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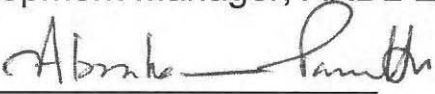
Thursday, October 19, 2006

## - TIRE FORENSICS REPORT -

PN 67722  
Purchase Order DTNH22-06-P-08366

Prepared for:  
U.S. DEPARTMENT OF TRANSPORTATION  
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION  
VEHICLE RESEARCH AND TEST CENTER  
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## EXECUTIVE SUMMARY

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Akron Rubber Development Laboratory was tasked with finding the root cause of failure in a group of Toyo tires submitted by Office of Defects Investigation, NHTSA. Nine Tires were tested at ARDL on 12 scientific tests to reveal the root cause of higher rate of failures seen in the field. Information from all the 12 tests is utilized to reveal the mechanisms of failure and tire integrity degradation in this group of tires.

We observe that the failed field tires A and J lost 72% and 52% of peel strength between belts 1 and 2 and 56% and 44% between belts 2 and 3. Four intact field tires identified as K, I, F, and C lost 52, 58, 58 and 61 percent of peel strength between belts 1 and 2 and 13, 20, 18 and 40% between belts 2 and 3 respectively. Two intact field tires were tested for peel strength after road wheel testing in the laboratory. These two tires B and G lost 67 and 52% between belts 1 and 2 and 43 and 13 % between belts 2 and 3 respectively. One unused tire is used as a baseline for the peel test. Tensile testing on rubber between belts 2 and 3 indicates rapid property degradation rate with a slope of -1.01 in comparison to -0.75 reported for heavy duty truck tires in reference 1. Centerline and shoulder modulus profiling independently confirms the finding that the belt coat compounds surrounding belts 1 and 2 have significant changes in modulus. Testing on this group of tires provides us with evidence that the Toyo tires are experiencing significant rubber degradation as a group in the region surrounding steel belts 1 and 2 depending on the severity of the field service.

The high severity service index (SEE DEFINITION) experienced can be caused by low inflation, high load, vehicle characteristics, high temperature of climatic conditions of storage and vehicle service, rubber layer properties, tire design or some combination of the above. Two tires submitted had catastrophically failed with rubber cohesively delaminating between all 5 steel belts (one steel body ply + 4 crown steel belts). This tire failed due to high severity service index in the field.

We expect the four other intact tires from the field submitted and analyzed by ARDL to follow a path of degradation similar to the failed tires if subjected to similar levels of high severity service index in the field.

This conclusion is reached based on 2 failed tires, 6 intact field tires, and 1 unused 3.5 year old tire from Toyo. A more detailed chemical testing on a larger sample size of aged peer tires from the field in this service environment with more detailed data on service histories is required to examine the probability of this type of field failure to occur on a large scale as well as to establish degradation benchmarks for reference.

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**SUBJECT:** Forensic Evaluation on 9 Toyo Tires.

**RECEIVED:** 7 structurally intact Toyo Tires  
2 catastrophically failed Toyo tires (marked in red)

Tire ID	DOT CODE
5095-h	DOT N3F2 5W11502
5095-B	DOT N3F2 5W11300
5095-I	DOT N3F25W10800
5095-A	DOT N3F2 5W1289
5095-F	DOT N3F25W1198
5095-G	DOT N3F25W1198
5095-C	DOT N3F2 5W1248
J-Failed	DOT N3F25W10300
K	DOT N3F25W11300

## FORENSIC ANALYSIS METHODOLOGY:

9 Toyo tires were received at Akron Rubber Development Laboratory.

Two of the tires submitted had catastrophic failure.

Each of the 9 tires is subjected to 12 independent scientific tests.

