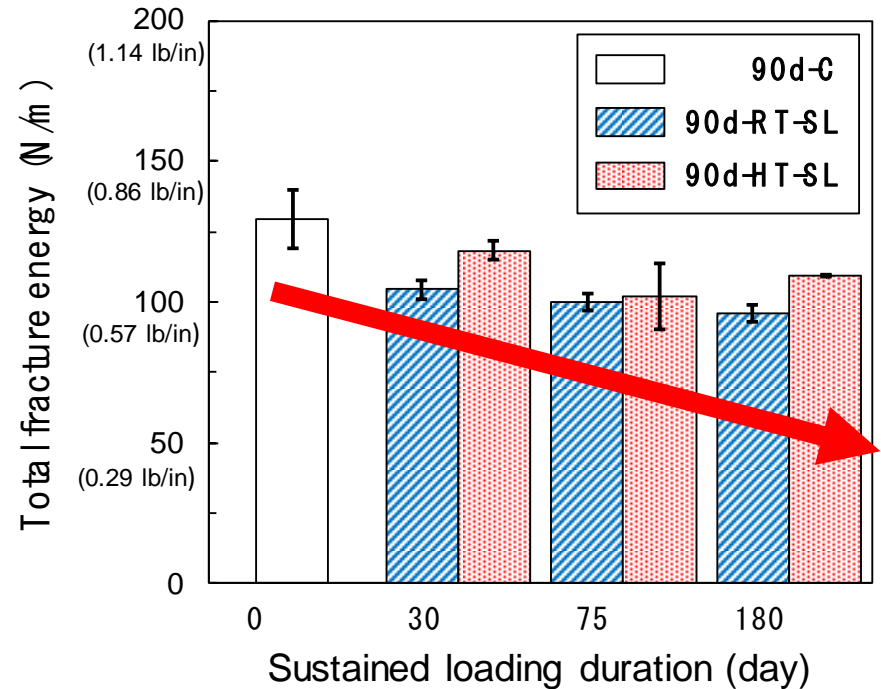
**Asymptotic decrease in the sustained load effect (change in ultimate load) regardless of curing time or temperature**

