CENTER FOR INFRASTRUCTURE ENGINEERING STUDIES

Nondestructive Ultrasonic Detection of FRP Delamination

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16. Abstract

We propose to test the effectiveness of commercially available ultrasonic devices in detecting de-lamination. We will send samples to the manufacture of the ultrasonic devices, and procure an appropriate device. We will then set up test samples with various sizes and positions of de-lamination, and evaluate the ability of the ultrasonic device to detect them in blind studies.

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FRP Delamination Determination Using Sonic Devices

Norbert H. Maerz

1. Introduction

The use of fiber reinforced polymers (FRP) for reinforcement of concrete members has emerged as one of the most promising technologies in materials and structural engineering to repair and strengthen infrastructure. FRP sheets are ideally suited for repair and strengthening of concrete structures in aggressive environments due to their non-corrosive, non-magnetic characteristics. They have high tensile strength to weight ratio and high elastic limit. Externally applied FRP sheets or laminates are bonded directly to a concrete surface with an epoxy providing additional flexural or shear strength capacity depending on the application and fiber alignment. This significantly increases the load carrying ability of a structural component and/or structural system.

Correct bonding of FRP sheets is crucial to the performance of the repair system. Delaminations affect the strength of the material and degrade the performance

2. Project Objective

The objective of the project was to develop a non-destructive sonic technique to map the delaminations in installed FRP sheets, using commercially available products.

3. Work

3.1 Material

For the experimental work, four blocks of concrete were obtained, covered with carbon FRP materials (tonen forscha) with forced delaminations (air injection during before the epoxy cured). In addition a sheet of FRP material installed on a bridge pier was used (See Appendix 1).

3.2 Inspection and Test Methods

The inspection and test methods included visual inspections and manual tapping, ultra sonic imaging, and impact-echo imaging. Matrix lines were drawn on all the test targets for research purposes. The matrix grid was on 10 mm centers; measurements were taken on this grid.

3.2.1 Visual Inspections and Manual Tapping

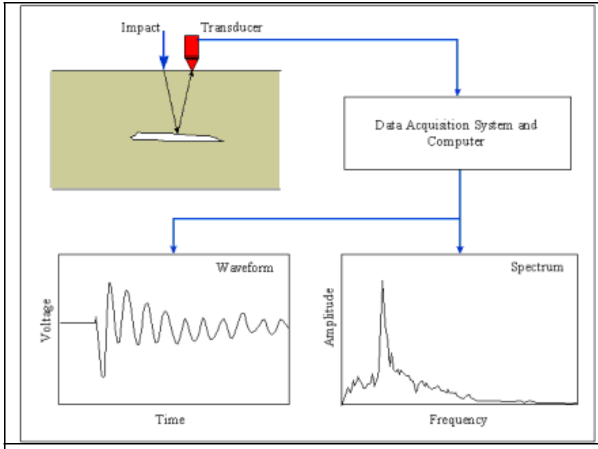
Visual inspection is a very valuable technique for monitoring performance. Many defects can be detected visually. Some visual defects inspections, such as discoloration, blistering, pitting, etc, were used in this research.

Manual tapping, a common technique to identify defects was used. By simply tapping the surface of the composite with a small hammer, delaminations are detectable. A well bonded composite free of voids and delaminations produces a clear, sharp ringing sound. A hollow or dull sound indicates the presence of delaminations and/or voids. The effectiveness of such a technique depends a great deal on the experience of the inspector.

3.2.2 Ultra Sonic Method Imaging

Ultrasonic devices send reflected high frequency sound waves to detect flaws in metals, concrete and other materials.

One of the blocks was sent to a distributor of ultrasonic devices for evaluation. In most cases the ultrasonic devices were not able to determine the difference between well bonded and delaminated FRP. This was thought to be because the ultrasonic waves were primarily reflecting off the FRP weave.



Principle of Impact Echo Testing (http://www.ndt.net/article/0298/streett/fig2m.gif).

Olson impact tester on FRP sheet with forced delaminations.

Testing head with impacter (center) and receiver (right).

Tester display.

Figure 1. CFG-1TF impact echo testing device

3.2.3 Impact-Echo Imaging

The impact echo device used was a CFG-1TF (Thickness measurement plus flaw detection) device from OLSON Instruments (Figure 1). A mechanical impact on the surface of the material introduces a seismic wave into the sample. The compression (P-wave) is the first to return, having been reflected back by a discontinuity such as a crack or the back of the sample. If the seismic velocity is known, then the thickness to the discontinuity can be measured.

A laminated block was sent to Olsen instruments, and later one of the devices was loaned to us and used for testing.

The normal, commercially available CTG unit was used first (using a microphone coupled with the FRP surface). This unit is designed to measure concrete thickness by analysis of the spectral energy resulting from an impact to the concrete surface. Tests with this model attempted to look at differences in mode frequencies between bonded and unbonded areas. The tests showed, however, that the major modal frequencies did not change in a predictable, repeatable pattern that could be easily used for defect detection. However, it appeared that the amplitude of the signal could be used for analysis. The CTG used for testing was therefore sent back to Olson Instruments for modification.

Figure 2. CFG-1TF modified impact echo testing device, with air coupled microphone.