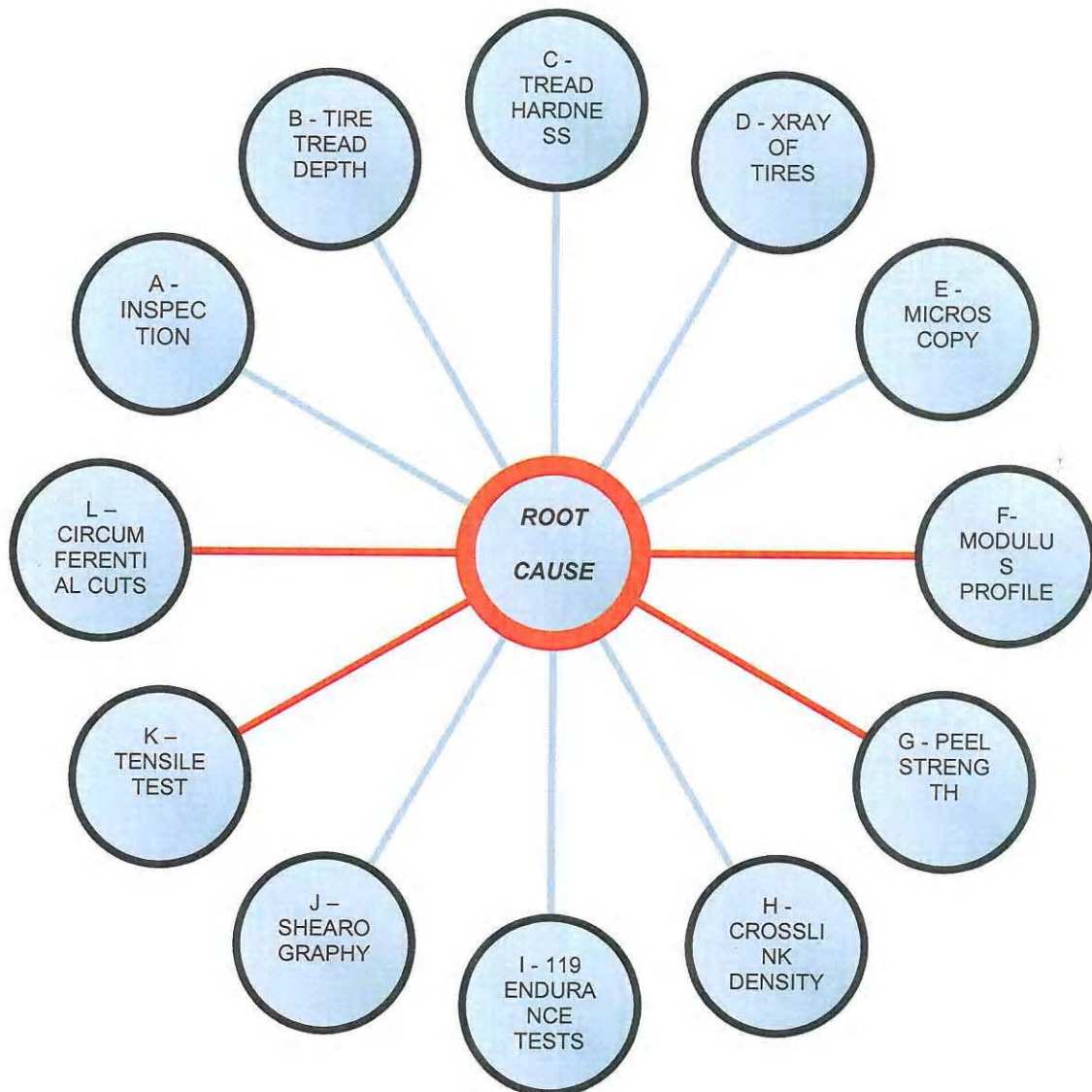
All 12 tests are evaluated to reveal the root cause of the failure.

Analysis is performed to contrast the failed tires within the group to understand the confounding factors of service history.

Data from each of the tests is analyzed as a group of 9 Toyo tires to study common degradation links.

Summary conclusions from each test are discussed below.

Refer to the individual appendices for data, plots and details for each of the 12 tests.



## **SUMMARY CONCLUSIONS**

### **A – INSPECTION OF TIRES – Refer to appendix A**

9 Toyo tires inspected did not indicate a common mechanism of tread wear visually. Circumference of each tire is divided into 12 equal sections marked with degrees 0 through 330 on the serial side in a clockwise direction. 0 degree marking starts at the letter “D” in the DOT code imprinted on the serial side of the tire. Tires are photographed from various angles and examined to reveal any unusual flaws. However, no evidence of unusual failure initiation is observed. We did not observe any innerliner bulges or anomalies in any of the tires. Some cracking in the root of the tread block and feathering on the tread blocks is observed. The feathering observed on two of the eight used field tires is possibly attributed to unbalanced forces resulting from conicity or tire pull due to tire design, tire uniformity, and possible slip/camber. However, we do not consider this to be contributor to the failure root cause. The two tires A and J had missing tread blocks as well as belt package elements along the circumference of the tire. In both tires the lowest region missing is belt 1. This indicates that the region surrounding belt #1 in the crown is a common link between both failed tires.

### **B - TIRE TREAD DEPTH – Refer to appendix B**

Tire Tread depth measurement is taken at 12 locations around the circumference of the tire. The tread depth measurement is taken for all 4 of the grooves in the tire. Tire tread depth did not indicate an unusual tread depth loss pattern or wear pattern for the catastrophically failed tires 5095-A and J compared to the other 7 Toyo tires. The failed tire A has no feathering on the tread block 1 and 5. The failed tire J has no feathering on the tread block 2 and 5. The two failed tires have significant tread life remaining based on tread depth readings.

### **C - TREAD HARDNESS – Refer to appendix C**

Tire Tread hardness measurements are taken at 12 locations around the circumference of the tire. The measurements are taken for all 5 of the tread blocks in the tire. The failed tire A has three missing center tread blocks throughout the circumference of the tire. The failed tire J has tread block 1, 3 and 4 missing throughout the circumference of the tire. Lack of this data does not allow for a scientific conclusion to the tread hardness information from the 9 Toyo tires. The failed field tire A has the lowest tread hardness for the tread block nearest to the OSS (opposite serial side) of the tire.