# 2 Mechanical Testing

Sustained loading effects  $G_F$  of 3PB specimens



7-day cured

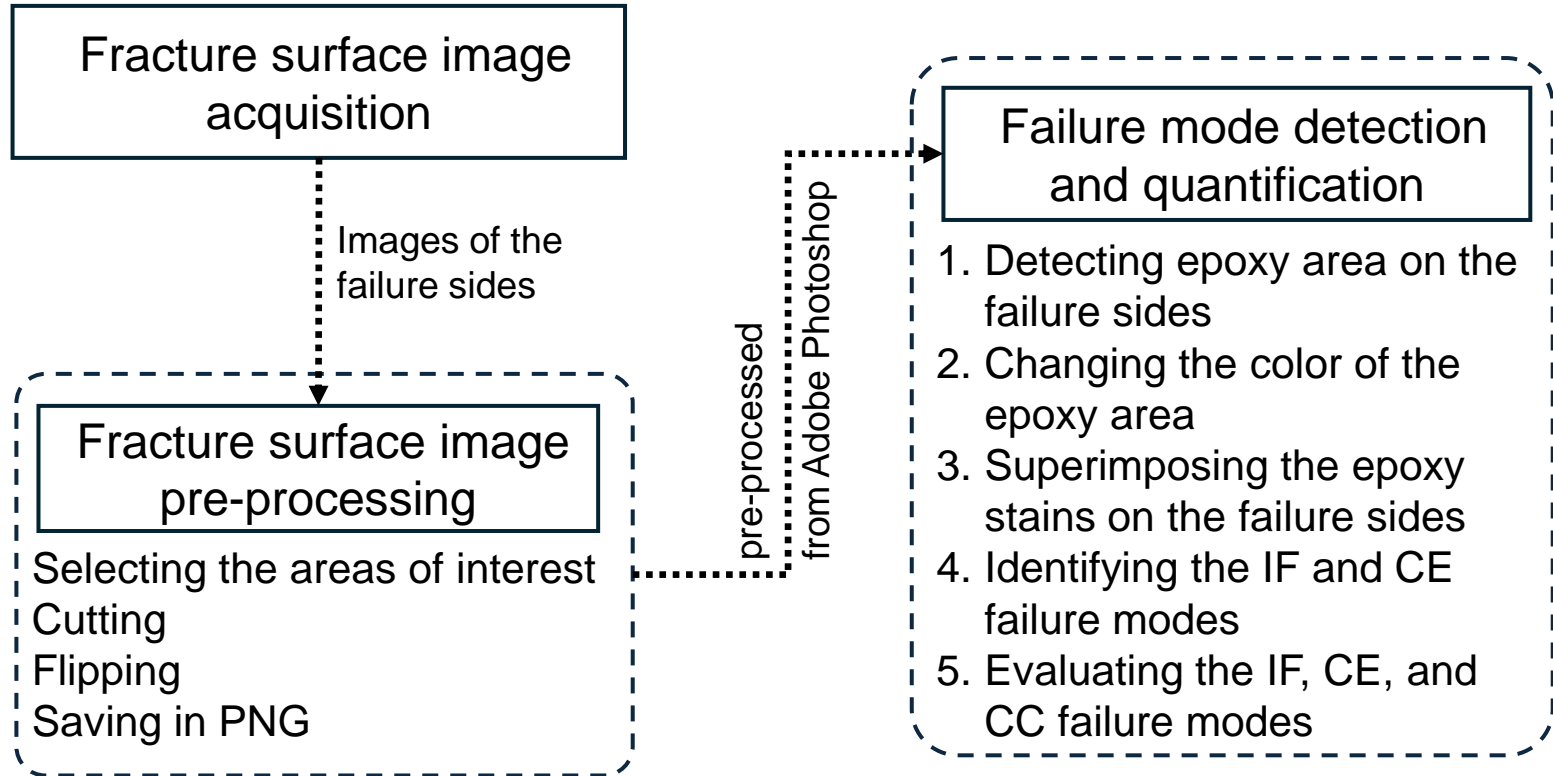


90-day cured

**A decrease in  $G_F$  as sustained loading duration increases**

# 3 Fracture surface analysis

## Flow chart: Image segmentation method

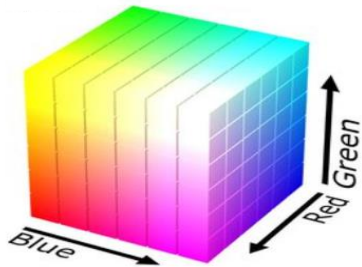


# 3 Fracture surface analysis

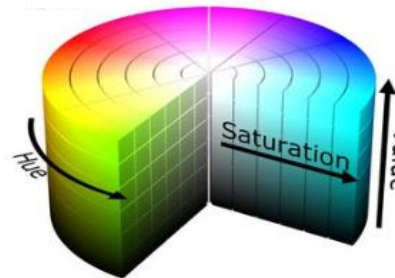
## Image processing technique (1/2)

Image processing segmentation using various color spaces is the image processing technique employed in this study.

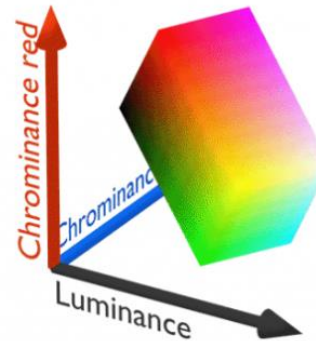
Common color spaces used for image segmentation include:



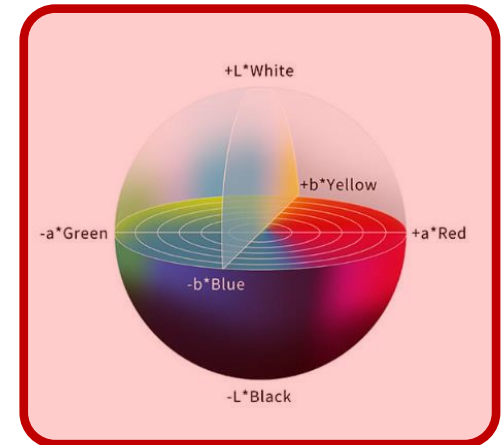
RGB Color Space



HSV Color Space



YCrCb Color space



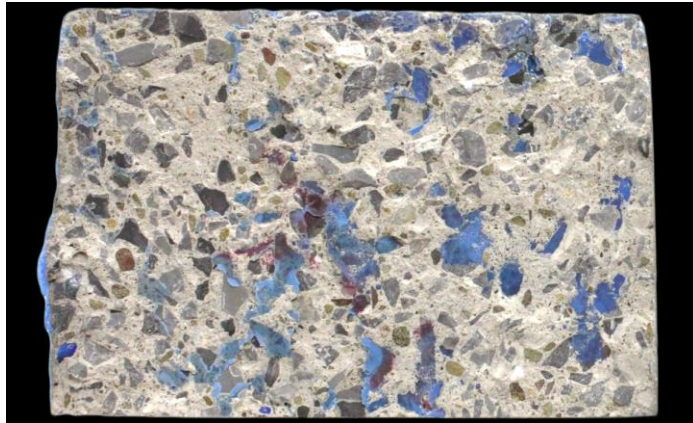
CIE L\*a\*b Color Space

**In this study, the CIE L\*a\*b color space was selected for its capability in quantifying minor color variations through sensitivity analysis.**