The modification of the CTG consisted of decoupling the microphone and make it air coupled (Figure 2). In this modification, the test head was changed to disconnect the displacement (contact) transducer normally used for thickness testing. In it=s place, a small microphone was mounted to sense the sound waves resulting from an impact on the surface. The microphone was expected to work better than the contact probe due to the nature of shallow surface debonds. A debonded area will have a relatively large area of thin material suspended above the concrete surface. During an impact, the entire suspended area will vibrate. This will act as a drum or acoustic resonator, and will effectively couple the energy of the impact much more efficiently into the air than will a solid, well-bonded area. An impact on a bonded area will excite a much smaller area of the surface, and will result in much smaller movement amplitudes that damp out quickly. The microphone, being sensitive to only sound waves in air, will allow better differentiation of debonded versus bonded areas.

In addition to the hardware modification, several modifications were also made to the software of the unit. These modifications enabled the unit to measure the amplitude of the resulting signal rather than the frequency.

The first amplitude measurement was a time-domain measurement of the peak amplitude (Fa). This routine simply scanned the raw time signal from the microphone (resulting from an impact) and picked the absolute peak value. This value was then scaled by the gain (x1, x2, x4, or x8) and stored.

The next part of the analysis computed the FFT of the signal (to give the amplitude spectra), and scanned the resulting spectrum for the peak amplitude (Fa). This was also scaled by the gain value and stored. Finally, both amplitude values were printed out on the screen, along with a plot of the spectrum. Note that the amplitude values are based on A/D counts with a scaling factor, and do not represent any type of engineering units at this time. This is not critical because the amplitude measurement is relative, with the response at sound locations being 5-10 times less than that at debonded locations

Chart 1 shows the results of 18 measurements of delaminated and well bonded sites. In both the Ta and Fa measurements the difference between the delaminated and well bonded sites is distinctive.

Delaminated		**Well bonded**	
Fa	Ta	Fa	Ta
10.3	655	0.765	46
7.42	506	0.753	48
6.59	488	0.801	41
7.48	427	0.766	44
2.11	331	1.02	41
1.62	278	0.476	55
2.84	232	0.724	40
3.57	234	0.667	41
7.05	327	0.774	47
6.13	496	0.419	3
4.32	216	0.479	0
5.93	178	0.349	2
7.01	303	0.393	0
6.86	428	0.816	39
3.31	320	1.08	33
3.52	281	1.03	44
3.48	284	0.842	42
3.29	286	0.837	52

Chart 1. Measurements of Fa and Ta for delaminated and well bonded sites.

3.3 Testing

Both tapping and the air coupled impact echo device were used for the testing. Four small bounded surface samples and one small bridge surface were inspected and tested.

4. Testing Results

Results are shown in Appendix 1. Measurements were taken on 10 mm centers, by drawing a grid on the laminate. Both the tapping and the modified impact echo gave the identical results, as shown in Appendix 1.

5. Sampling Facility

For production applications, it is not convenient to draw a sampling grid on the laminate. Consequently a sampling mechanism was developed. A 670 nm, 20 mW laser with a 7 by 7 dot matrix projection optic head was acquired (Figure 3). The laser is projected onto the surface to be measured (Figure 4), and the indicated point are sampling targets for measurement. If the ambient light is too bright, a 670 nm bandpass optical filter (Figure 5) can be used to accentuate the sampling points (Figure 4).

Figure 3. Targeting laser

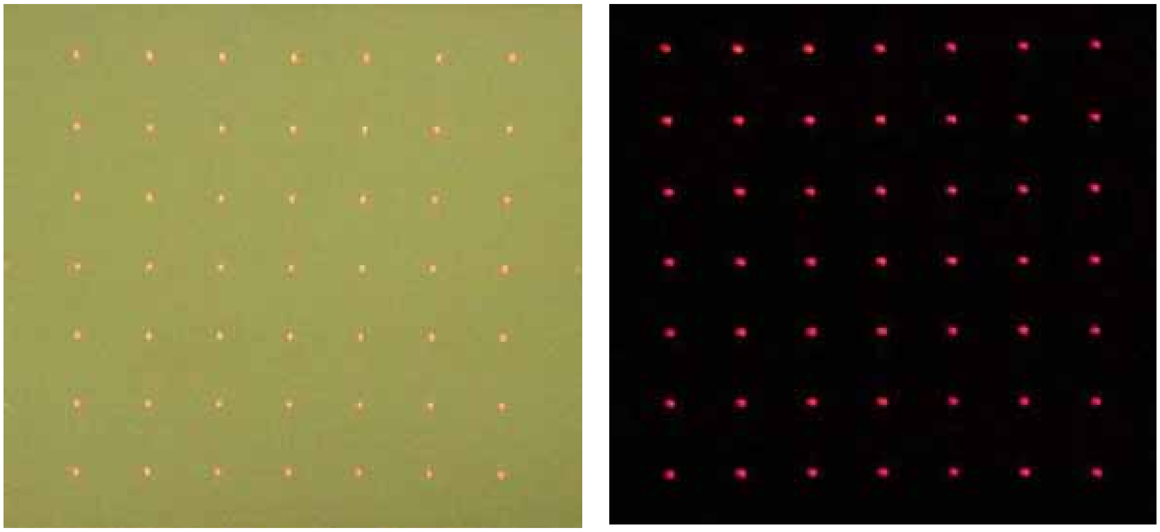


Figure 4: Left. 7 by 7 dot matrix target. Right: Target through 670 nm optical filter.