#### D – X-RAY OF TIRES – Refer to appendix D

The tires under study have one steel body ply in addition to 4 steel belts in the crown area. X-ray of tires did not reveal the start of the failure in the tread separated tires 5095-A and J. X-ray of other 7 tires did not indicate unusual steel wire construction technique or quality issues. Minor flaws in belt to belt spacing are consistent and within the bounds of steel belted tire construction experience.

#### E – MICROSCOPY – Refer to appendix E

Microscopy of the tires is performed. The cross-sectional microscopy cut confirms the presence of all the expected layers of rubbers in the tire composite construction in all tires. We did not observe steel cord abrasion into the sidewall rubber or inner liner coloration. As a result we conclude that significant under inflation can be ruled out for the 9 tires under study. We did not observe sidewall steel cord abrasion along the flexed area indicating absence of unusually severe low pressure inflation across the broad spectrum of tire service histories of the 8 tires. The inner liner thickness was 1.49 mm for 7 tires at the centerline. Further testing is necessary to determine quality of liner. Evidence of sidewall cord abrasion would indicate that the affected tires have been operated at tires pressures significantly below the inflation pressure appropriate for the load. The inspected tires did not exhibit evidence of sidewall cord abrasion indicating that these tires were not severely underinflated. However, these tires may have been operated under moderate underinflation conditions that would be detrimental to tire life but not of sufficient magnitude to deflect the relatively rigid truck tire sidewall to cause sidewall cord abrasion

## F- MODULUS PROFILE – Refer to appendix F

### Belt Edge/Shoulder Region

Modulus profiling was performed in the tire shoulder region at belt edges of “new (tire H)” and field tires (tires A, I, F, and C). Oxidative hardening was observed in the innerliner, ply coat, shoulder wedge, belt 1 coat, and underlay gumstrip compounds. Oxidative hardening was observed in the overlay gumstrip, tread base and tread components. Oxidative hardening was sometimes (generally) observed in belt-2 coat, 2-3 wedge, belt-3-coat, and overlay gum strip; however, the modulus changes were sometimes dominated by mechanical softening. The results indicate that for these tires, rubber degradation was primarily caused by oxidation. Clearly, the aging mechanism is predominantly oxidation. Lack of evidence of significant mechanical softening at belt edge indicates that the shear strains are in the normal range. This suggests that the tire aging occurred during shorter service runs and long parked tire conditions. These tires are different (unlike) long haul truck tires where the tire experiences long (or continuous) tire service (runs), by which oxygen permeation to internal components is limited and thermal reversion is the predominant degradation mechanism.

### Centerline Region

Modulus profiling was performed in the tire centerline region of “new (tire H)” and field tires (tires A and I). The overlay plots showed very large modulus increases in the squeegee, plycoat, belt-1-coat, and belt-2-coat compounds. The modulus change was especially high in belt-1-coat compound. The modulus increase is a result of oxidation. This was an unusually high level of property deterioration. The results point out that the major durability factor in this tire is probably oxidation in the belt-1-coat and belt-2-coat compounds in the centerline region. This may be associated with 1) high heat and strains in this region of the tire or 2) oxygen somehow reaching this compound (i.e., cord wicking), or 3) a combination of the two.

## G - PEEL STRENGTH – Refer to appendix G

Peel strength testing is performed on the failed tire as well the other 8 tires. The rubber between steel belts 1 and 2 and 2 and 3 is pulled apart at a rate of 2 inches per minute on a tensile testing machine. The peeled surface is seen to be cohesive in nature. The rubber sticks to the steel belts as it is peeled apart. This is indicative of good adhesion between rubber and steel belts. This is also indicative that the temperature in the failed tire did not reach levels where the adhesive bond between rubber and steel is likely to break. The peel data indicates that the rubber between steel belts 1 and 2 for failed tires A and J lost 72 and 52 percent respectively of its strength normalized to an unused 3.5 year old Toyo tire. The peel data indicates that the rubber between steel belts 2 and 3 for tires A and J lost 56 and 44 percent of its strength normalized to an unused 3.5 year old Toyo tire. Two intact field tires

were tested for peel strength after road wheel testing in the laboratory. These two tires B and G lost 67 and 52% between belts 1 and 2 and 43 and 13 % between belts 2 and 3 respectively. Oxidative aging affects the peel strength of tires. Data confirms oxidative aging of the 8 field tires manufactured by Toyo. One unused tire is used as a baseline for the peel test. The severity index plot shows that the average severity index across the range of tires is highest for rubber between belts 1 and 2.

