CENTER FOR INFRASTRUCTURE ENGINEERING STUDIES

FINAL TECHNICAL REPORT:

DEVELOPMENT OF A PROTOTYPE IMAGING CONCRETE ROUGHNESS MEASUREMENT DEVICE

To

ACI CONCRETE RESEARCH AND EDUCATION FOUNDATION

by

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University of Missouri-Rolla

CIES
00-20

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ABSTRACT

This report describes the activities, findings, conclusions, and recommendations of a study into the development of a prototype imaging concrete roughness measurement device. The work funded by the Concrete Research Council, with a 100% match by the University Transportation Center at the University of Missouri-Rolla.

1. INTRODUCTION

The failure of a reinforced concrete member strengthened with FRP laminates may be caused by crushing of concrete, rupture of FRP laminates, or by the de-lamination of the FRP sheet. Therefore, the effectiveness and failure mode of fiber-reinforced polymer (FRP) sheets applied to beams and columns is related to the degree of adhesion of the epoxy to the concrete surface. When a peeling or de-lamination failure can be avoided, a more effective engagement of the FRP sheet occurs which results in more efficient use of material.

One of the principal factors affecting the bond behavior between the concrete and epoxy is the roughness of the concrete substrate. To prepare the bond surface, sand blasting or grinding is typically used to roughen the concrete. To that end, a portable device has been developed to measure the roughness of concrete surfaces. This device can be used as a quality control tool to characterize surface roughness and identify when an adequate surface preparation has been attained. The method uses laser striping and image analysis, and may have applications in other aspects of concrete repair.

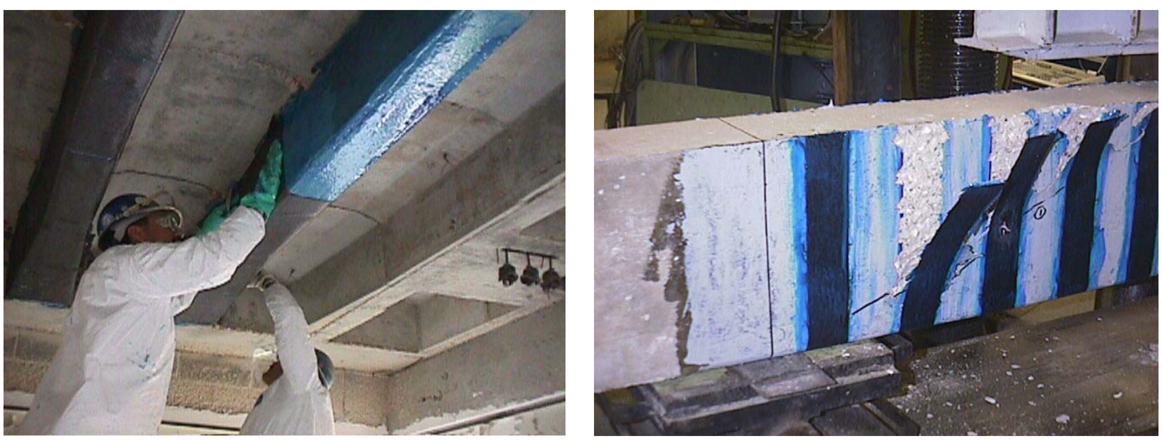


Figure 1, left: Application of FRP sheet on one-way joist, right: De-lamination of externally bonded FRP sheets.

2. WORK COMPLETED

2.1 Development of a Prototype Measuring Device

A prototype measuring device has been developed (Figure 1).

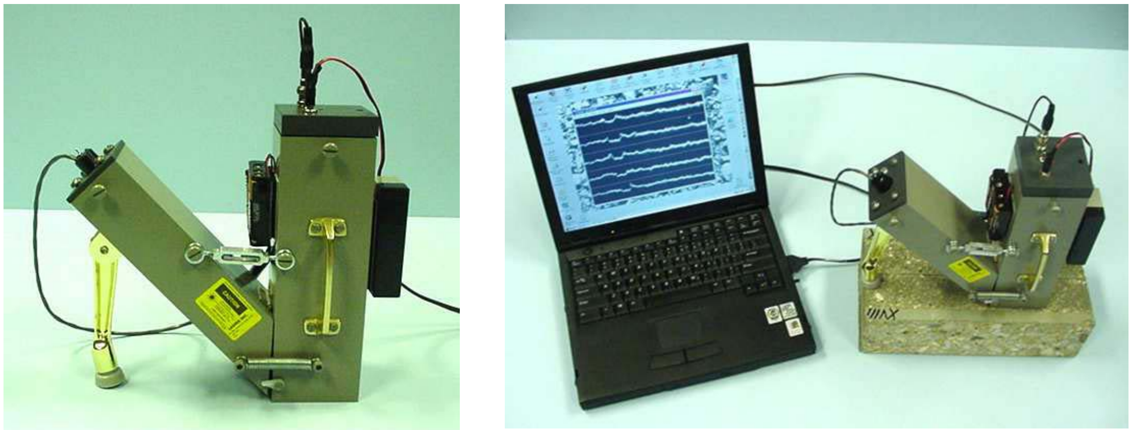


Figure 2 left: Laser profilometer, right: Profilometer and laptop computer.

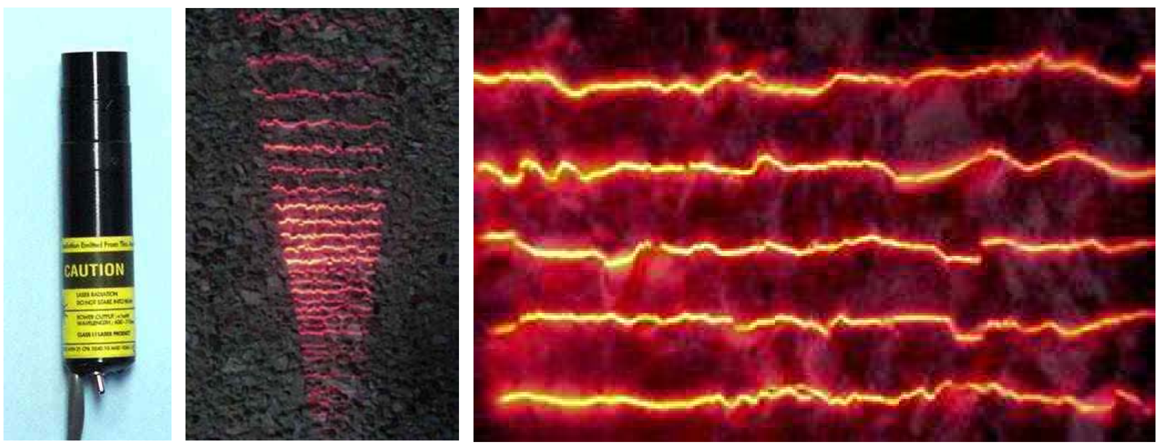


Figure 3 left: Striping laser. Figure 2, right: Profilometer and laptop computer.

Figure 4 left: Camera and mount, right: lens with laser bandpass filter.

The device consists of a portable lightweight aluminum housing designed to hold the camera and a striping laser. It has handles for field use where the device can be held against a horizontal wall or upwards against a ceiling. It has a single retractable leg so that it can stand freely on horizontal surfaces and in the lab. A four "AA" battery pack to power the laser is attached, and a 12 volt gel cell to power the camera is also attached.

The system uses a 670 nm 20 mW striping laser mounted at 45º to the concrete surface to generate five (or nine) profile lines (Figure 3). These lines follow the contours of the surface, and get progressively more undulating as the roughness of the surface increases. The device uses a miniature video camera, mounted at 90º to the surface, to image the profiles (Figure 4). A 670 nm laser band pass filter is mounted on the lens to admit the laser-illuminated profile, and reject other ambient light.

The video signal is transmitted to a laptop computer via coax cable or wireless video. At the computer the signal is digitized by a PCMCI digitizing card or framegrabber (Figure 5). This is one of the few devices available for bringing images into a laptop computer.

2.2 Development of Windows Image Analysis Software

The image analysis software was developed to run under Microsoft Windows®, and developed in Visual C++®. The image is captured using the PCMCIA framegrabber, and displayed on the screen (Figures 6, 7).

Image processing consists of the following operations:

1. Conversion of the color image to a monochrome (red) image.
2. Digital low pass filtering (guassian) to remove noise.
3. Further low pass filtering using a horizontal median 5 by 1 pixel filter.
4. Identification of the edge of the profiles (Figure 8).
5. Conversion of profiles from raster to vector data format.
6. Calculation of 10 measures of roughness (Figure 9) (Chepeur 2000).

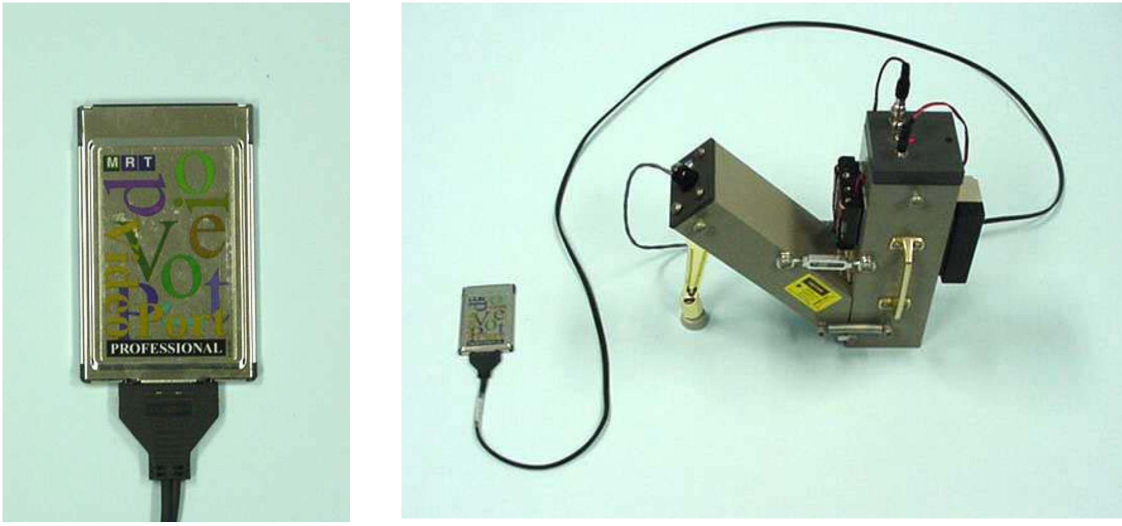


Figure 5 left: PCMCI framegrabber, right: wired video connection.