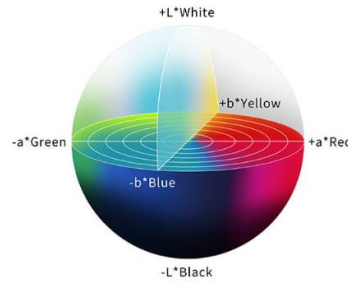


# 3 Fracture surface analysis

## Image processing technique (2/2)



A typical failure surface



CIE L\*a\*b image segmentation with all possible blue colors for epoxy

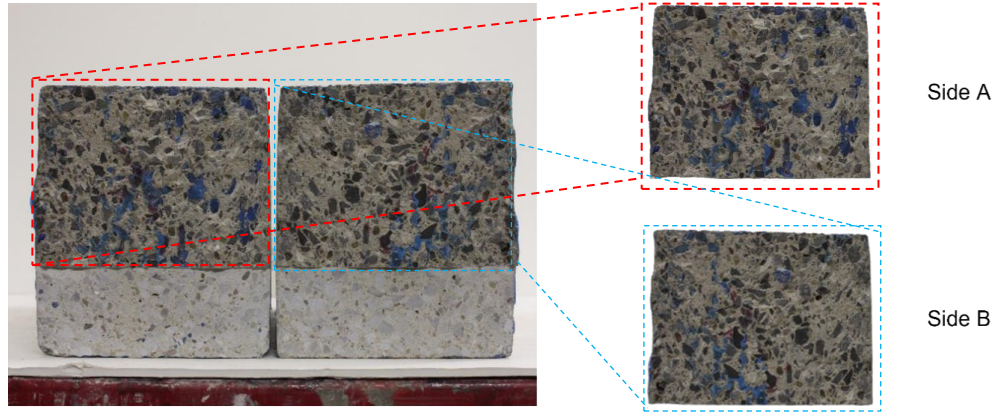


Output from CIE L\*a\*b color space segmentation

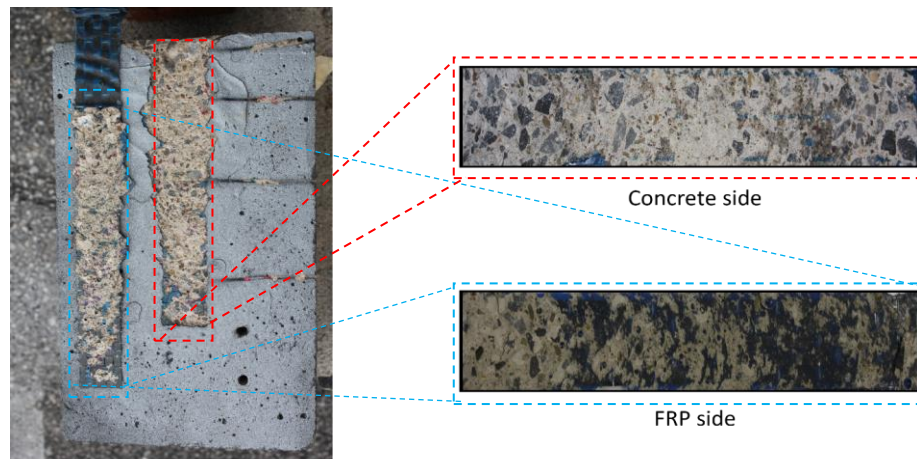
**The distinguishing feature used in the image segmentation process is the epoxy color (blue).**

# 3 Fracture surface analysis

## Image Processing: Fracture surface image pre-processing



(a)