#### H - CROSSLINK DENSITY – Refer to appendix H

Crosslink density testing by toluene swelling method is performed on rubbers extracted from the centerline of the belts 1 and 2 and 2 and 3. The crosslink density does not correlate with DOT age. When plotted versus the Severity index we observe that the two failed tires have values closer to the central region of the trend line of the 9 tires. Tire ID A and J do not have the highest severity service index as would be expected. Again these results indicate oxidative aging is the typical service aging mechanism for the nine tires under study. Additionally fixed oxygen percent testing indicates no trend with DOT age. We conclude that failed tire rubber chemistry did not change significantly between the time the tire catastrophically failed and the time the vehicle came to a complete stop post blowout.

#### I – FMVSS 119 ENDURANCE TESTS

FMVSS 119 endurance testing is performed on two tires with DOT age 5.9 and 8.1 years for tires identified as B and G respectively. The tires pass this test without failure. We conclude that the mild parameters of the endurance test performed is not capable of reproducing field conditions that caused two of the 9 Toyo tires to fail.

#### J – SHEAROGRAPHY

Shearographic laser interferometric evaluation is performed on the 9 tires. The phase diagram data from shearography does not indicate presence of belt edge defects or holes in the internal components of the rubber in all 9 tires. Comparison of the pre and post endurance tested tires indicates that both tires B and G did not form any belt edge defects during the endurance test. Shearography does not indicate any other defects due to manufacturing in any of the 9 tires.

#### K – TENSILE TEST – Refer to appendix I

Tensile testing is performed on dumbbells cut from rubbers extracted from between belt 1 and 2 and 2 and 3 from the centerline of the tire. Ahagon charts are plotted to show the rates of degradation. The chart indicates a steeper rate of rubber 2-3 degradation compared to rubber 1-2 for the group of 9 Toyo tires. All nine Toyo tires fall on degradation line for rubber 2-3 that is steeper than the degradation line reported by A. Ahagon for heavy duty truck tires. Refer to technical paper as per

reference 1. The failed tires A and J do not significantly stand out in this type of group aging mechanism trend. We conclude that all 9 tires have the phenomena of rubber degradation taking place at a rate that indicates a process of cross linking reaction due to oxygen permeating from the tire cavity through the rubber layers in addition to scission of links due to higher operating temperatures caused by higher severity service index. Possibly the 2 – 3 wedge rubber experiences some thermal reversion (crosslink loss) from higher operating temperatures. Analysis of crosslink types in the 9 tires may reveal whether thermal reversion occurred. The tensile testing indicates a slope of -0.67 with a R<sup>2</sup> value of 0.70 for the rubber between belts 1 and 2. Comparatively, the rubber between belts 2 and 3 indicate a more rapid loss of strength with a slope of -1.01 with a R<sup>2</sup> value of 0.81

### L – CIRCUMFERENTIAL CUTS

Circumferential cut is a microscopy technique where we extract specific rubbers from the belt edge sites to visually observe if the tires had any belt edge defects before failure. Based on the cuts we performed on the failed tire we observed that the two failed tires as well as the seven intact tires have some socketing at the ends of the steel belts. However, we did not observe at the belt edges evidence of crack growth as expected in the catastrophically tread separated tire. This indicates that the tire A failed due to higher levels of SEVERITY SERVICE INDEX affecting the rubber layer integrity primarily between belts 1 and 2 as well as between 2 and 3 in the centerline of the tire. The circumferential cut results correlate with our findings from shearography for the endurance tested tires.

## **SEVERITY INDEX**

ARDL adopted the term "Severity Index" to describe to describe the cumulative effects of different aging inputs on a tire. The severity index of a tire is a number between 1 and 10. A higher severity index number indicates greater severity of the aging on a given tire. In the absence of a large population of failed tires for analysis tires we have used this technique to rank order different field tires. The assumption made for this report is linearity of property loss between a new tire and a theoretical calculated (unacceptable) tire property. The different field tires are shifted such that they lie on this line. This gives us a number between 1 and 10 for every field tire and property such as tensile elongation, peel, or roadwheel endurance time to failure.

The severity index is a theoretical complex function of inflation, load, vehicle characteristics, temperature of climatic conditions of storage and vehicle service, rubber layer properties, tire design or some combination of the above. One way to elucidate and separate the different inputs of aging is to analyze the common underlying observations on failed tires in the field.

Study of the 4 intact Toyo field tires submitted indicates an average severity index of 7.03 for belt 1-2 rubber and 4.33 for belt 2-3 rubber peel strength. Study of the 2 catastrophically failed Toyo field tires submitted indicates an average severity index of 7.55 for belt 1-2 rubber and 7.00 for belt 2-3 rubber peel strength.

## **THEORY: MECHANISTIC COMMON LINKS**

The 12 independent scientific tests point towards the following main conclusions

- The failed tire had significant loss of strength in the rubber layer surrounding steel belts 1 and 2 based on tensile tests, peel tests and modulus profile testing compared to a new tire.
- The failed tire A had a higher loss of strength (72%) compared to other tires because of a higher severity service index history on the tire. A higher severity service index can be caused by higher load, lower pressure, and environmental factors of service as well as storage.
- The intact Toyo tires K, F, C and I with varying service histories also had significant property reduction in rubber layers between steel belts 1 and 2 & 2 and 3 with the four field tires losing more than 50 percent of the rubber strength between belts 1 and 2 peel strength compared to a unused 3.5 year old intact tire.
- Summary plots for all 12 tests exclude the possibility of significant changes in the failed tires rubber chemistry between the time the tire catastrophically failed and the time the vehicle came to a complete stop.