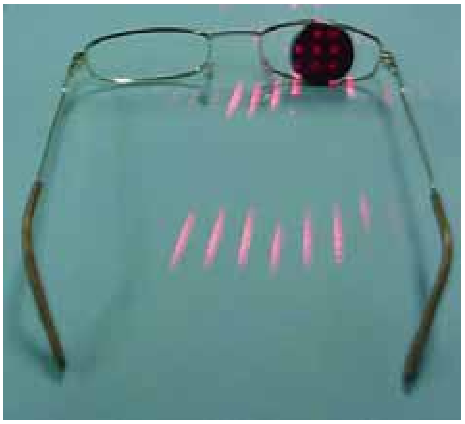


Figure 5. 670 nm bandpass filter fitted to empty eyeglass frames.

6. Conclusions

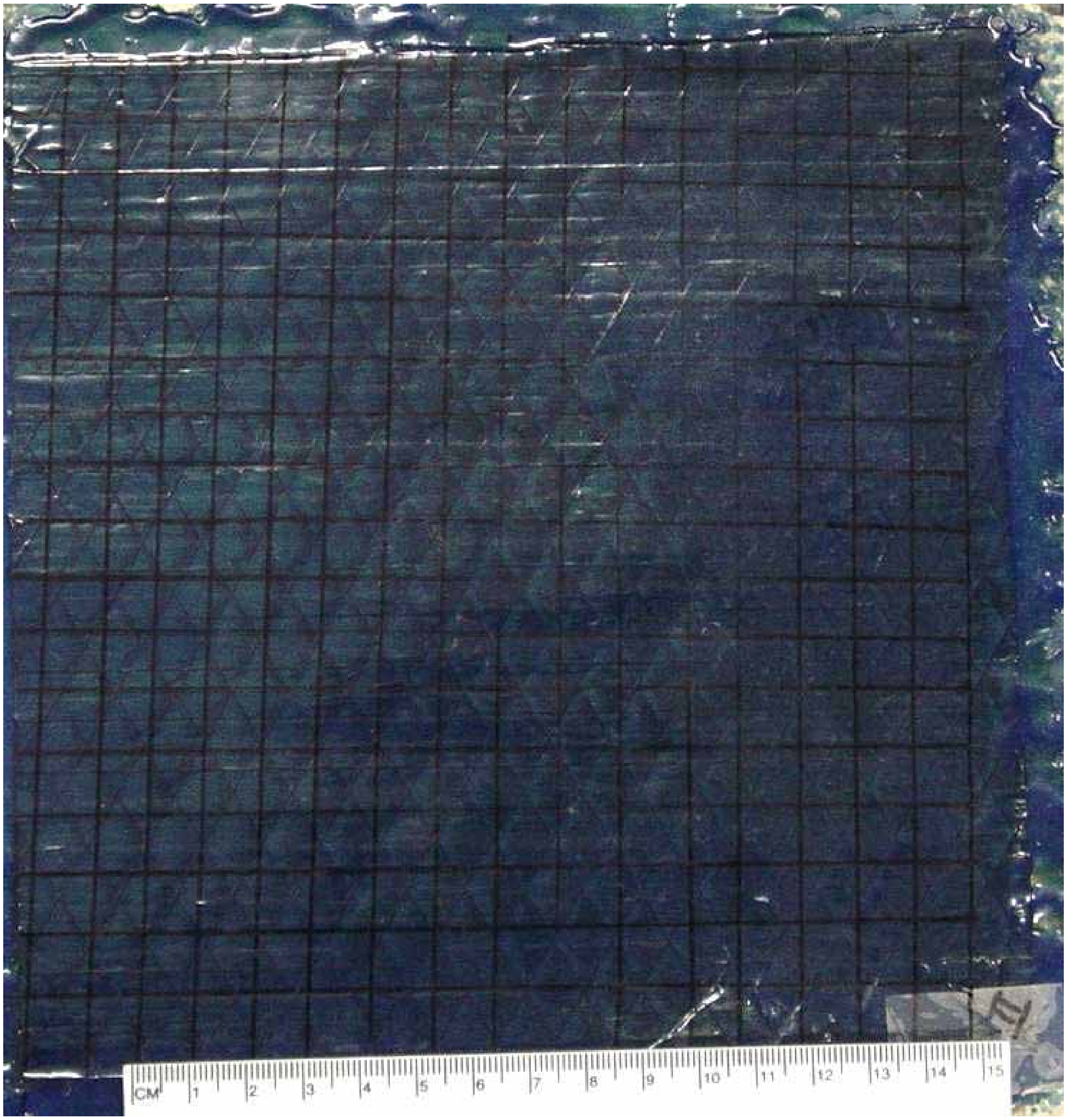
This project has demonstrated that ultrasonic devices could not reliably distinguish between well bonded and delaminated FRP surfaces.

Impact echo devices however were able to perfectly match tapping results for finding delaminated surfaces, when modified with a decoupled microphone.