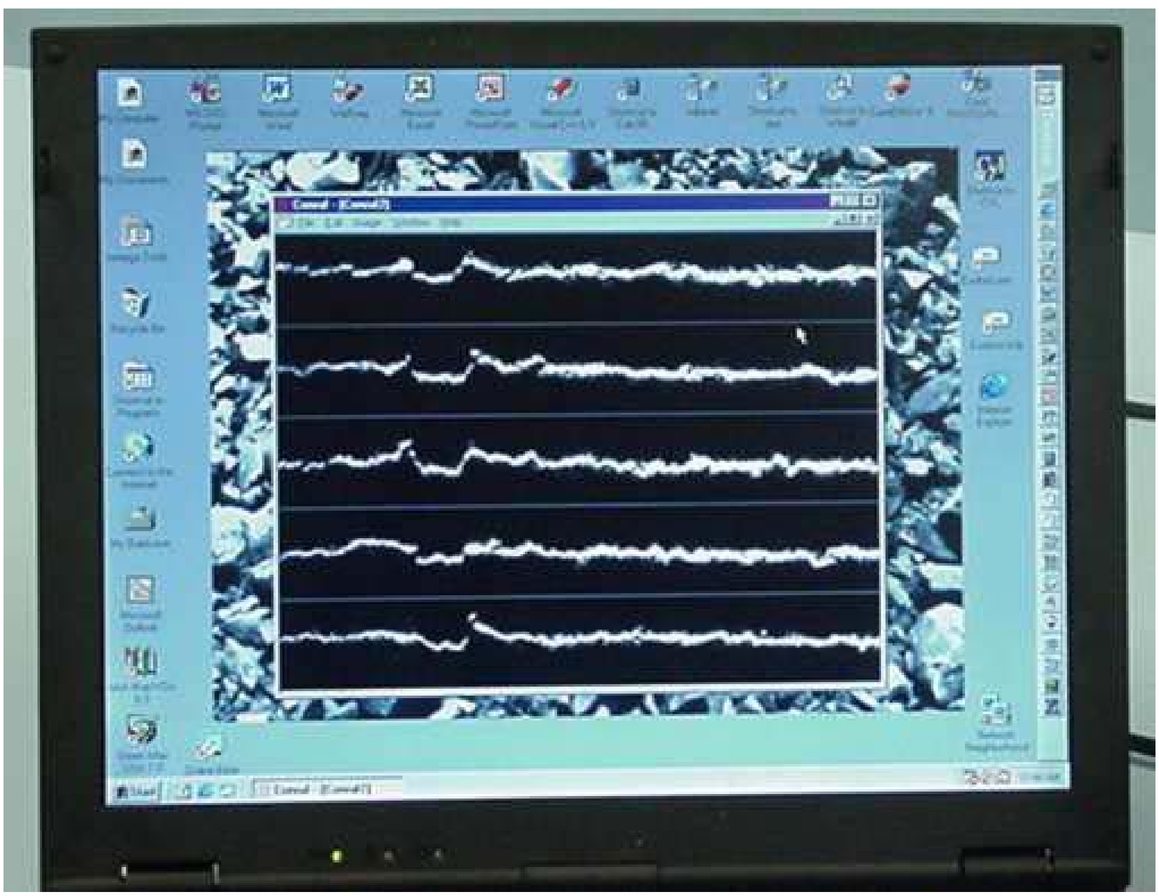


Figure 6: Laptop computer screen.

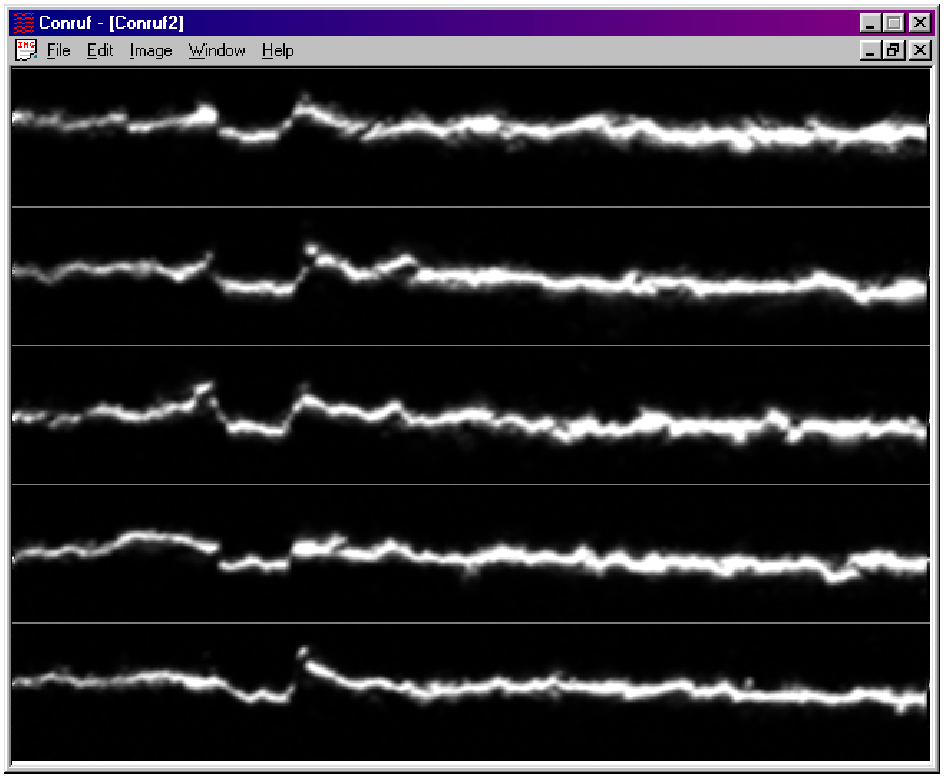


Figure 7: Monochrome digital image a rough surface.

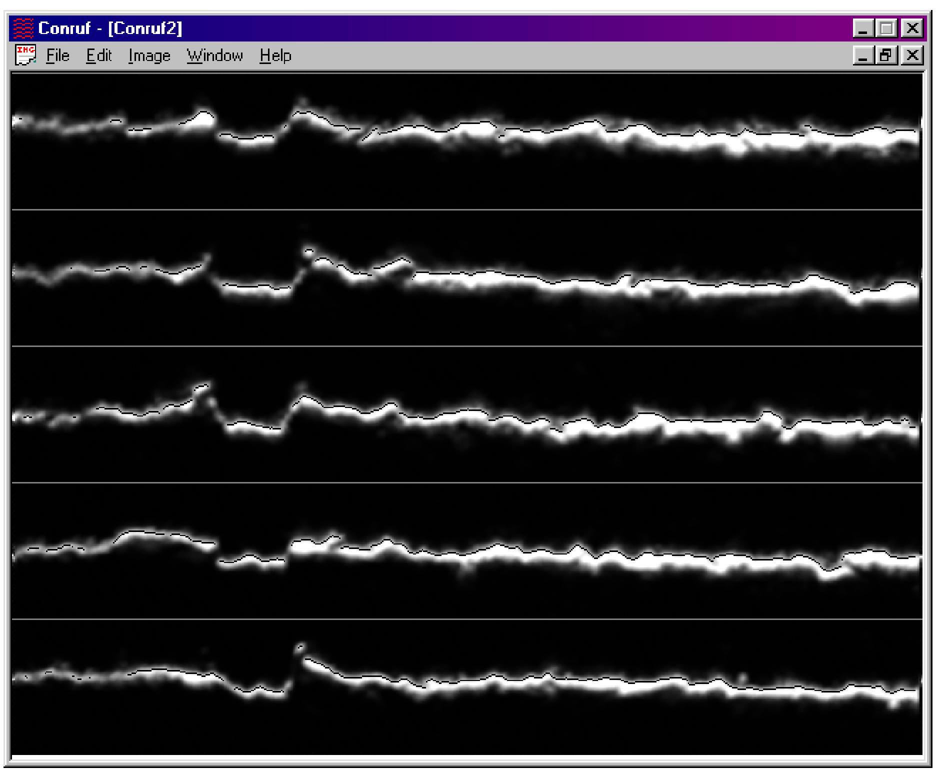


Figure 8: Identification of profile edges.

