CLASSIFICATION OF SURFACE FINISH TO BOND NEW TO OLD CONCRETE

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This study develops a classification method to understand the relationship between the interfacial bond strength and the surface finish of newly added concrete to old. An experimental program is developed to evaluate the interfacial bond strength between new and old concrete with a various degree of surface finishes. Water jet technology is used to treat the finished surface of the old concrete. The degree of surface finish is determined by the exposure time and the number of repetitions under constant pressure. Each surface finish is analyzed by a 3D scanner focusing on indentation. A sufficient number of images is obtained to develop the classification scheme. The interfacial bonding strength is obtained by testing standard three point bending specimens with two prefabricated interfacial cracks. These specimens are tested to failure in a Mode I fracture only. The results indicate that bonding is improved with the degree of finish up to a peak value that is the optimal finish. Also, the study shows that the strain energy release rate for each surface finish remains to be constant and independent of the of the initial crack length.

Keywords: 3D Scanner, Fracture energy release rate, Surface preparation, Water jet, Interfacial bond.

1 INTRODUCTION

This paper is focusing on the effects that surface preparation has on the interfacial bond between new and old concrete. The factors that greatly affect bonding are concrete substrate characteristics, interface (surface) roughness, microcracking, and laitance (He et al. 2017). The surface roughness has been established as a major factor to the bond strength of concrete (Far and Zanotti 2019). There are many techniques that can be used to treat the surface of concrete such as water jetting, sand blasting, wire brush and chipping with a pneumatic hammer. So, considering the major bonding factors, water jetting with a pressure washer was selected as the method for preparing the concrete to be bonded. It was determined that water jetting could be most effective by removing laitance and unwanted debris while increasing surface roughness and limiting microcracking.

Image processing and machine learning tools have been widely utilized in numerous fields from different detection systems to autonomous vehicles (He et al. 2017, Garfo et al. 2020, Muktadir and Yi 2021). A study proposes a method to reduce the ratio of a concrete surface to the maximum diameter of bug holes, a type of surface voids by image processing methods (Liu et al. 2017). Another study illustrates a method to detect the crack on concrete surfaces based on image processing and supervised machine learning for the shadowed and dirt condition of a
surface by considering the pixel of the target and features of the cracks (Chun et al. 2021). A research study used two new methods to estimate, quantitatively, the concrete surface roughness from image processing (Valikhani et al. 2021). In this study, three-dimensional (3D) image processing has been used for the analysis of concrete surfaces that range from no treatment to 3rd treatment. For the capturing data a high-resolution a 3D scanner has been used.

2 EXPERIMENTAL

2.1 Materials, Specimens, and Surface Preparation

2.1.1 Materials

The mix design used to create the concrete specimens is shown in Table 1. The concrete used to create beam halves (old concrete) was a 3000-psi mix that included 120 pounds of fly ash. The fly ash is a common additive used to increase the density of the concrete but is not needed. The concrete used to bond to the old concrete (new concrete) was of the same mix design, however the fly ash was not included. The mix design is not the focus of this research, so the mix design used is what was easily accessible from the concrete plant.

<table>
<thead>
<tr>
<th>Material</th>
<th>Old Concrete</th>
<th>New Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>57 Agg (lbs)</td>
<td>1905</td>
<td>1905</td>
</tr>
<tr>
<td>Sand (lbs)</td>
<td>1320</td>
<td>1435</td>
</tr>
<tr>
<td>Cement (lbs)</td>
<td>470</td>
<td>475</td>
</tr>
<tr>
<td>Fly ash (lbs)</td>
<td>120</td>
<td>0</td>
</tr>
<tr>
<td>MB700N (oz)</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Slump (in.)</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

2.1.2 Specimens

A total of 42 concrete beam specimens created for testing while all specimens had either an initial crack of one inch or of one-half inch. Six specimens were cast as whole beams to represent the desired strength of bonded concrete, three beams for each crack length. Six beams were bonded with no surface treatment as a control group, three beams for each crack length. Ten beams were bonded for each of the surface treatments, five beams for each crack length. The first half of the bonded concrete specimens were cast using a steel plate as a divider which created two half beams. After curing, the surface preparation was performed, and a piece of tape was placed at the bottom of the interface to simulate the desired crack length. At this stage, the beam half was ready to be placed back in the form and the new concrete placed to bond. All specimens were created following ASTM C31 and ACI 308 standards to ensure consistency and to control hydration to reduce shrinkage cracks during the curing process (ASTM 2021a, ACI Committee 308 2021). The final specimens had dimensions of 6in X 6in X 20.5in.

2.1.3 Surface preparation

Water jetting with a 3400-psi pressure washer was used to perform the surface preparation. Each degree of the surface preparation was performed with a 25-degree tip and held two inches away from the concrete surface. A grid pattern was used to ensure consistent surface preparation. To ensure a uniform treatment, each direction of the grid pattern, such as vertical and horizontal, was
completed before moving on to the next. Three degrees of preparation were used and distinguished by time of treatment. The treatment times are 1.5, three, and six minutes, which respectively correlates to 24, 12, and six square inches per minute.