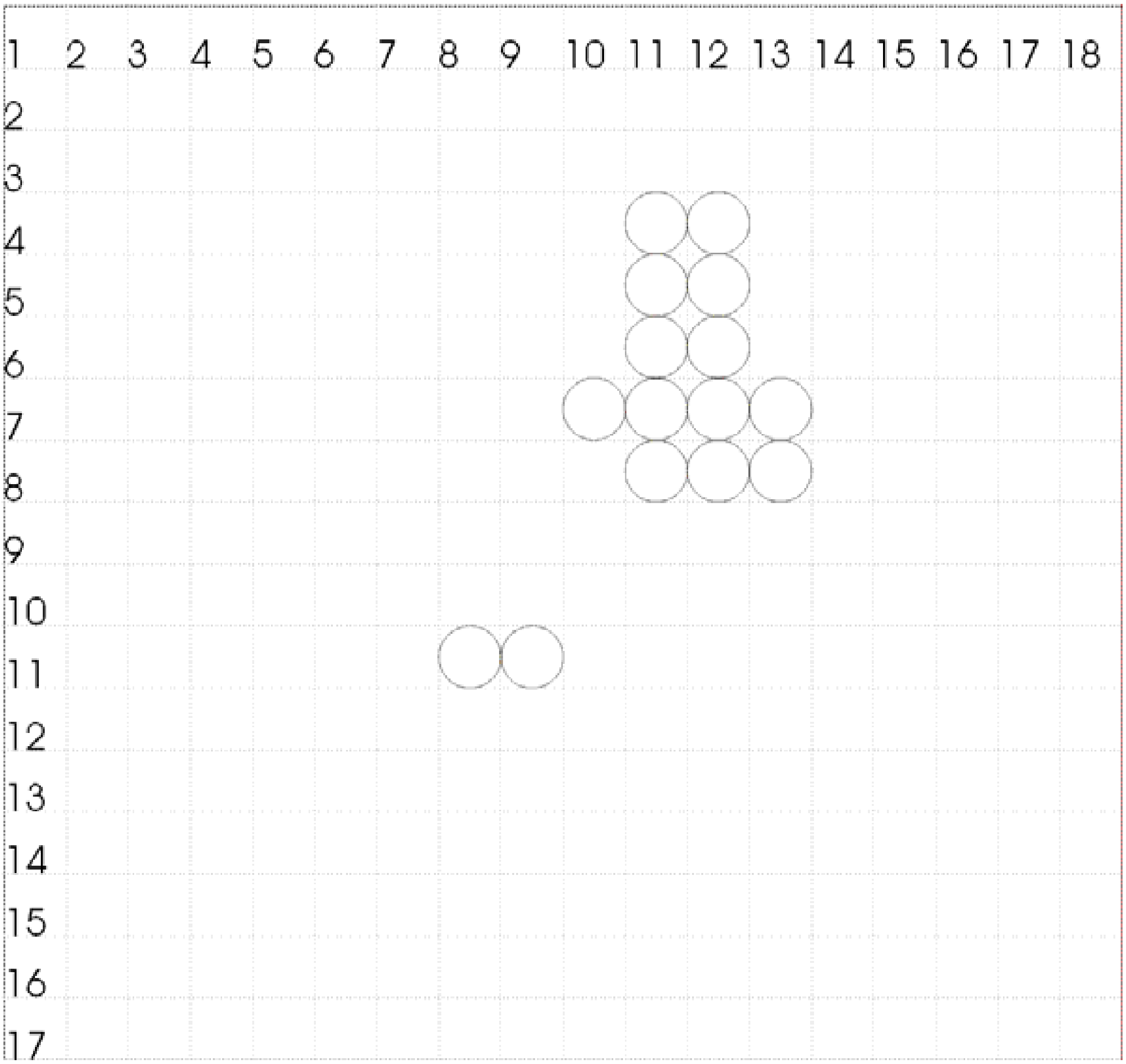
In addition, a sampling procedure using a 7 by 7 dot matrix projected laser point grid was developed.