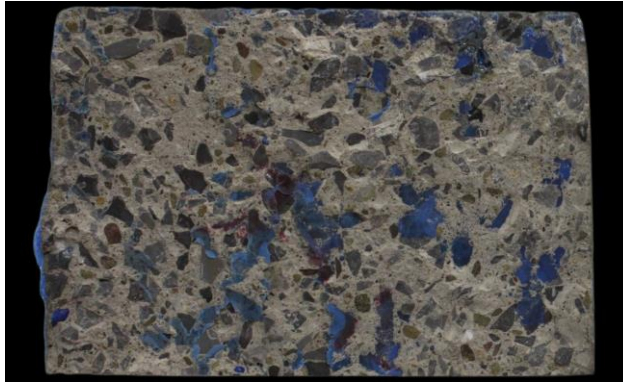


(b)

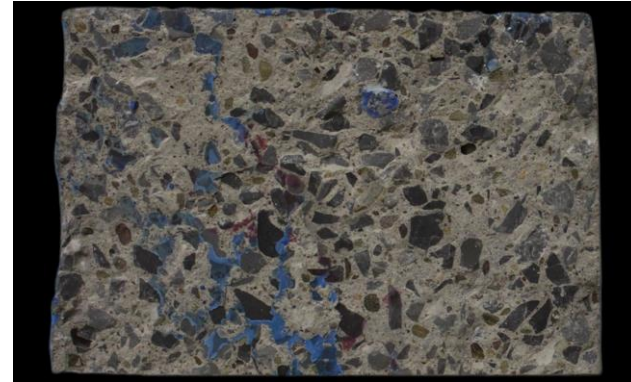
Adobe Photoshop pre-processed CEI fracture surface from (a) 3PB (b) SLS specimen failure sides

# 3 Fracture surface analysis

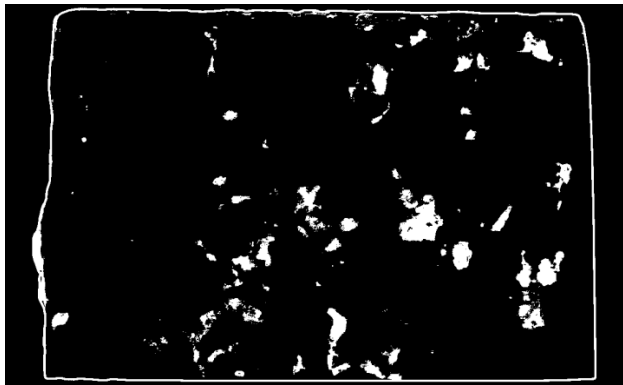
Image Processing: Failure modes detection and quantification (1/5)



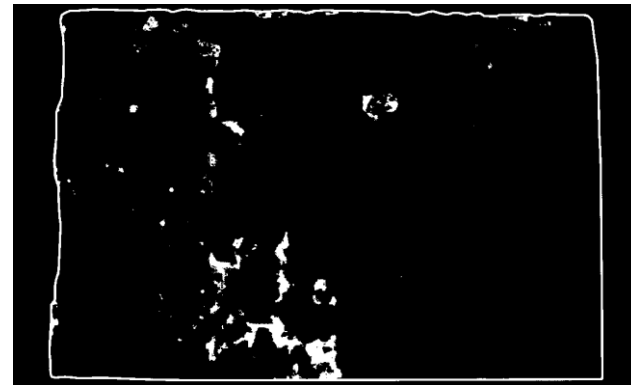
Preprocessed image (side A)



Preprocessed image (side B)



Edges and epoxy stains on (A)



Edges and epoxy stains on (B)

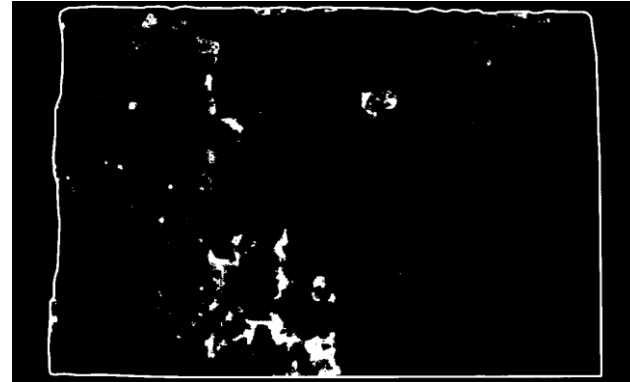
Step 1: Detecting the epoxy stains on the failure sides of a fractured 3PB specimen