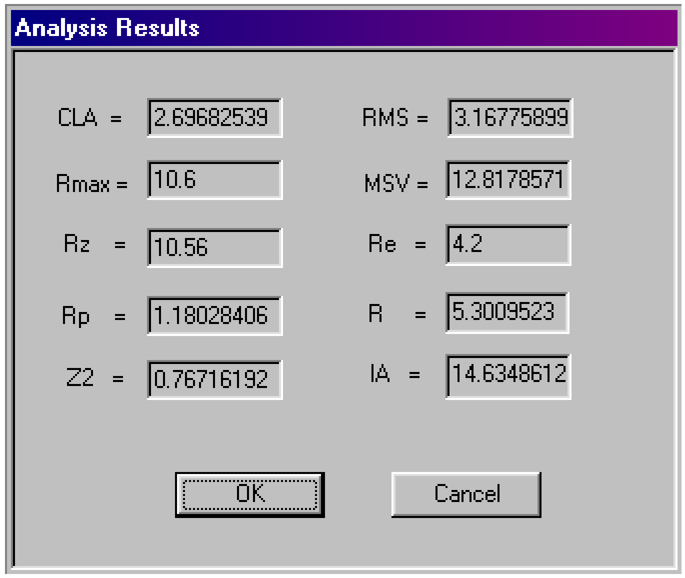


Figure 8: Ten measures of roughness 1) Center Line Average (CLA), 2) Root Mean Square (RMS), 3) Maximum peak to valley height (Rmax), 4) Mean Square Value (MSV), 5) Ten Point Height (Rz), 6) Leveling depth (Re), 7) Roughness Profile index (Rp), 8) Average valley to peak roughness (R), 9) RMS of the first deriviative (Z2), 10) Micro average angle (IA).

3. FINDINGS

3.1 Prepared Concrete Surfaces

An initial study was undertaken to evaluate the proposed measurement technique, two sets of concrete surfaces were prepared. Six concrete blocks of size 300-mm x 300-mm x 100-mm were cast (Figure 10). Five of the concrete surfaces were prepared by sandblasting, each progressively made rougher by increasing the duration of sandblasting. (While there was nominally a linear increase in the duration of sandblasting, the difference in roughness between samples was found to be decidedly non-linear). One surface was made smooth by grinding.

A series of measurements were taken Figure 11. The results of the measurements showed that the roughness differences were statistically significant although not linear (Figure 12). Other results indicated that orientation of the profiles was not significant, while position on the profile was. For complete analysis results see (Maerz et al., 2000).

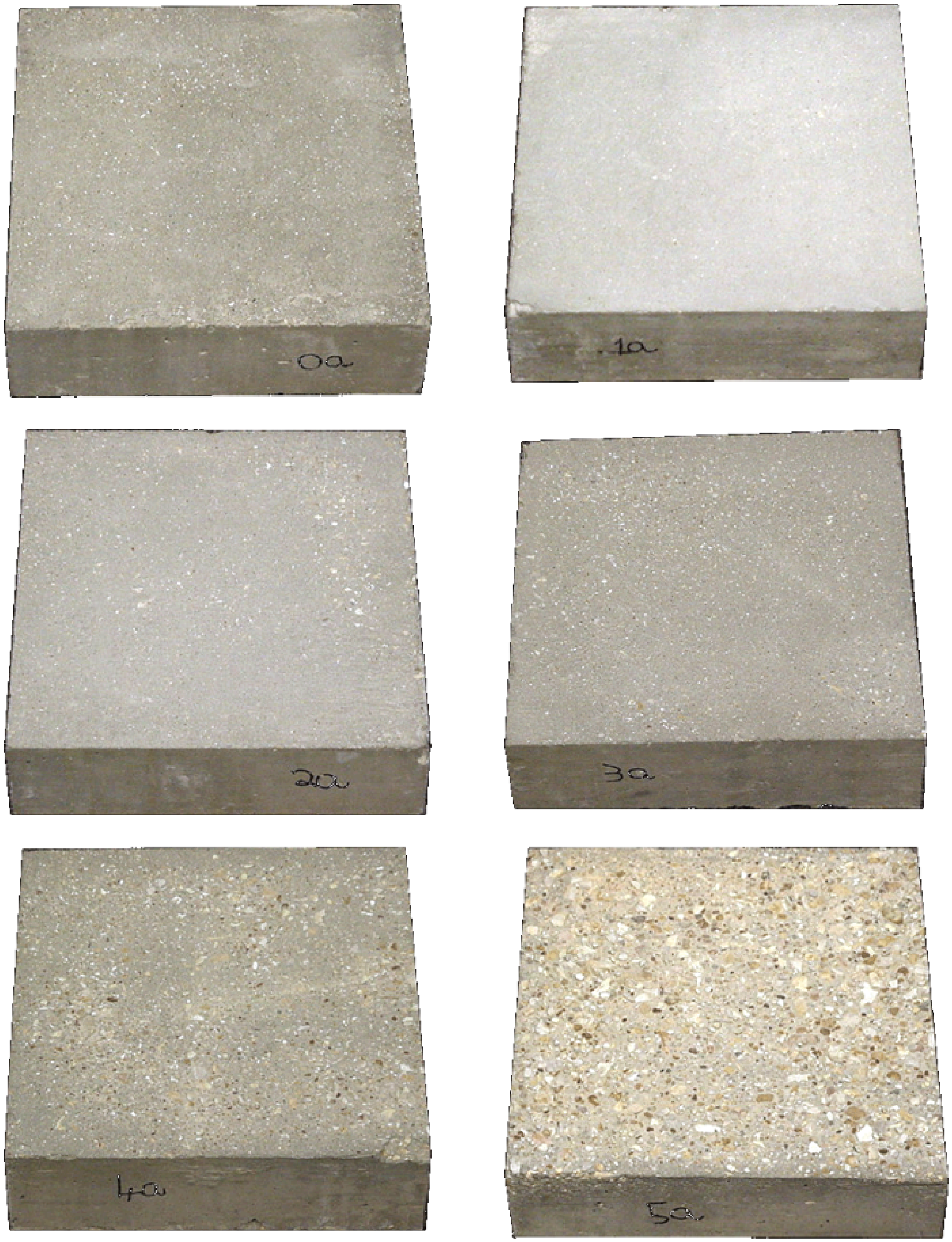


Figure 10. Concrete surfaces used for testing.

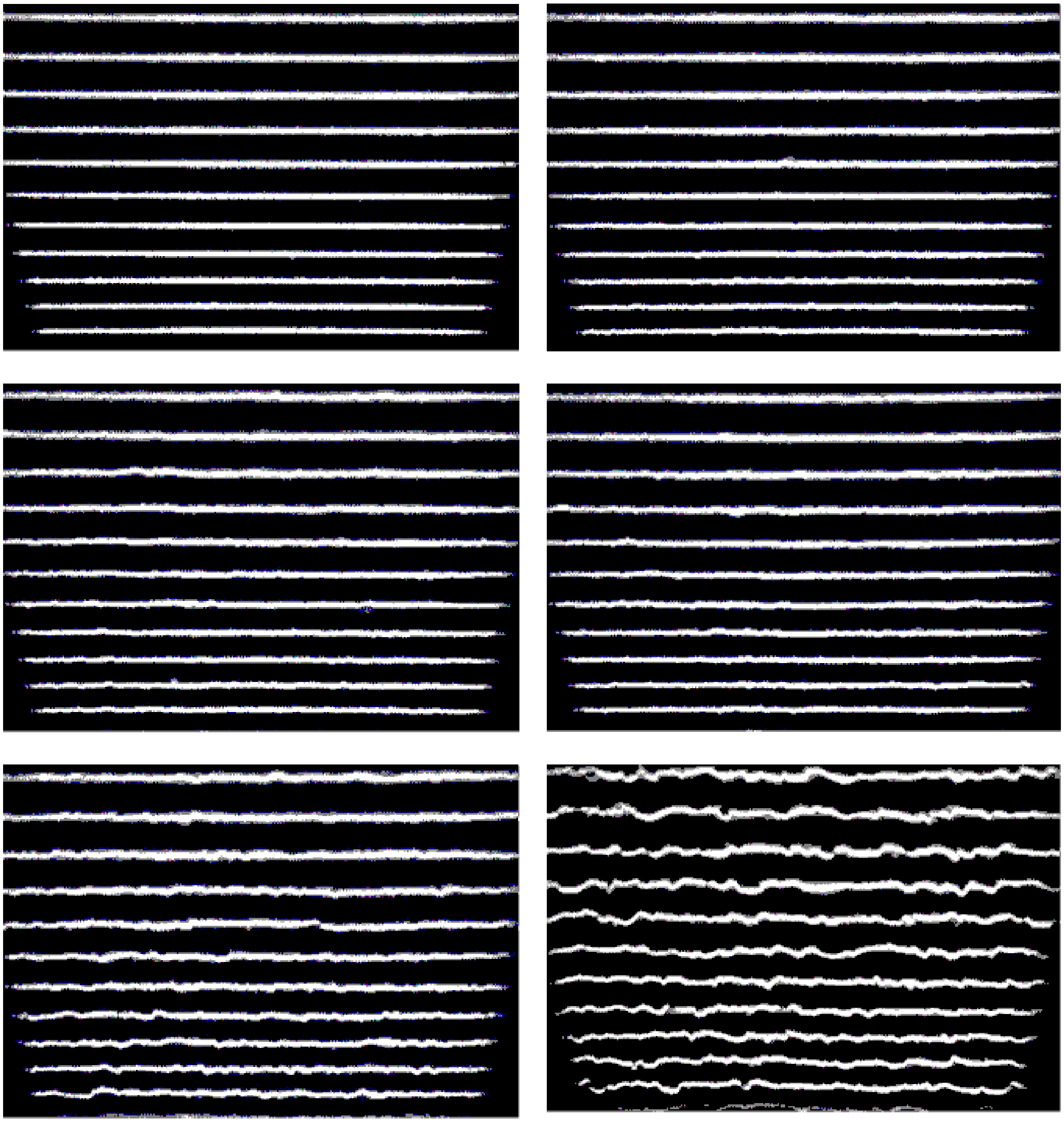


Figure 11. Laser profiles for the 6 different roughened concrete surfaces of figure 10 (9 line laser).