Appendix 1: FRP Sample Blocks

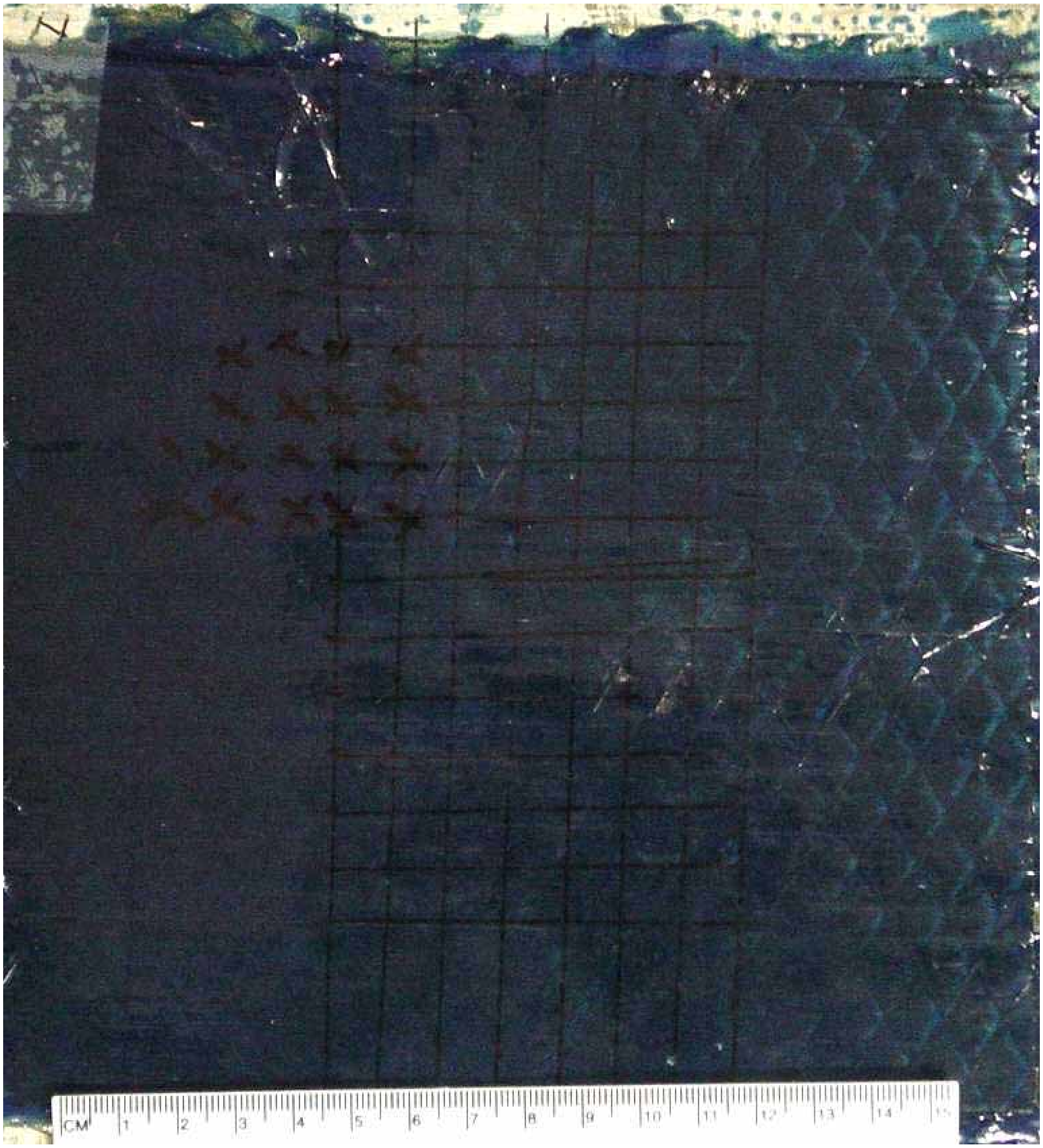
Surface 1 Image



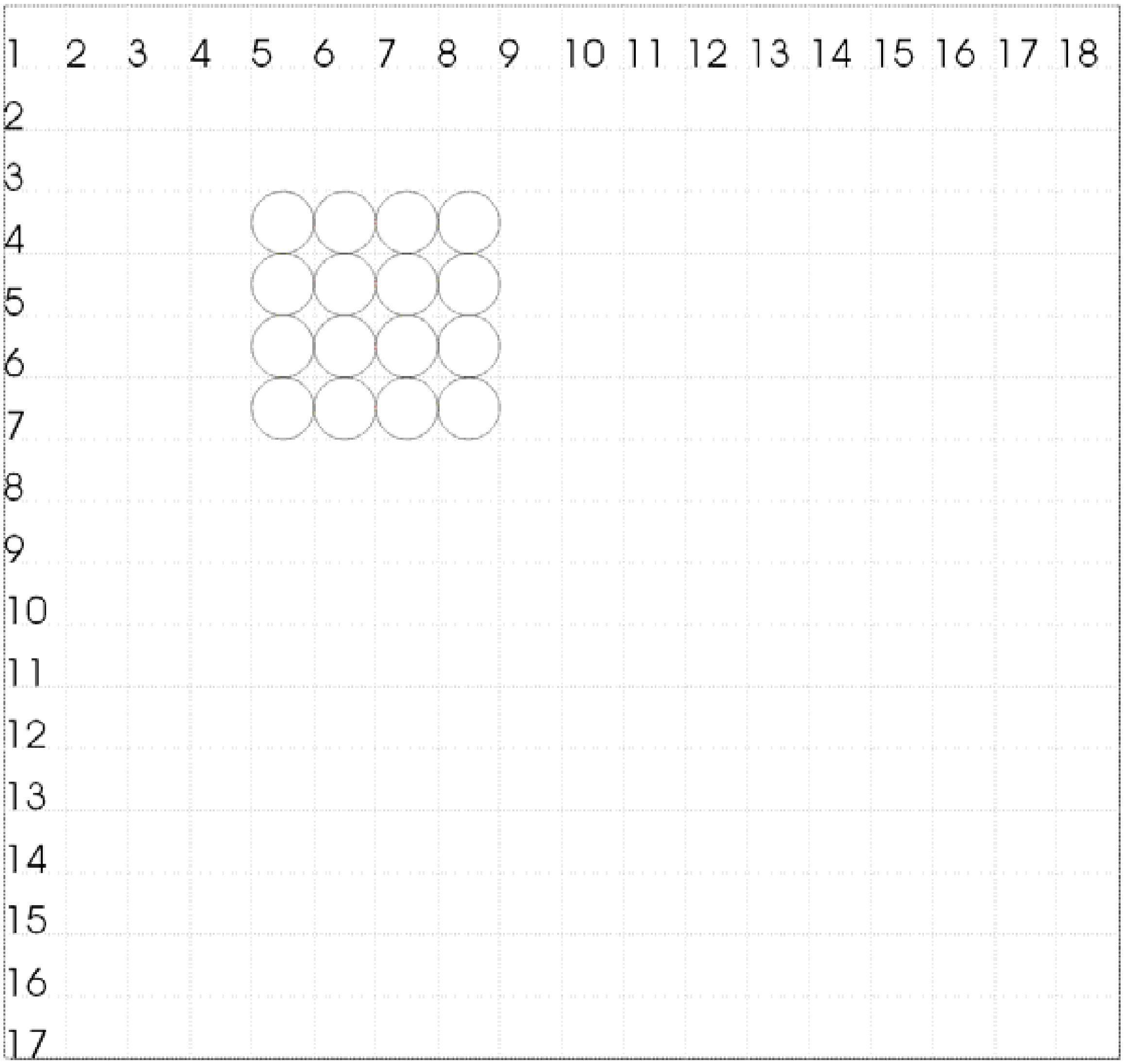