## **CONCLUSIONS AND RECOMMENDATIONS**

- Testing on the Toyo tires indicate existence of a significant rate of degradation in the rubber material between steel belts 1 and 2 as well as between 2 and 3 with field service.
- The degradation is occurring on the Toyo tires as a group.
- The failed tires A and J do not stand out in this group of 9 Toyo tires in terms of rubber crosslink density and tensile property degradation. Peel strength data indicates higher material property degradation in tire A, particularly in 1-2 rubber.
- The severity of the service conditions on this tire vehicle combination can be due to high load, low inflation, hot climatic conditions, rubber layer properties, design of tire or a combination of the same.
- Tire component testing indicates that the Toyo tires are experiencing a higher degree of severity service index in the field as a group in the vehicle class under consideration. This points out to a higher possibility of failure rates in this service environment. The higher severity index can be caused by conditions such as high load, low inflation, hot climatic conditions, rubber layer properties, design of tire or some combination of the above.
- We conclude that based on extensive testing that it is highly likely that the intact field tires submitted will degrade similar to tire A and J if they are subjected to similar service conditions in the field.

# Appendix A

## - INSPECTION-

- Tire A – images
- Tire B Pre and Post Endurance – images
- Tire C – images
- Tire F – images
- Tire G Pre and Post Endurance – images
- Tire H – images
- Tire I – images
- Tire J – images
- Tire K – images

# Appendix A - INSPECTION- Tire A – OBSERVATIONS AND IMAGES

TIRE OBSERVATIONS	0 DEG	30 DEG	60 DEG	90 DEG	120 DEG	150 DEG	180 DEG	210 DEG	240 DEG	270 DEG	300 DEG	330 DEG
Groove 1 nearest to SS												
Groove 2											4MM GOLUGE @320DE G	
Groove 3												
Groove 4												
Tread Block 1 nearest to SS	Visible	Visible	Visible	Visible	Missing	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Tread Block 2	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing
Tread Block 3	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing
Tread Block 4	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing
Tread Block 5	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Tread crown area												
Overall Tire												
Steel belt 0 - Radial Plies	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Rubber between steel belt 0 and 1	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Steel belt 1	Visible	Visible	Missing	Missing	Missing	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Rubber between steel belt 1 and 2	Visible	Visible	Missing	Missing	Missing	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Steel belt 2	Visible	Visible	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Visible
Rubber between steel belt 2 and 3	Visible	Visible	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Visible
Steel belt 3	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Visible
Rubber between steel belt 3 and 4	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Visible
Steel belt 4	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Visible