# 3 Fracture surface analysis

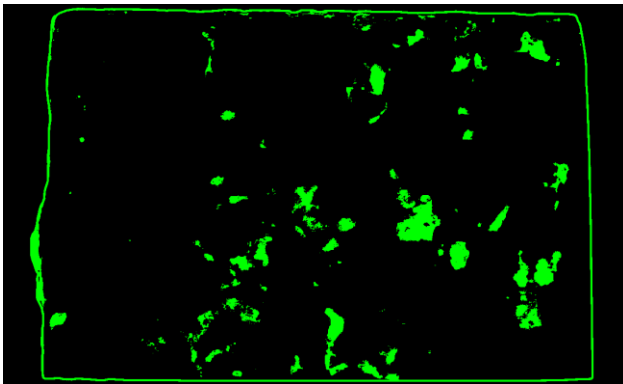
Image Processing: Failure modes detection and quantification (2/5)



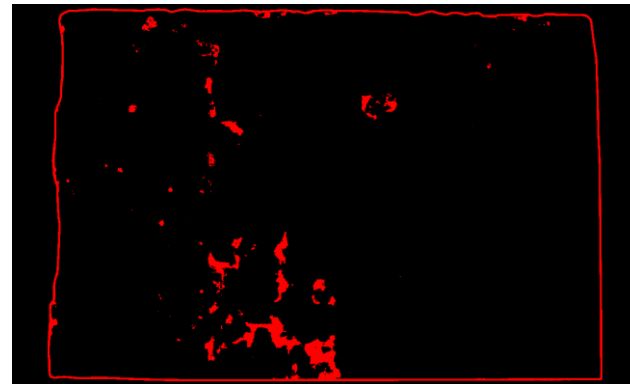
Edges and epoxy stains on (A)



Edges and epoxy stains on (B)



Edges and epoxy stains on (A)



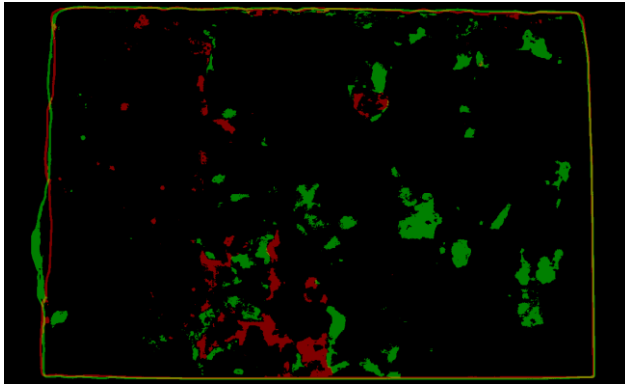
Edges and epoxy stains on (B)

Step 2: Changing the color of the epoxy stains on the failure sides of the fractured 3PB specimen to distinct primary colors



# 3 Fracture surface analysis

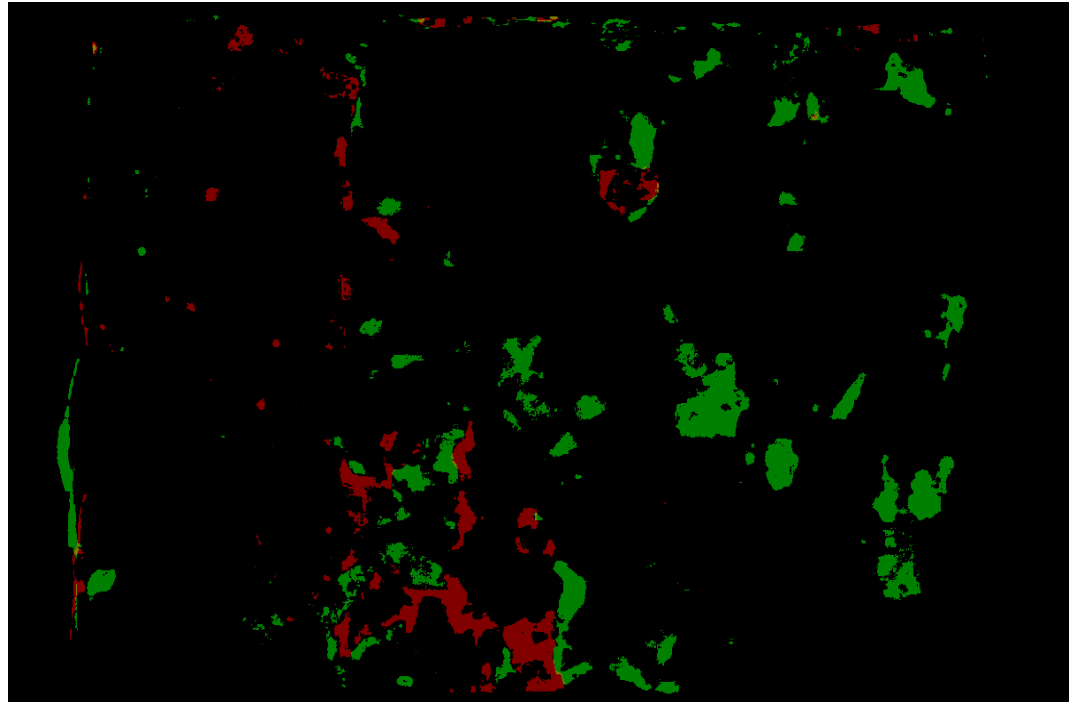
Image Processing: Failure modes detection and quantification (3/5)