Surface 1 Delamination Map



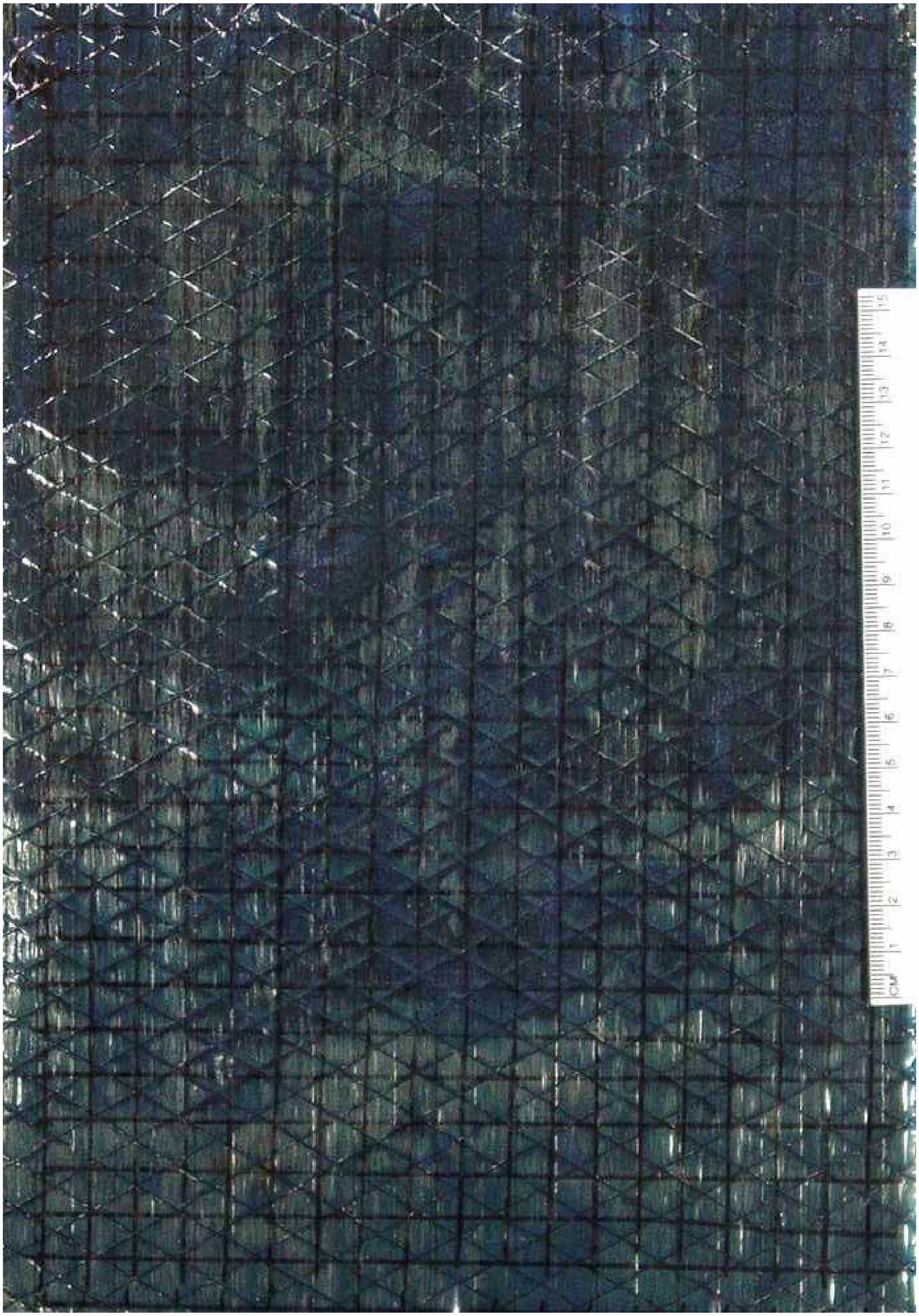
Surface 2 Image



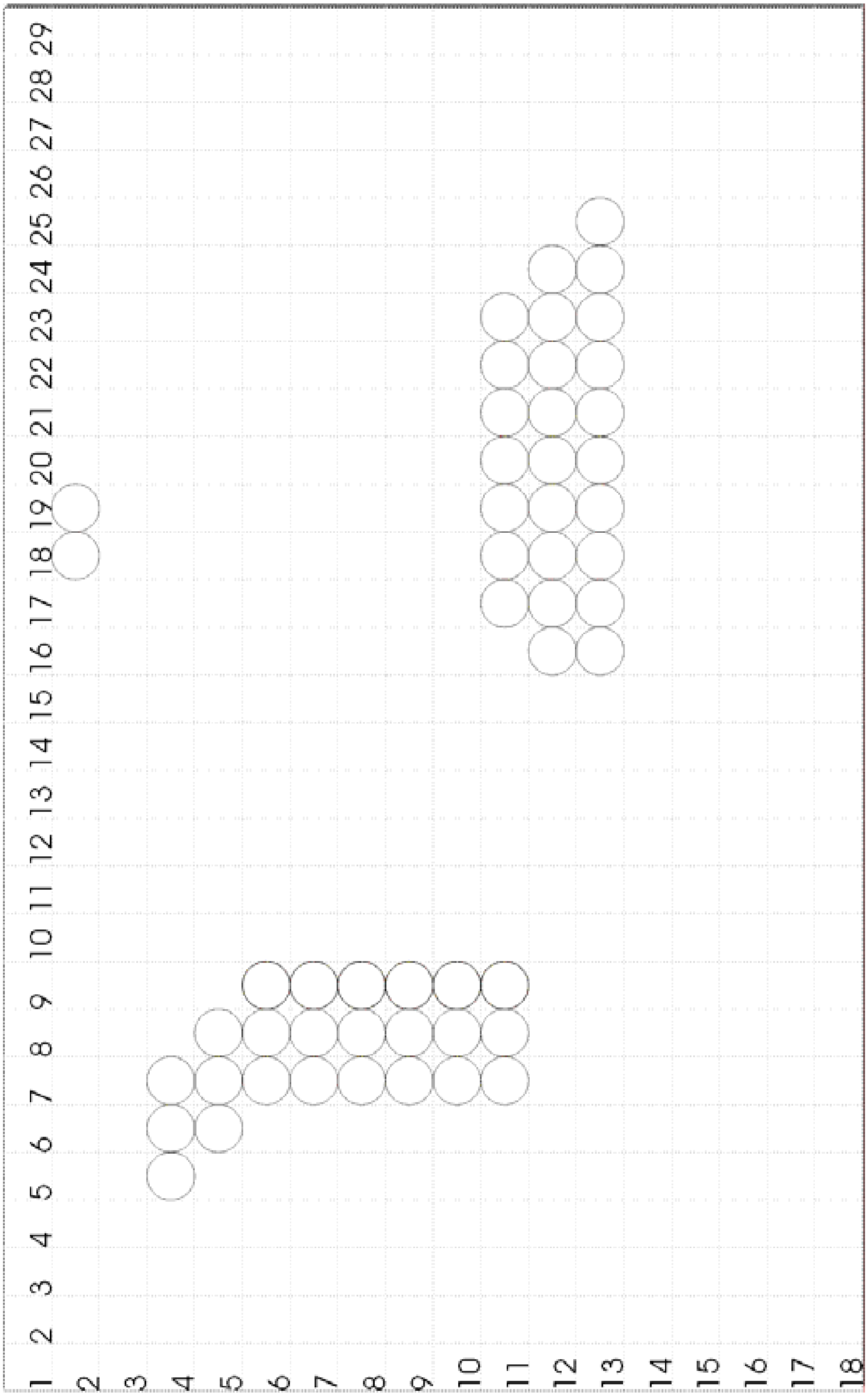