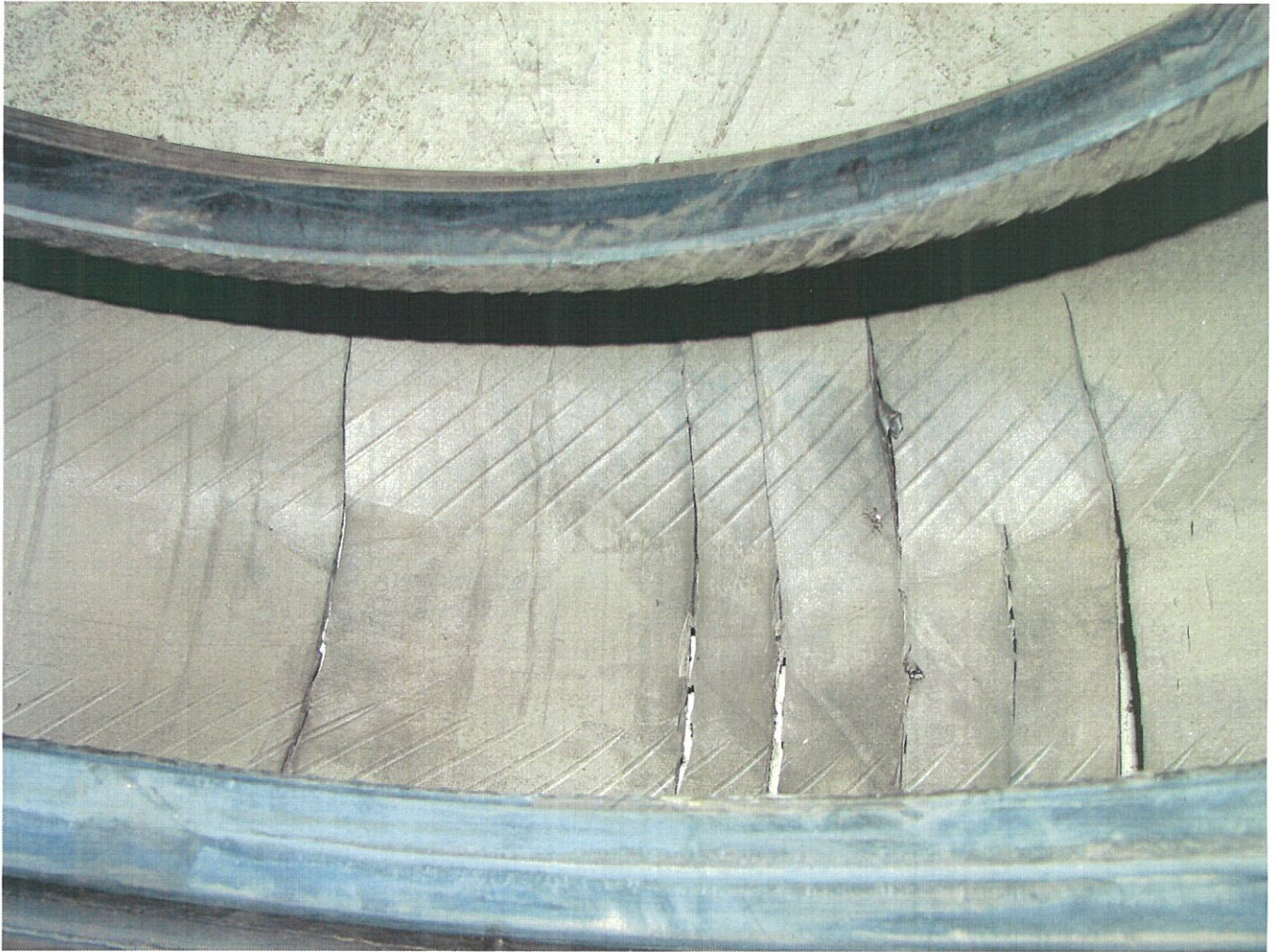
















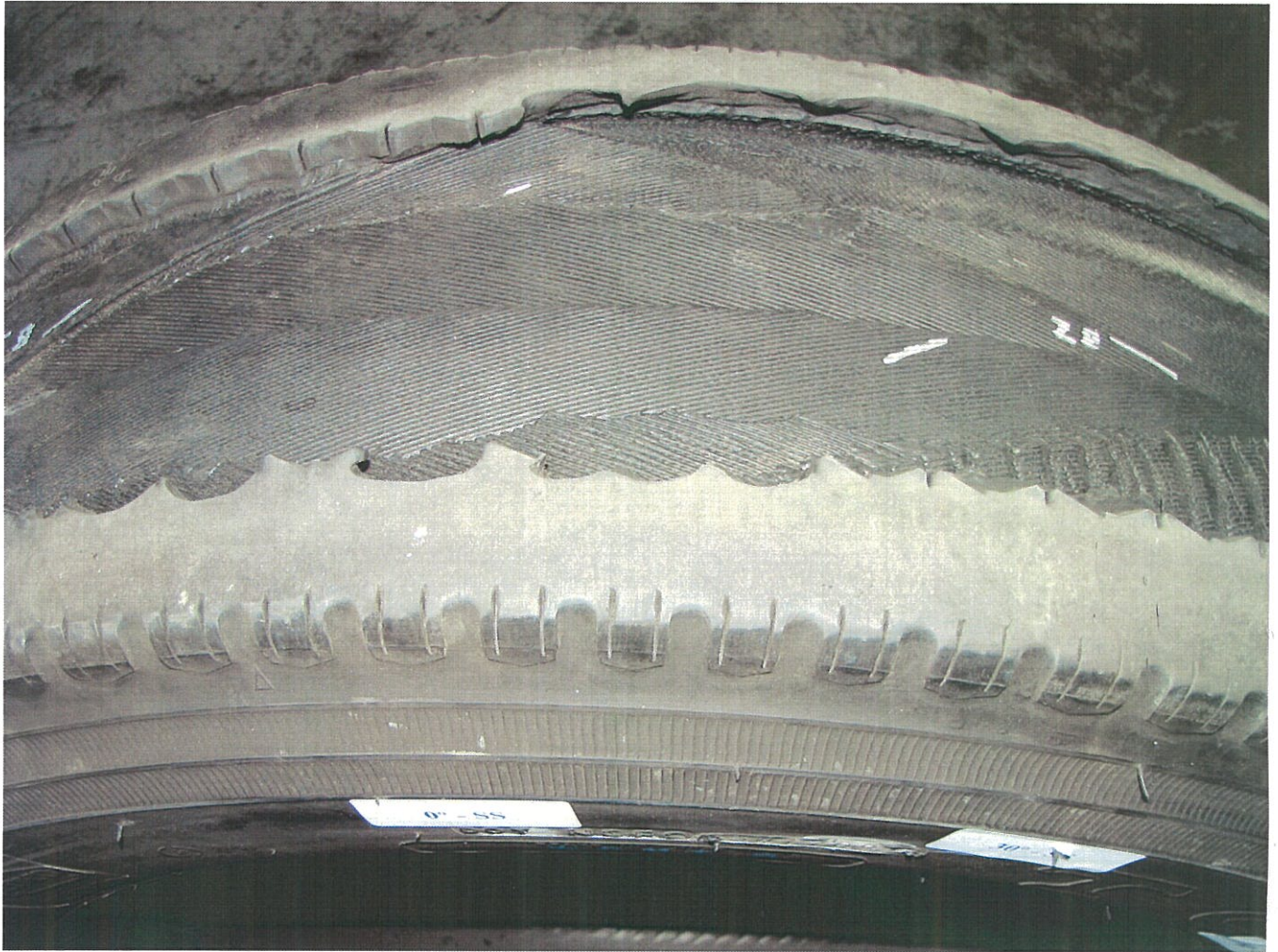












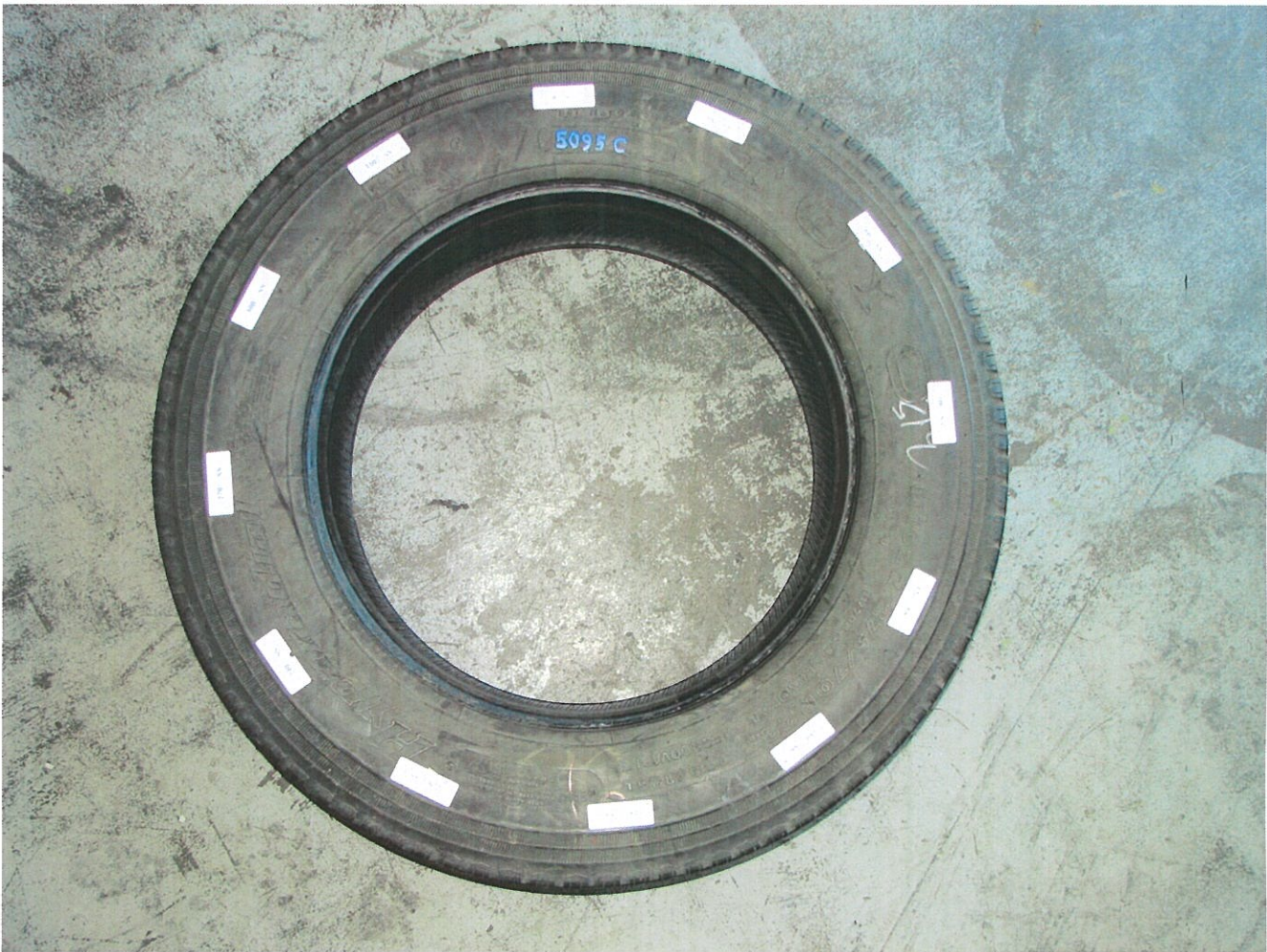






# Appendix A - INSPECTION- Tire C – images

TIRE OBSERVATIONS	0 DEG	30 DEG	60 DEG	90 DEG	120 DEG	150 DEG	180 DEG	210 DEG	240 DEG	270 DEG	300 DEG	330 DEG	Overall
<b>TIRE IDENTIFIERS</b>													
Groove 1 nearest to SS													