Super imposed edges and epoxy stains on the failure sides

 : CE

 &  : IF

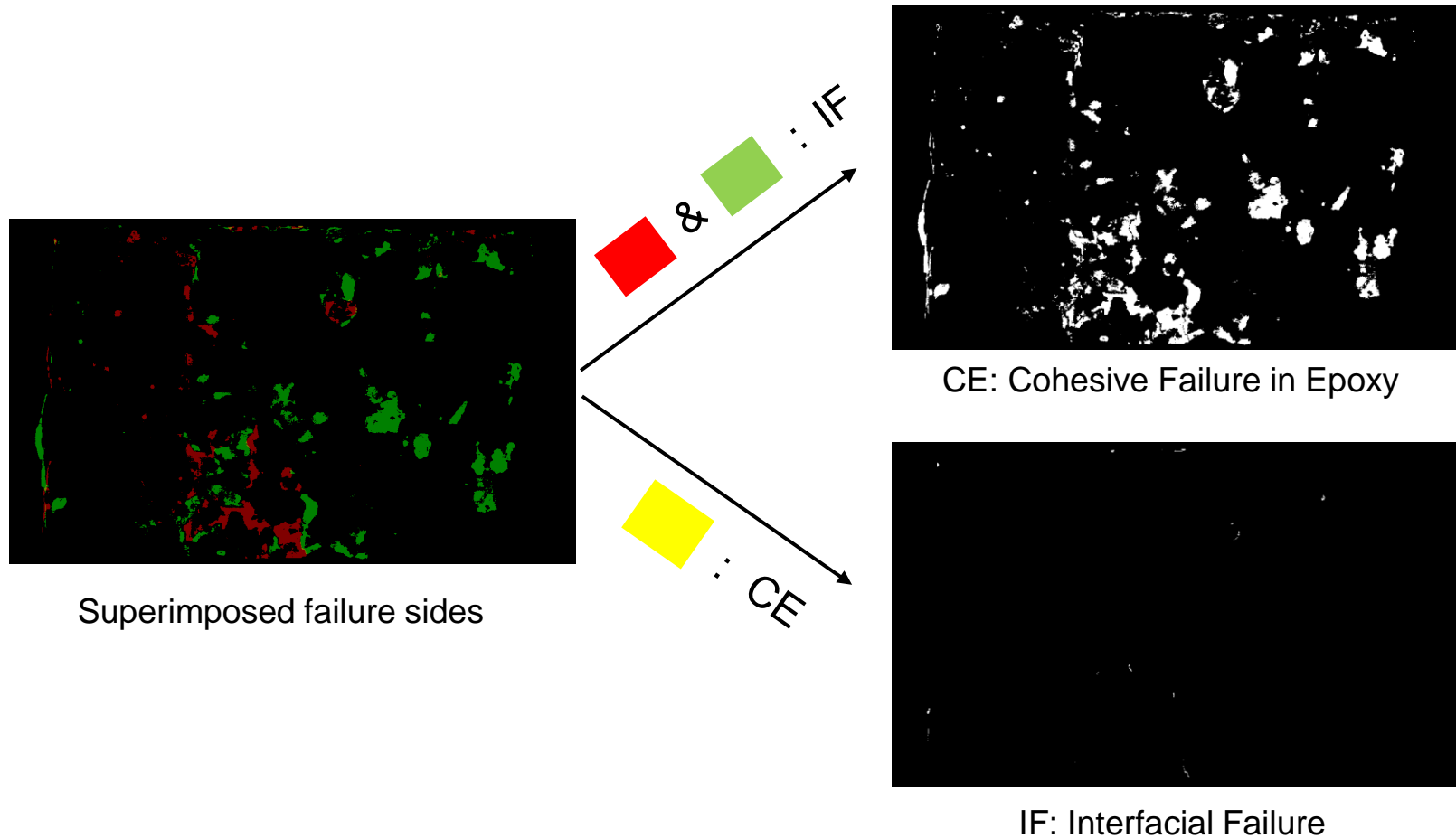


Super imposed epoxy stains on the failure sides

Step 3: Superimposing the epoxy stains on the failure sides of the 3PB specimen

# 3 Fracture surface analysis

Image Processing: Failure modes detection and quantification (4/5)