Surface 2 Delamination Map



Surface 3 Image

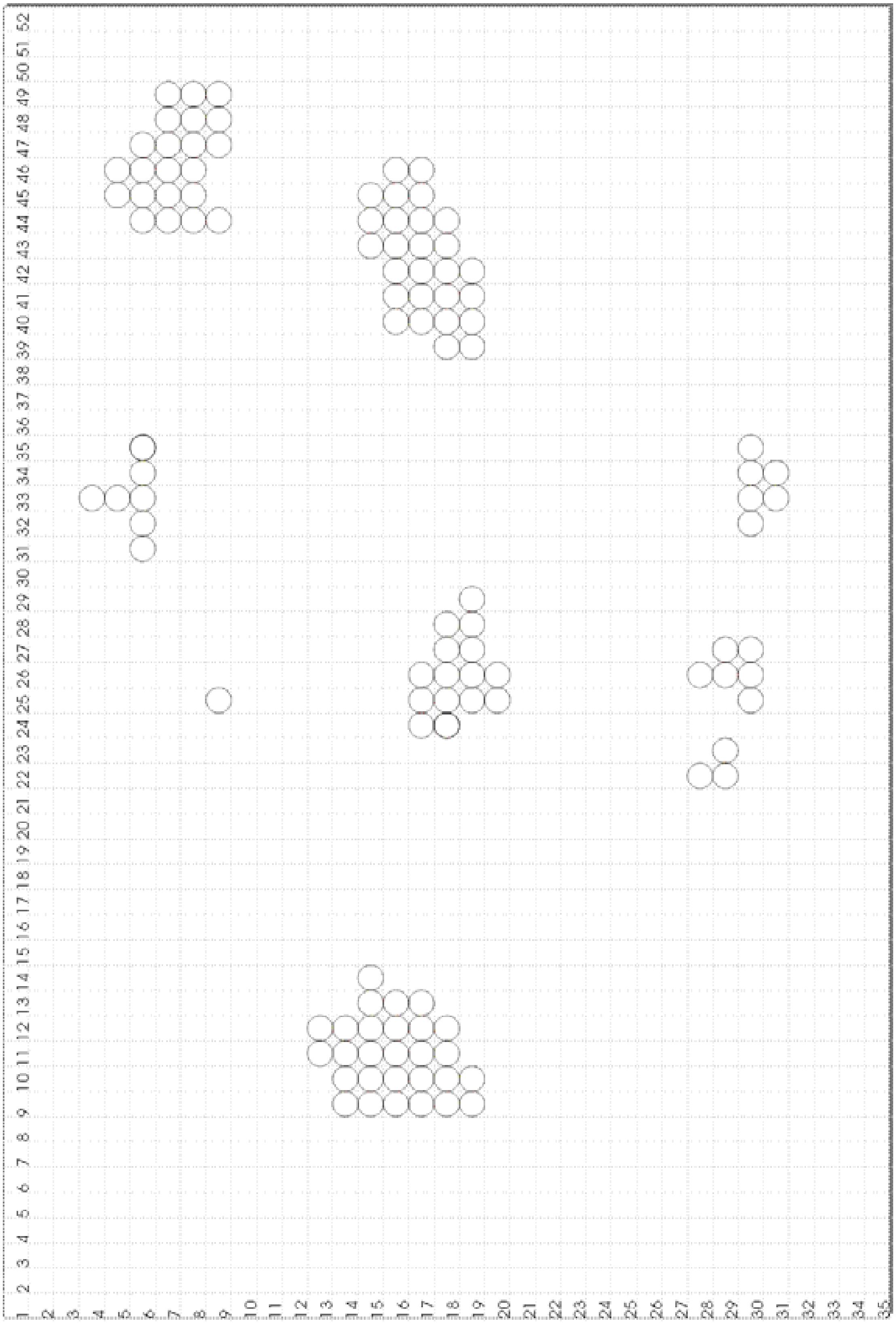


Surface 3 Delamination Map