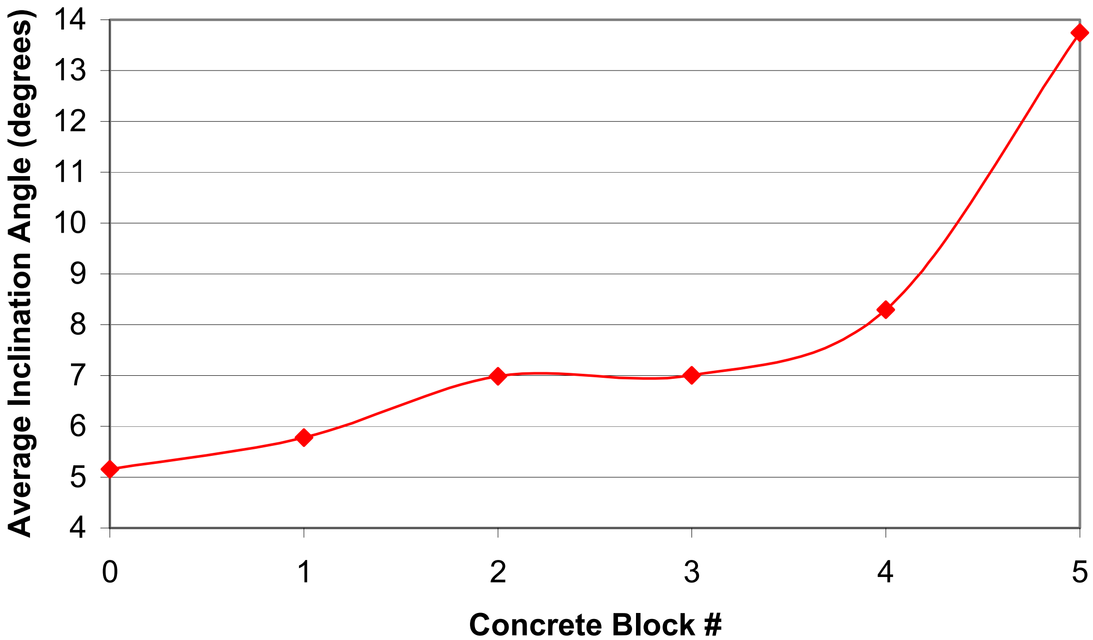


Figure 12. Roughness measurement results for the 6 concrete surfaces in terms of the average inclination angle of the profiles.

Figure 13: Plastic model concrete surface profiles. The profiles are ordered 1 to 9 in order of increasing roughness, and correspond to acid etching, grinding, light shotblast, light scarification, medium shotblast, medium scarification, heavy abrasive blast, scabbing, and heavy scarification.

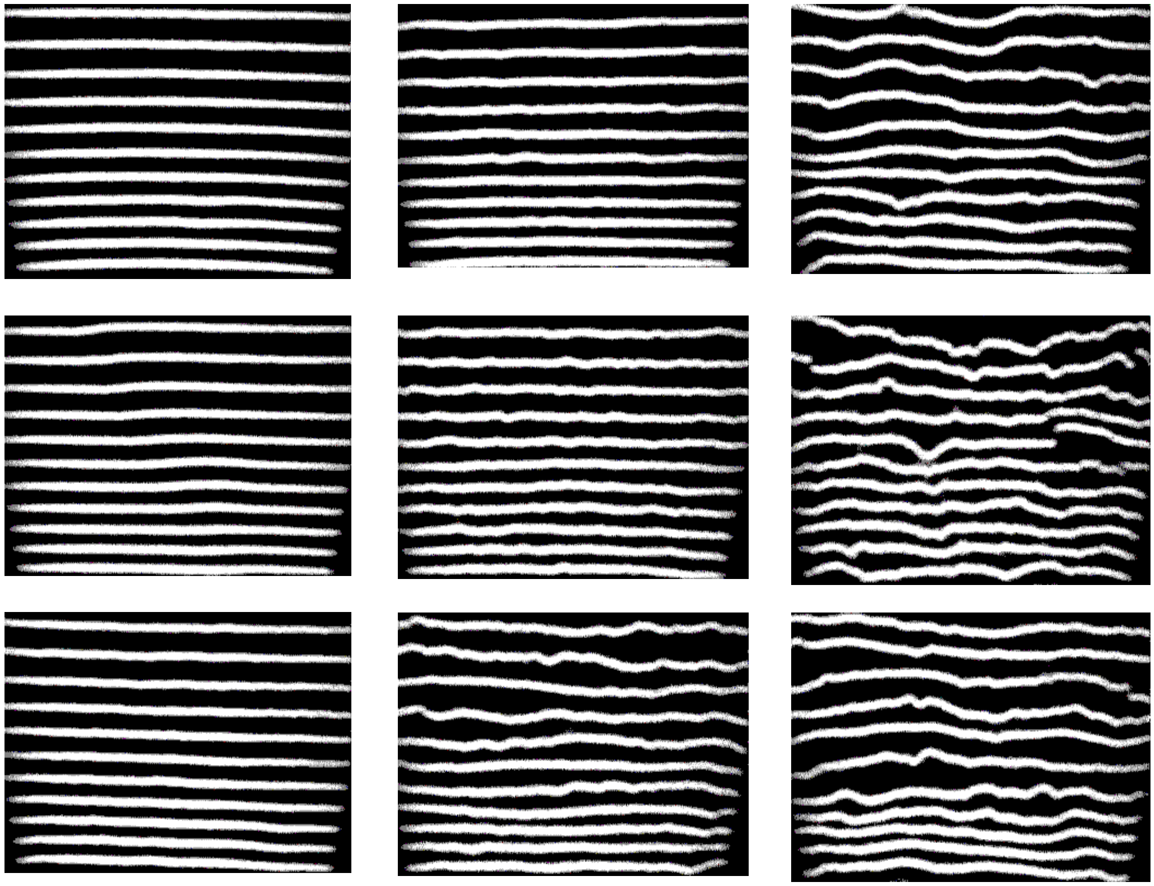


Figure 14. Examples of laser profiles for the 9 different plastic type profiles of Figure 13 (9 line laser).

3.2 Concrete Surface Profiles

A second study was undertaken to look at an existing standard, the Concrete Surface Profiles distributed by the International Concrete Repair Institute (Figures 13, 14). These profiles replicate the degree of roughness, which were considered for the purpose of application of coatings and sealers up to a thickness of 6.35-mm. Each profile carries a CSP number ranging from a base line of 1 (nearly smooth) through CSP 9 (very rough).

Because these are replicates of surface, these tend to be devoid of high frequency roughness, and consequently will measure "smoother" than the comparable original surface. However for the purpose of measuring trends they are sufficient.

The results of the measurements showed that the roughness differences were statistically significant and near linear, with the exception of surface #8 (Figure 15). For complete analysis results see (Maerz et al., 2000).

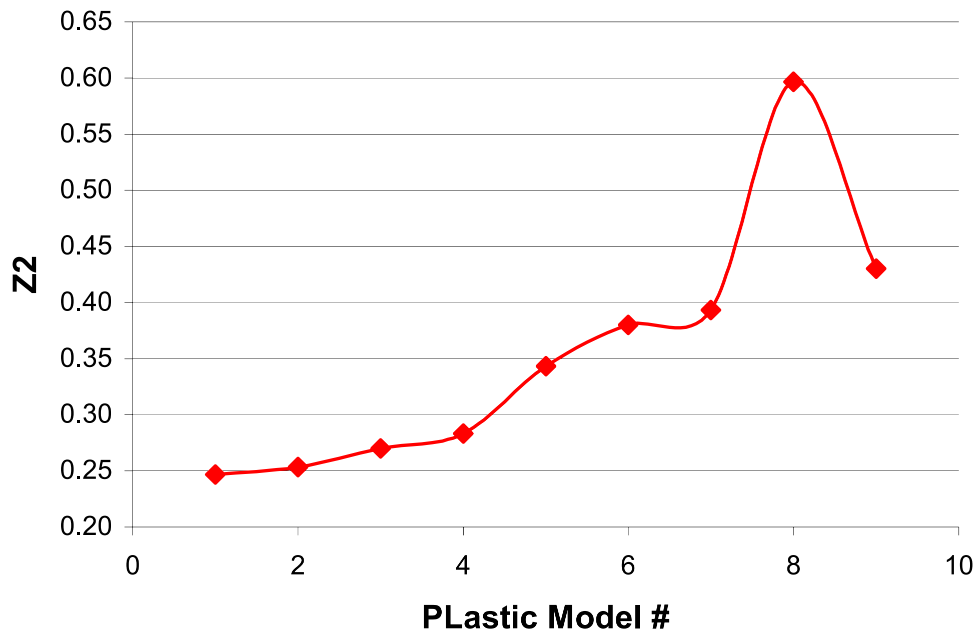


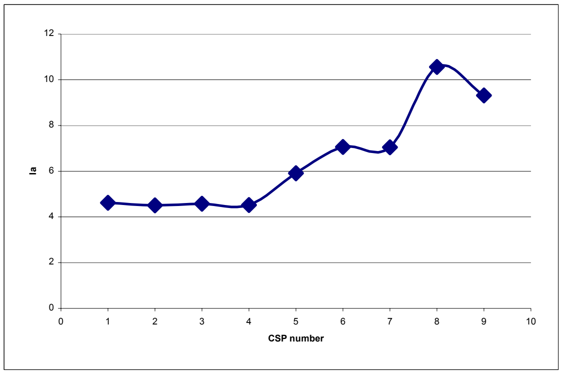
Figure 15. Roughness measurement results for the 6 plastic type profiles in terms of the average inclination angle of the profiles.