Step 4: Identifying the failure mode IF and CE on the 3PB specimen

# 3 Fracture surface analysis

Image Processing: Failure modes detection and quantification (5/5)

$$\text{Net area} = (\text{area covered by failure side A and B})/2, \quad (1)$$

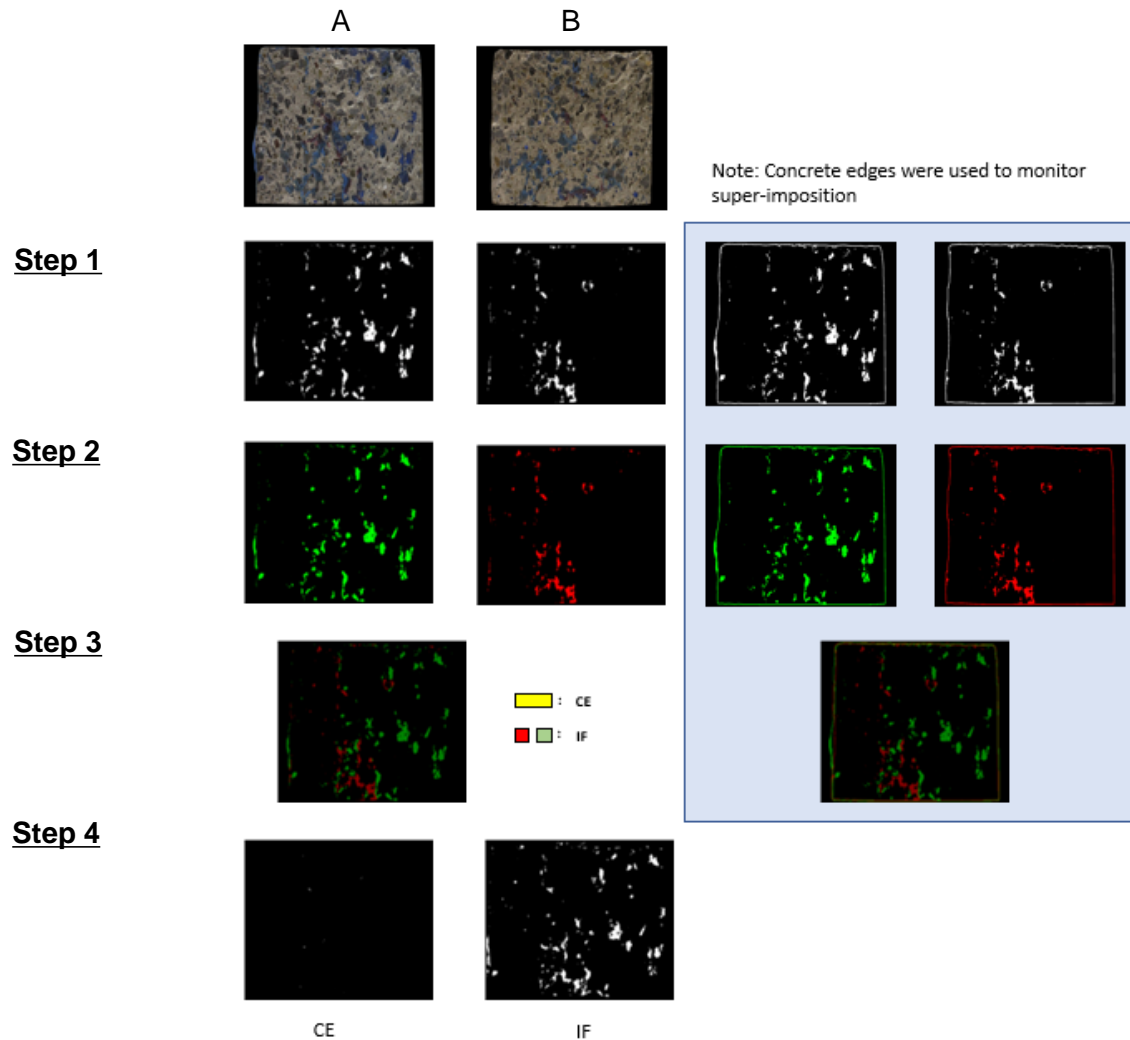
$$IF = (\text{area covered by IF} / \text{net area})100, \quad (2)$$

$$CE = (\text{area covered by CE} / \text{net area})100, \quad (3)$$

$$CC = (\text{net area} - [\text{area covered by (CE + IF)}] / \text{net area})100, \quad (4)$$