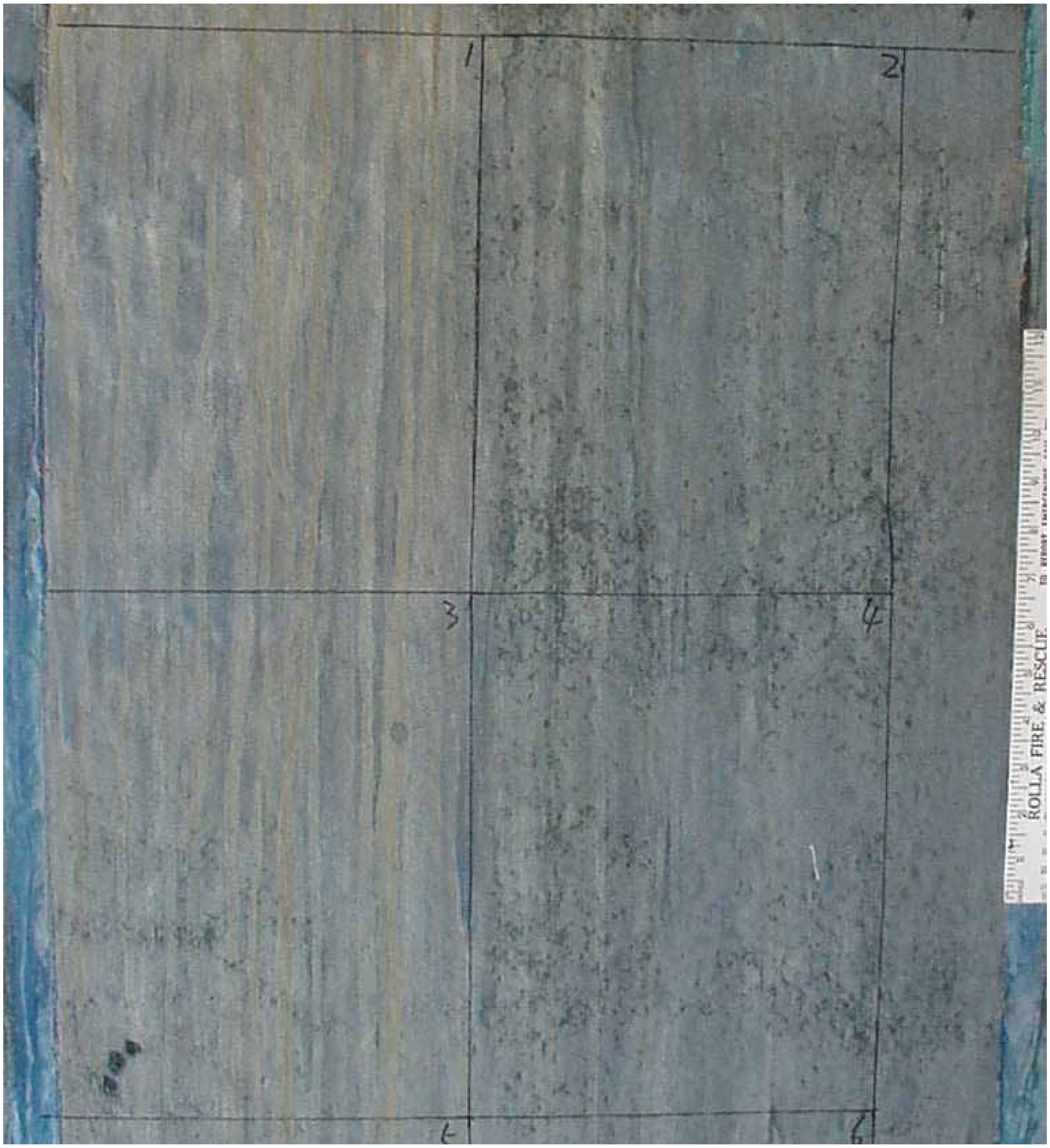


Surface M Image

Surface M Delamination Map



Surface B Image



Surface B Delamination Map