3.3 Analysis of smooth surfaces

One of the issues that arose as a result of this investigation is the issue of smooth surfaces. While the method discriminates “rough” surfaces it does less well with smooth surfaces. In general a perfectly smooth surface should have roughness values near zero. In reality the measurements of a smooth surface are considerably higher than zero (Figure 16).

This can be attributed to “noisy” images. The laser line on a completely flat surface should be completely flat. Because of laser speckling effects some random noise is introduced in the stripe. This is interpreted as texture and thus smooth surfaces measure rougher than they really are.

In addition the PCMCI frame grabber, despite a high-resolution camera, accentuates this noise at the time the image is digitized. Because of technical limitations, this frame grabber is inferior to full size card devices that can only be used in desktop computer. A small study confirmed this. Using images digitized on a desktop computer gave better results than when digitized using the laptop frame grabber (Figure 16).



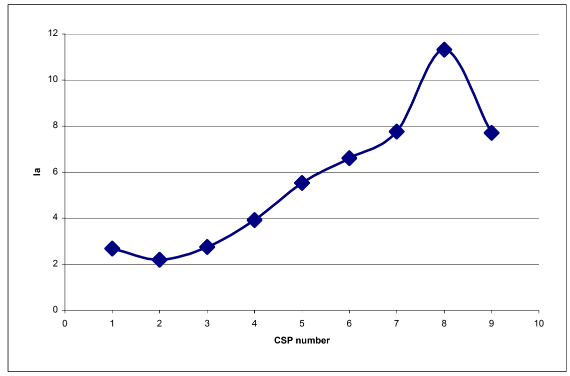


Figure 16: Measurement results on CSP samples using laptop framegrabber (left) and desktop framegrabber (right).

3.4 Repeatability and Calibration Issues

No studies on repeatability have been conducted to date. However it is believed it may be an issue, as it usually is in imaging applications. Small lighting differences, differences in cameras, differences in computer settings may result in somewhat different measurements.

It may be that a pair of calibration standards needs to be manufactured, one polished smooth surface, and another with approximately the same roughness of for example the CSP #8 surface. In this way the profilometer can be calibrated using these two standards to define the entire ranges of roughness with linear interpolation and with linear extrapolation on the rough end. Roughness could perhaps be recorded on a scale of 1 to 10 or 1 to 9 as with the CSP.

4. CONCLUSIONS

The manufactured roughness is undoubtedly an important requisite in the proper adhesion and performance of fiber reinforced polymers on concrete substrates. Characterization of that roughness is then also of significant importance, although the current state of the art allows only subjective evaluation of roughness, rather than a quantitative measurement.

1. A prototype of a new device for measuring roughness in the laboratory and in-situ has been developed.

2. The device has been improved to the point that it is easy to use and can be used in field applications, tethered only to a laptop computer.

3. This device has been demonstrated to have the accuracy and precision to distinguish between a wide range of roughness.

4. The device may require improvements to increase the resolution of relatively smooth surfaces.

5. The device may need calibration to compensate differences in the imaging process.

Ultimately, the roughness measurements will be related to FRP bond strength in an effort to correlate surface roughness to bond strength. In addition, the research program intends to provide specifications of acceptable and optimum levels of roughness.

5. RECOMMENDATIONS

1. Make changes in the device to better measure surfaces of low roughness. This includes acquiring lasers with lower speckle and higher quality laptop imaging devices.

2. Develop a calibration methodology to standardize the measurements.

3. Start collecting data from real applications, generate a data base of measurements that can later be linked to performance.

Current studies, under different funding are looking at surfaces generated by waterjets. This surfaces, although more difficult to produce are more consistent.

6. Acknowledgements

I would like to thank joint sponsors of this research project, the American Concrete Institute (ACI) Concrete Research Council, and University Transportation Center (UTC) at the University of Missouri-Rolla for providing funding for this study to be conducted.

7. Publications

Chepeur, P. R., 2000. Concrete Roughness Profile Characterization using Laser Profilometry for Better Bond Strength with Fiber Reinforced Polymers. M.Sc. Thesis, Department of Civil Engineering, University of Missouri-Rolla.

Maerz, N. H., Chepur, P, Myers, J., J., and Linz, J., 2001. **Concrete roughness measurement using laser profilometry for fiber reinforced polymer sheet application.** Presented at the, Transportation Research Board 80th Annual Meeting, Jan. 7-11 2001, 12 pp.

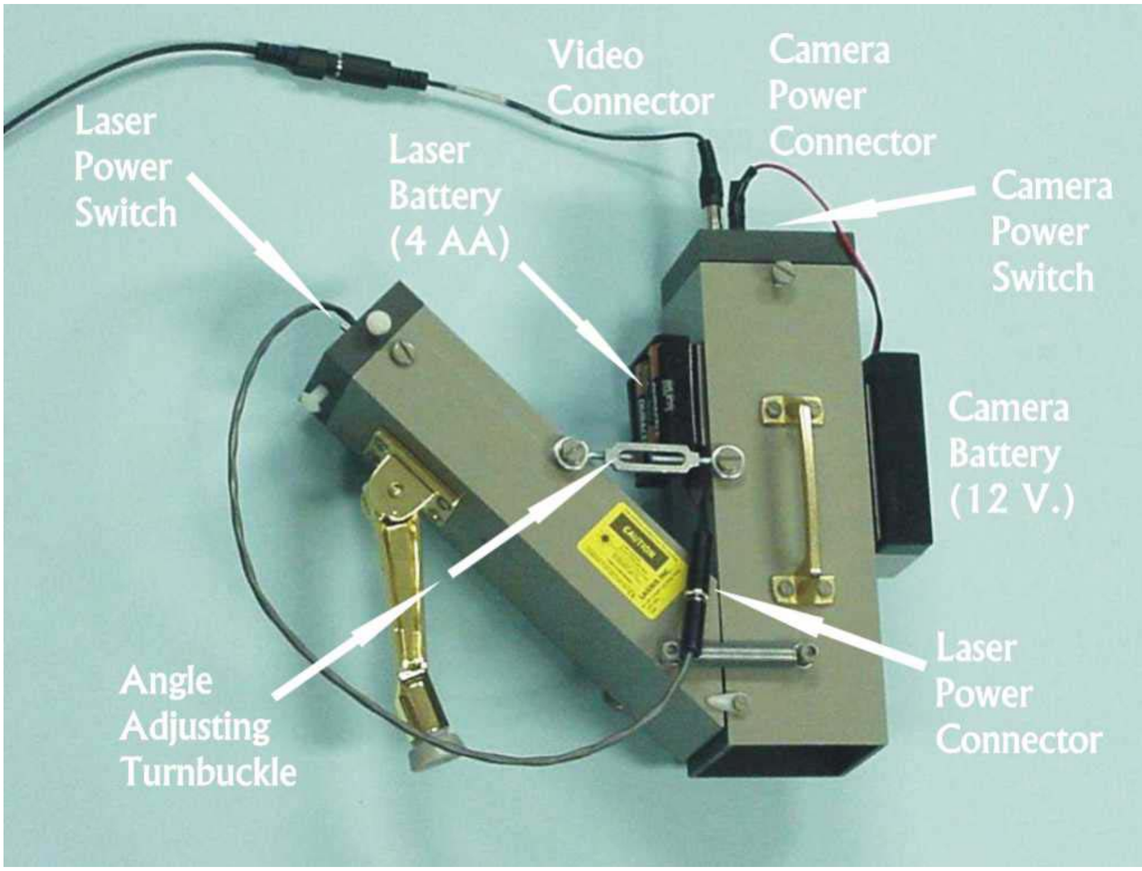
Maerz, N. H., Chepur, P, Myers, J., J., and Linz, J., 2001. **Concrete roughness measurement using laser profilometry for fiber reinforced polymer sheet application.** Accepted for publication, Transportation Research Record, 12 pp.
Maerz, N., Nanni. A, Myers, J., and Galecki, G, 2001. **Laser Profilometry For Concrete Substrate Characterization Prior to FRP Laminate Application**, Submitted to the Bulletin of the International Concrete Repair Institute.

APPENDIX 1. COMPLETED TASKS

Tasks	**Deliverables**	**Results**
1. Software Development	Imaging Software	Software package “CONRUF” has been developed to run under Windows NT/98/2000/ME platform.
2. Measurement Protocol	Measurement Protocol User Manual	Users manual and protocol (Appendix2).
3. Technology Transfer to Industry	Technical Seminar or Presentation	Presented at the Transportation Research Board annual meeting. Will be published in the Transportation Research Record.
4. Development of Imaging Prototype	Prototype Imaging Concrete Roughness Device	The prototype device has been developed (Figure 2).
5. Technical Report	Technical Report deliverable to ACI ACI Committee 440 and 546*	(This document).
6. Preparation of Phase II Proposal	Phase II Proposal	A proposal has been submitted to NSF for further funding.