# 3 Fracture surface analysis

## Image Processing: Failure modes detection and quantification

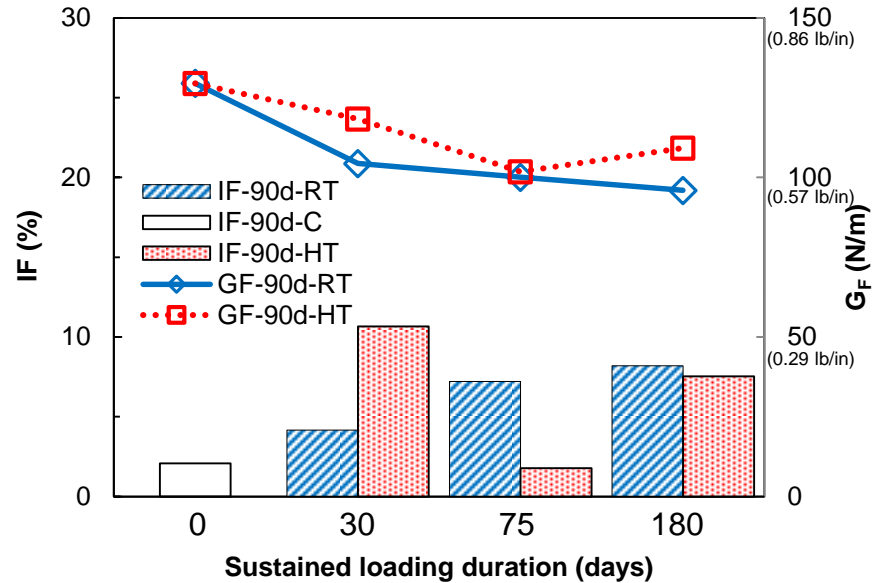
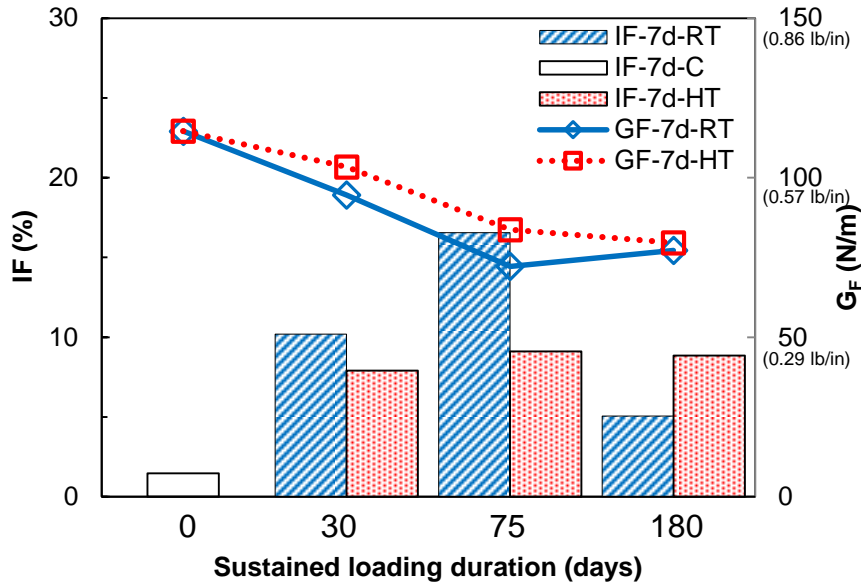


Failure mode detection (3PB specimen)



# 3 Fracture surface analysis

Image analysis results on  $G_F$



The reduction of  $G_F$  can be correlated to an increase in interfacial (IF) failure mode

# 4 Summary and Conclusion

## Summary and conclusion

- ❖ The duration of the sustained loading period adversely impacts the bond strength and the overall fracture energy of the specimens tested.
- ❖ The image segmentation approach described in this study is effective for evaluating the performance of CEI in 3PB specimens where the epoxy, FRP, and concrete substrate are distinguishable by color.
- ❖ Accurate evaluation of the failure modes can help practitioners improve their design and installation technique of FRP and epoxy during retrofitting tasks by providing valuable insight into the causes of failure.

# Thank you