2.2 Surface Analysis
A 3D scanner (ARTEC RAY 3D) has been used to collect the raw point cloud date a form of 3D imaging format. This scanner can scan up to 110m distance with horizontal 360 degree and vertical 270-degree rotation, and the maximum resolution is 80 points per degree. For the analyses of the raw data, post processing is a must to remove the noises that comes from the environment outside of the region of interest. Artec 3D ray scanner software has been used for the post-processing. After that the analysis have been done for all the cases, no treatment and with the treatment surfaces.

2.3 Testing
A three-point bend test was chosen to test the interfacial bond between new and old concrete because it limits the specimens to Mode I fracture only (ASTM C78 (ASTM 2021b), ASTM C293 (ASTM 2016)). This procedure is illustrated in Figure 1, where $S$ is the span, $a$ is the initial crack length, $P$ is the load, and $b$ is the thickness of the beam. The tests were performed on an MTS 55-kip load frame. The beams were set on a span of 18 and $5/16$ inches and the loads were applied in the center at the interfacial bond. The rate of loading was set at 0.003 in/s and the specimens were tested to failure.

![Figure 1](image1.png)

Figure 1. Example of three-point test on a beam with initial crack (Abdel-Fattah and Hamoush 1997).

3 IMAGE (3D) ANALYSIS RESULTS
Visually, it is possible to differentiate the surface roughness between no treatment surface and the treatment surfaces ($1^{st}$, $2^{nd}$, and $3^{rd}$). However, it is not possible to differentiate among first, second, and third treatment. Figure 2 and 3 show the 3D surfaces of the concrete sample face. A 3D plot with MATLAB was drawn, as illustrated in Figure 4, to analyze the surface roughness. It depicts that the surface roughness increases as the degree of treatment increases.

![Figure 2](image2.png)

Figure 2. 3D surface of no treatment and Treatment 1 (left to right).
Figure 3. 3D surface of Treatment 2 and Treatment 3 (left to right).

Figure 4. Plotting of surface roughness of no treatment, treatment 1, 2, and 3 (top to bottom).

4 TEST RESULTS

The test results in the following figures represent the data collected at this time. Only one specimen from each surface treatment for each crack length has been tested at this time. Figures 5 and 6 respectively represent the data collected during the test procedure. The test specimens were labeled Solid Beam (Solid), No Treatment (NT), First Treatment (FT), Second Treatment (ST), and Third Treatment (TT).

Figure 5. Plot of load vs. deflection for initial crack (\(a\)) of one inch.
Figure 6. Plot of load vs. deflection for initial crack (a) of one-half inch.

The test results were used to calculate the Fracture toughness ($K_{IC}$) by using the equations formulated by Abdel-Fattah and Hamoush (1997). In this case $K_{IC}$ is equal to the Mode I stress factor ($K_I$) because of the beams having a central crack. The moment on the specimen is computed by substituting the critical load at failure into Eq. 1. The moment is then substituted into Eq. 2 to calculate the stress. A function of the ratio ($a/b$) is represented as $F(a/b)$ and is given by Eq. 3. Using the variable calculated in Eq. 1, 2, and 3, the fracture toughness can be computed by using Eq. 4. The fracture toughness of each specimen is illustrated in Figure 7.

\[
M = \frac{PS}{4}
\]

\[
\sigma = \frac{6M}{b^3}
\]

\[
F\left(\frac{a}{b}\right) = 1.09 - 1.735\left(\frac{a}{b}\right) + 8.2\left(\frac{a}{b}\right)^2 - 14.18\left(\frac{a}{b}\right)^3 + 14.56\left(\frac{a}{b}\right)^4
\]

\[
K_I = \sigma\sqrt{\pi a F}\left(\frac{a}{b}\right)
\]

Figure 7. Calculated fracture toughness for solid (1), no treatment (2), first treatment (3), second treatment (4), and third treatment (5).
5 DISCUSSION AND CONCLUSION

Although this is incomplete data, the results are showing that our predictions are within the expected trend. It was predicted that the fracture toughness would remain constant for each surface treatment regardless of the initial crack length. In Figure 7, the fracture toughness for treatments one, two and three are very close. The solid and non-treated beams are not as expected, however there may be some irregularities that were noticed when applying the load to the specimens and these irregularities were resolved. The fracture toughness and test data also show that the second stage of surface preparation has created the strongest bond which suggests the optimum treatment. This indicates that the surface treatment improves the bonding between the two concrete mixes up to the peak value in the second treatment and continuing treatment degrades the bonding surface. In the case of image analysis, previously, a 2D image analysis have been done which shows the percentage of black pixel increases with the increment of surface treatment where the no treatment shows the minimum results. However, in this study a new 3D scanner has been used to get higher resolution surface roughness. In future, a machine learning approach will be done to get more accurate results and a new approach, reverse engineering will be applied to solve those issues.

References
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