APPENDIX 2. MEASUREMENT PROTOCOL AND USERS MANUAL

1. Hardware Setup



1. Remove profiling device from the case.
2. Plug in the camera power connector and turn camera on (A single charge will last about 1.5 hours).
3. Plug in the laser power connector and turn on the laser.
4. Connect the video cable to the VideoPort Professional PCMCIA imaging card.
5. Turn on the computer.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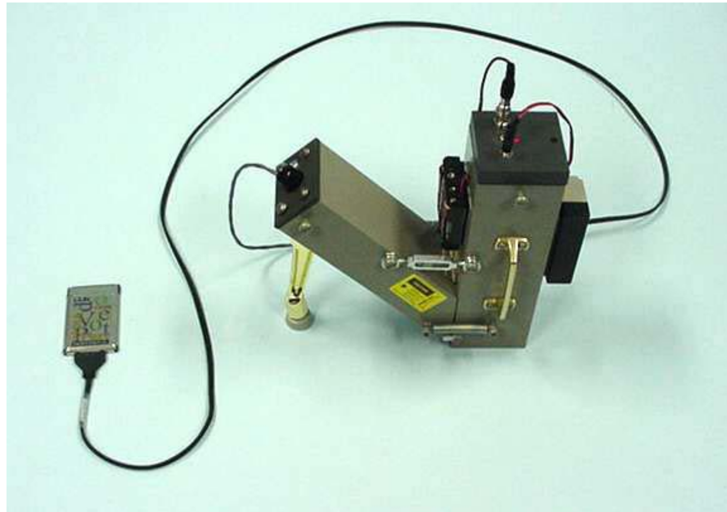
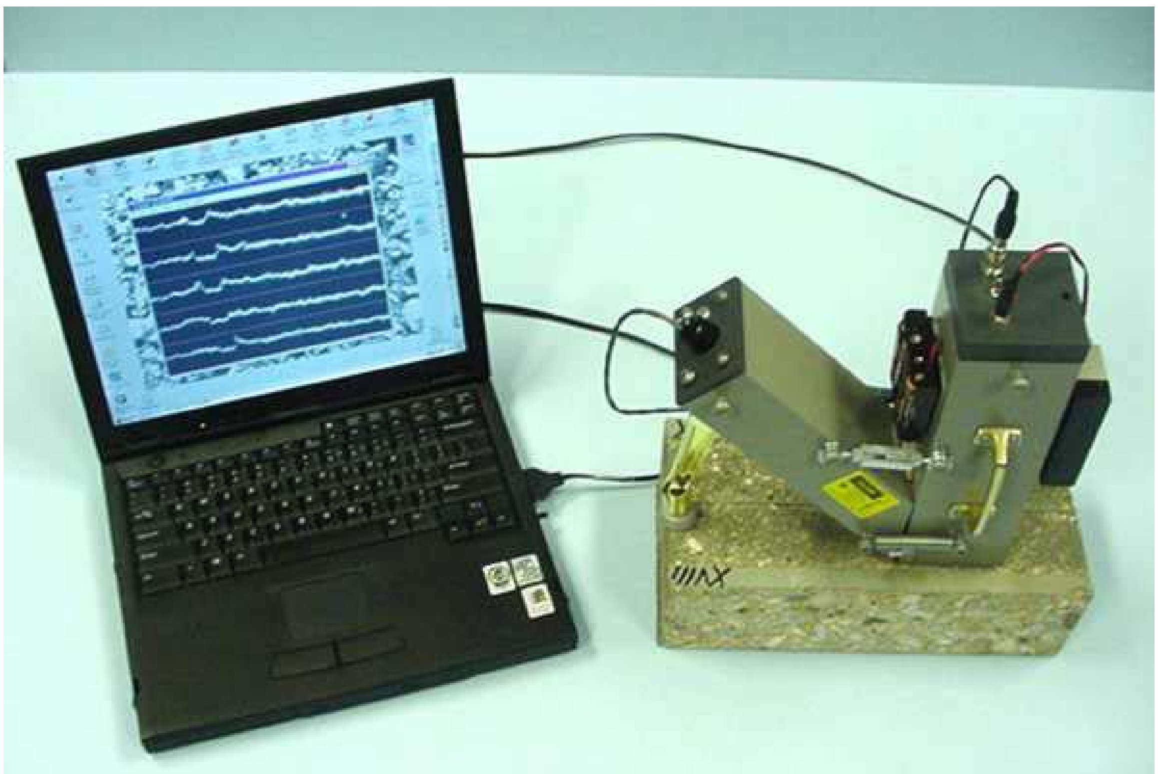




2. Measurement

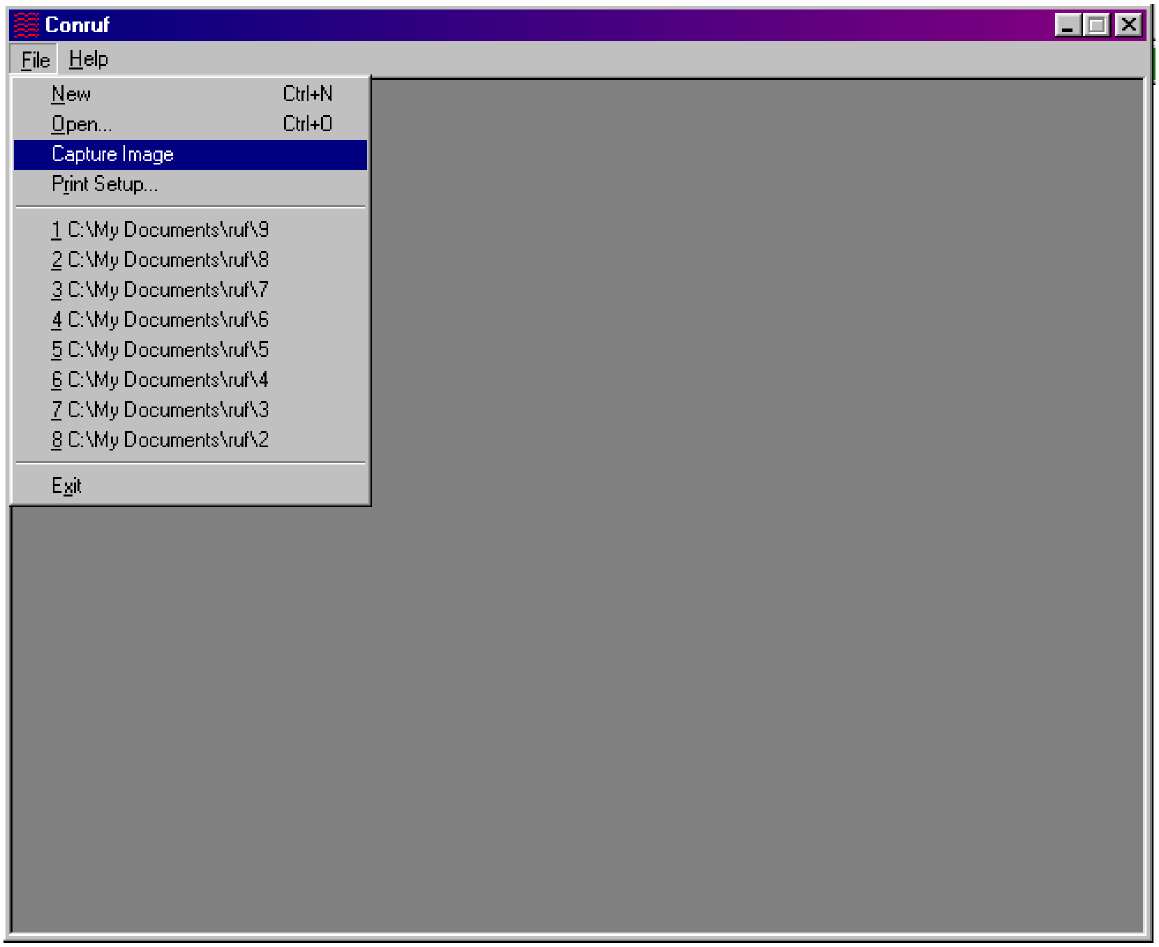
To make measurements in the file:

1. Set up the equipment as in section 1 above.
2. Hold the device against the concrete surface to be measured.
3. Follow the software instructions as in section 3 below.

Multiple measurements should be taken to reduce variability. If the roughness appears anisotropic, measurements should be taken at multiple orientations.

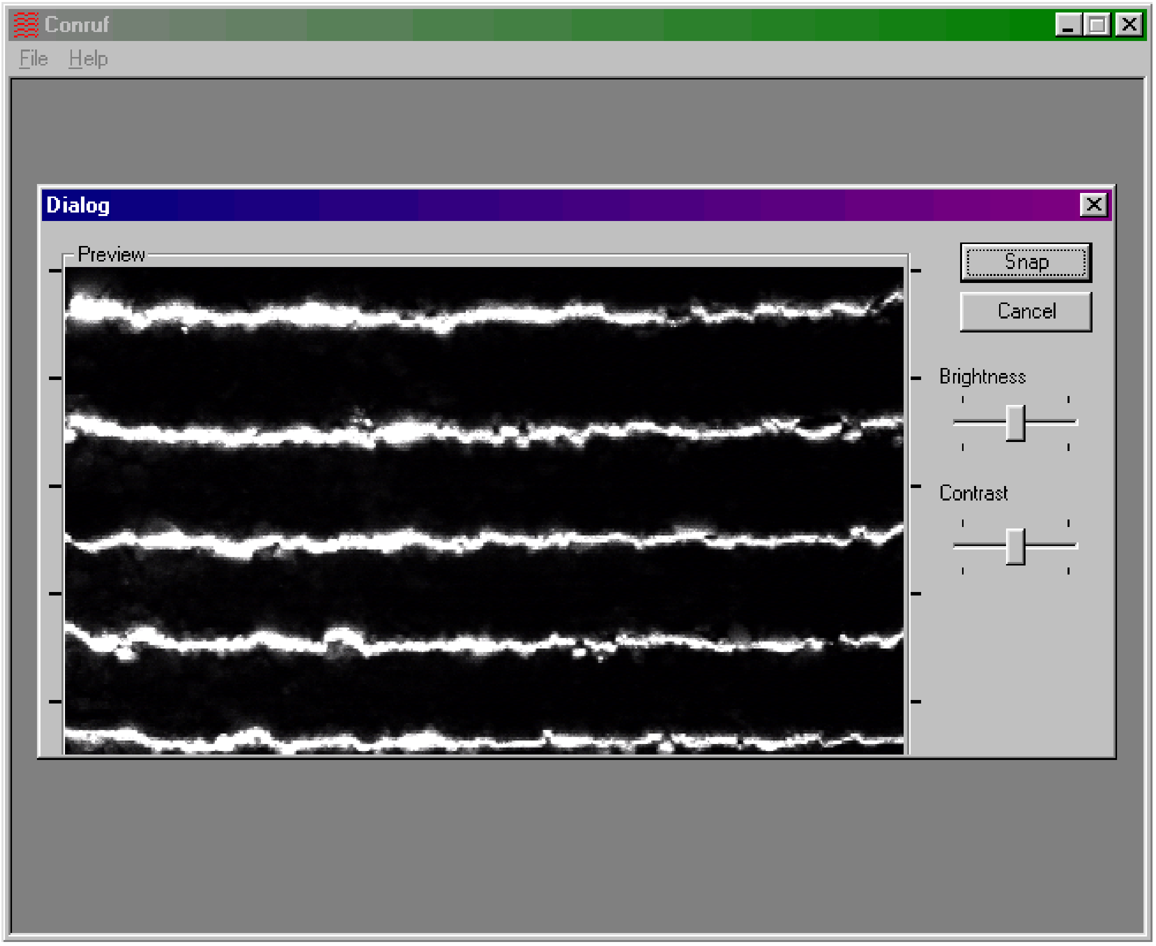
3. Software

To run the software, double-click on the Conruf icon on the Windows® desktop. Open the File menu, and select Capture image as shown below:



(Alternatively the Open menu item can be used to import a bitmap disk file.)

When Capture image is selected, the capture image dialog box will appear. This dialog will contain a live image from the profilometer:

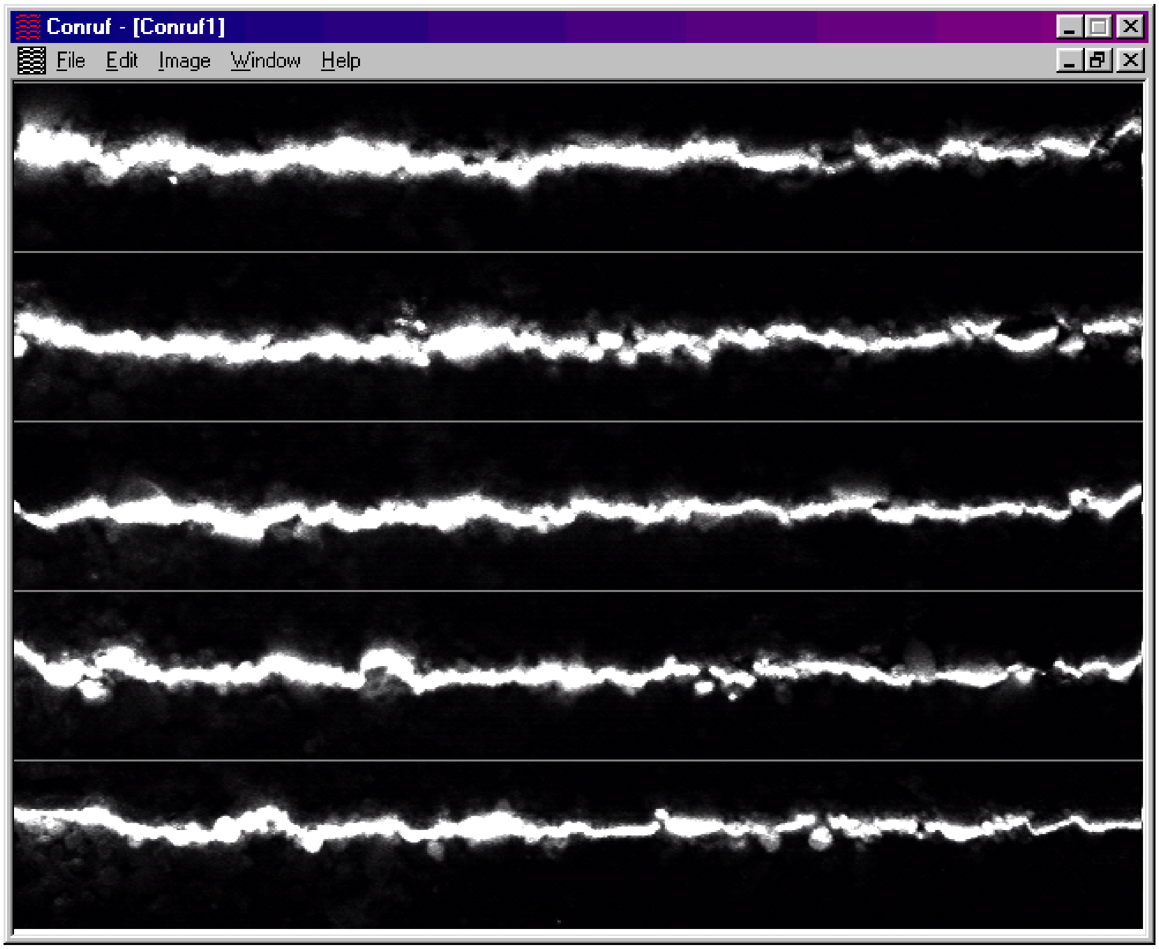


The brightness and contrast of the image can be adjusted if necessary, but adjustments should be used only in cases where the concrete surfaces are very dark or very bright. Changing these setting substantially can result is measurement errors. Alternatively, the brightness can be adjusted by changing the aperture on the camera.

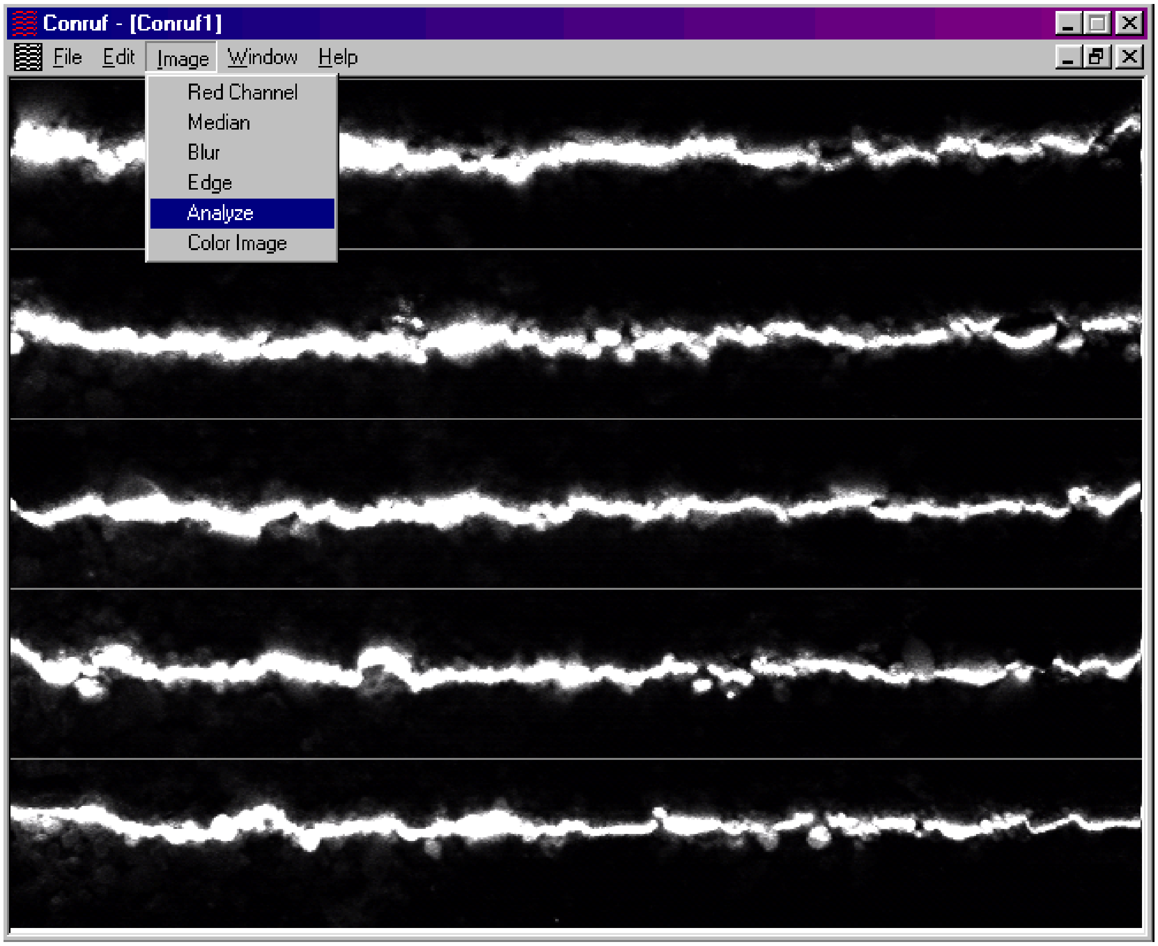
The angle adjusting turnbuckle on the profilometer can be used to ensure that the five profile lines are positioned between the six tick marks on the dialog.

When completed, click on the Snap button to capture the image.

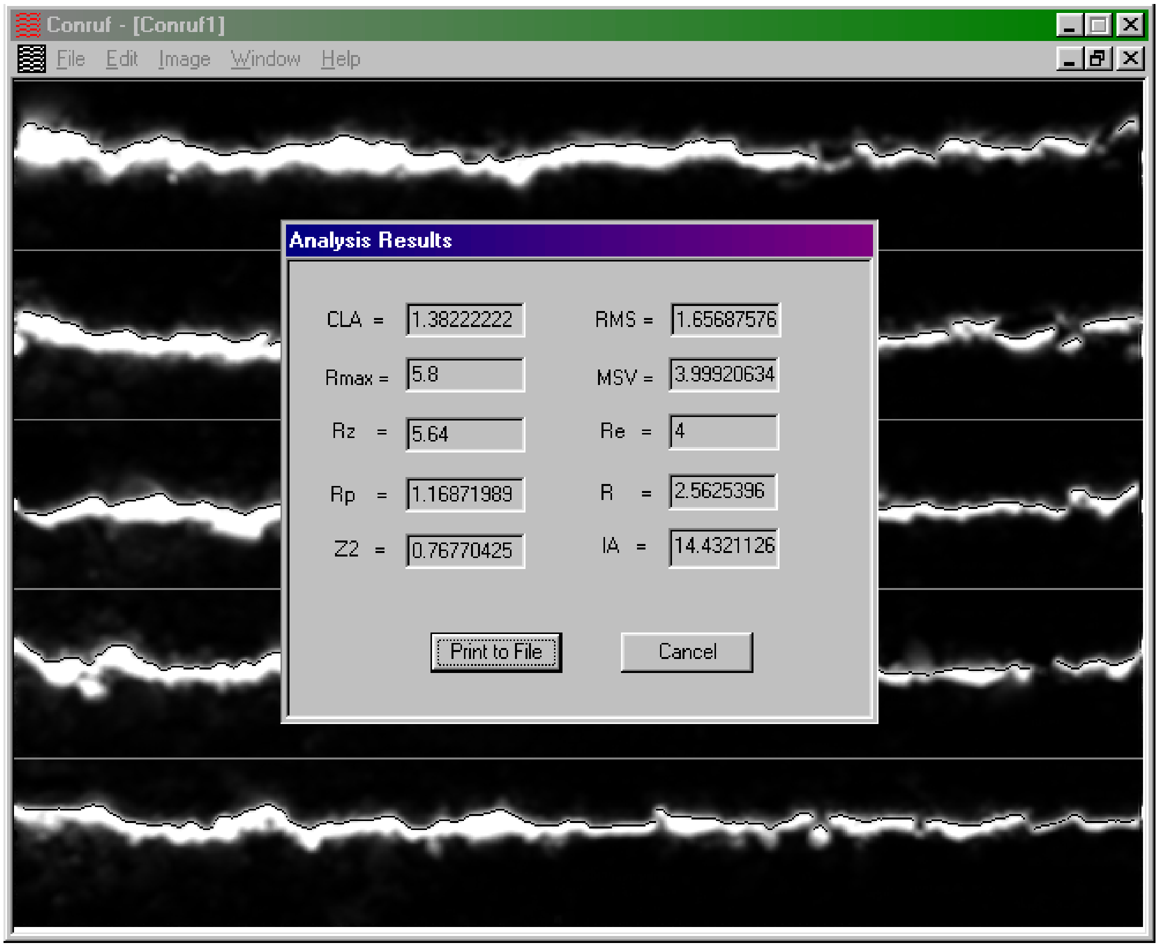
The image will then fill the entire window. Horizontal dividing lines superimposed on the image are used as guidelines. None of the five profiles should cross over any of the dividing line. If they do, the image must be re-captured, first adjusting the angle adjusting turnbuckle on the profilometer.



Next, Open the Image menu, and select Analyze as shown below.

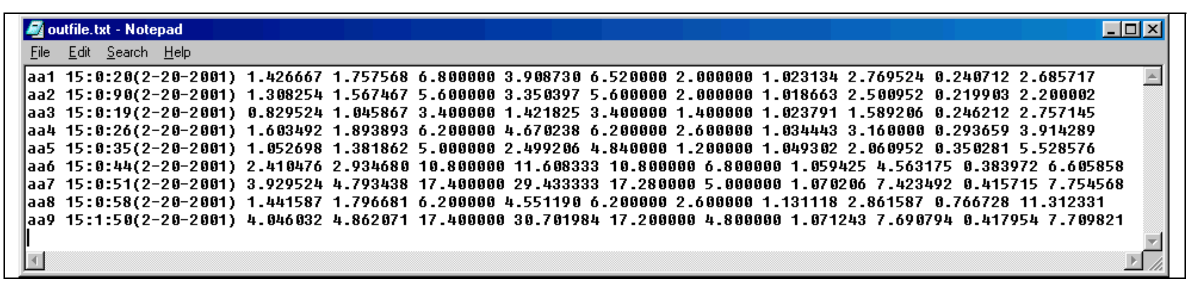


This will bring up the Analysis Results dialog box and show the edge of the profile in black.



Check the profile to see if is reasonable. Small gaps in the profile are permissible, and will not adversely affect the outcome.

The analysis results are written to the dialog box and may be recorded or the Print to File Option may be invoked. In that case, the results of the analysis are written to a text file called outfile.txt (one line per measurement):


outfile.txt - Notepad

```
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aa2 15:0:90(2-20-2001) 1.308254 1.567467 5.600000 3.350397 5.600000 2.000000 1.018663 2.500952 0.219903 2.200002
aa3 15:0:19(2-20-2001) 0.829524 1.045867 3.400000 1.421825 3.400000 1.400000 1.023791 1.589206 0.246212 2.757145
aa4 15:0:26(2-20-2001) 1.603492 1.893893 6.200000 4.670238 6.200000 2.600000 1.034443 3.160000 0.293659 3.914289
aa5 15:0:35(2-20-2001) 1.052698 1.381862 5.000000 2.499206 4.840000 1.200000 1.049302 2.060952 0.350281 5.528576
aa6 15:0:44(2-20-2001) 2.410476 2.934680 10.800000 11.608333 10.800000 6.800000 1.059425 4.563175 0.383972 6.605858
aa7 15:0:51(2-20-2001) 3.929524 4.793438 17.400000 29.433333 17.280000 5.000000 1.070206 7.423492 0.415715 7.754568
aa8 15:0:58(2-20-2001) 1.441587 1.796681 6.200000 4.551190 6.200000 2.600000 1.131118 2.861587 0.766728 11.312331
aa9 15:1:50(2-20-2001) 4.046032 4.862071 17.400000 30.701984 17.200000 4.800000 1.071243 7.690794 0.417954 7.709821
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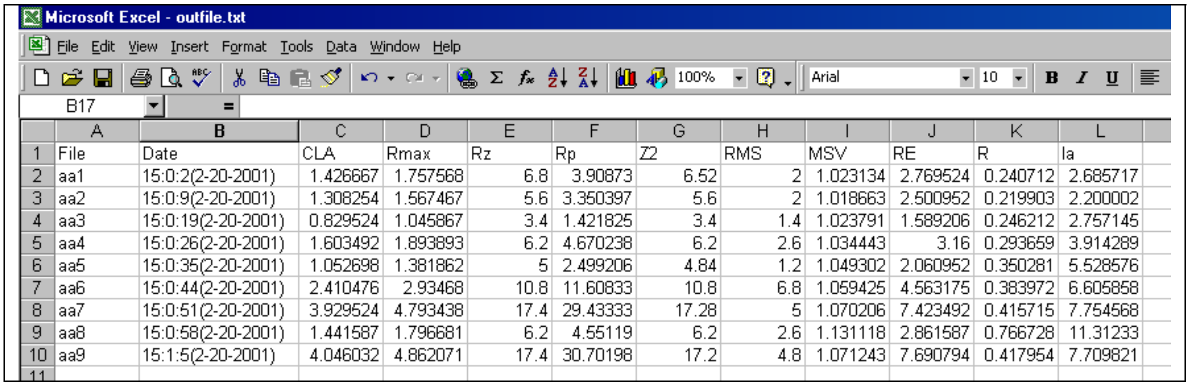
This file can then be imported to a spreadsheet such as Excel®, (space separated fields) as below for further analysis (title row added):



	A	B	C	D	E	F	G	H	I	J	K	L
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4	aa3	15:0:19(2-20-2001)	0.829524	1.045867	3.4	1.421825	3.4	1.4	1.023791	1.589206	0.246212	2.757145
5	aa4	15:0:26(2-20-2001)	1.603492	1.893893	6.2	4.670238	6.2	2.6	1.034443	3.16	0.293659	3.914289
6	aa5	15:0:35(2-20-2001)	1.052698	1.381862	5	2.499206	4.84	1.2	1.049302	2.060952	0.350281	5.528576
7	aa6	15:0:44(2-20-2001)	2.410476	2.93468	10.8	11.60833	10.8	6.8	1.059425	4.563175	0.383972	6.605858
8	aa7	15:0:51(2-20-2001)	3.929524	4.793438	17.4	29.43333	17.28	5	1.070206	7.423492	0.415715	7.754568
9	aa8	15:0:58(2-20-2001)	1.441587	1.796681	6.2	4.55119	6.2	2.6	1.131118	2.861587	0.766728	11.31233
10	aa9	15:1:5(2-20-2001)	4.046032	4.862071	17.4	30.70198	17.2	4.8	1.071243	7.690794	0.417954	7.709821
11												