Groove 2													
Groove 3													
Groove 4													
Tread Block 1 nearest to SS													
Tread Block 2													
Tread Block 3													
Tread Block 4													
Tread Block 5													
Tread crown area								"hold nail marking" @210- 270deg					Blue marking "Mittin ger"
<b>TIRE OBSERVATIONS</b>													
Groove 1 nearest to SS													
Groove 2											4MM GOUGE @320DE G		
Groove 3													
Groove 4													
Tread Block 1 nearest to SS													
Tread Block 2													
Tread Block 3													
Tread Block 4													
Tread Block 5													
Tread crown area													
Overall Tire													
Steel belt 0 - Radial Plies													





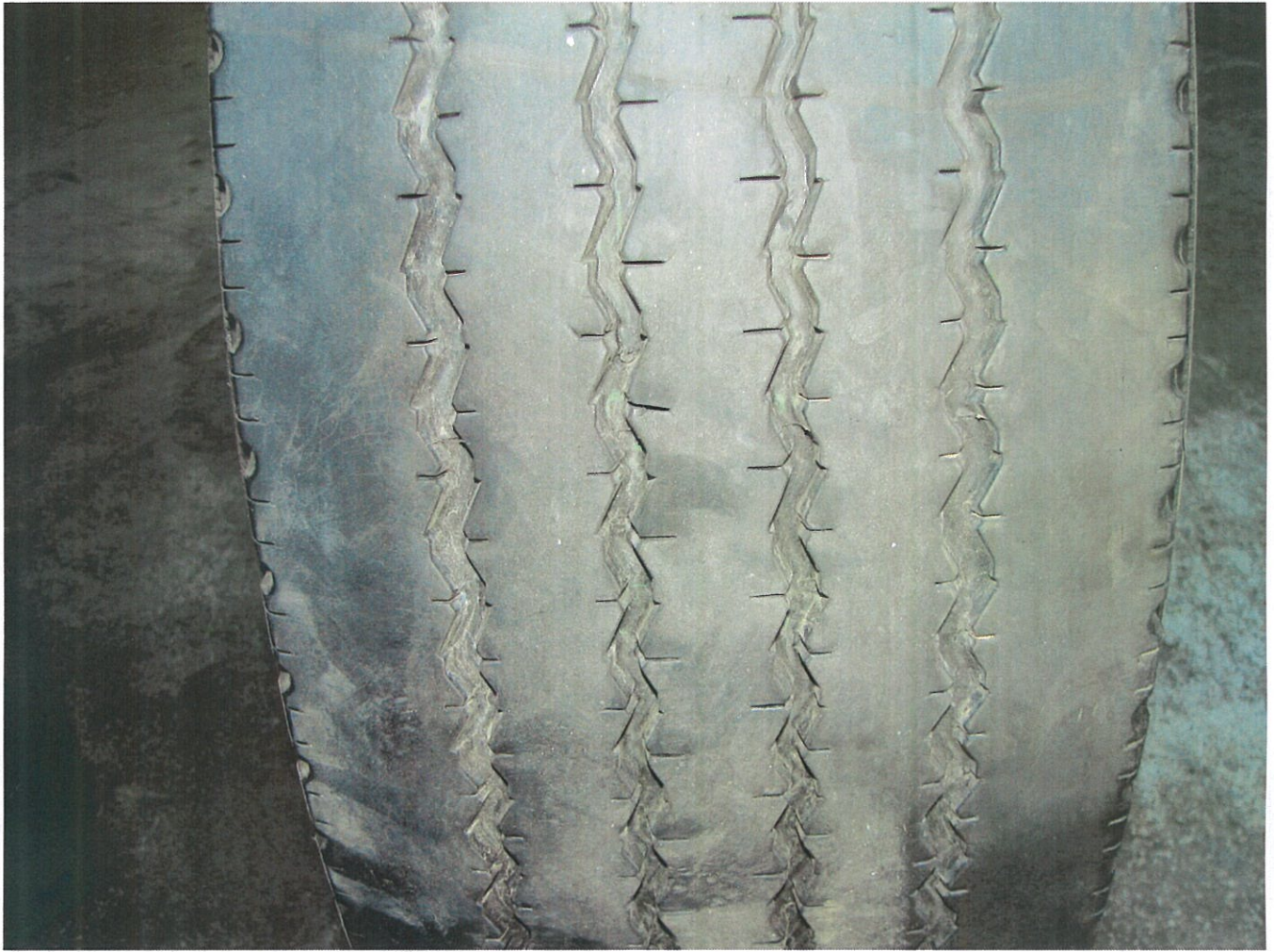
















# Appendix A

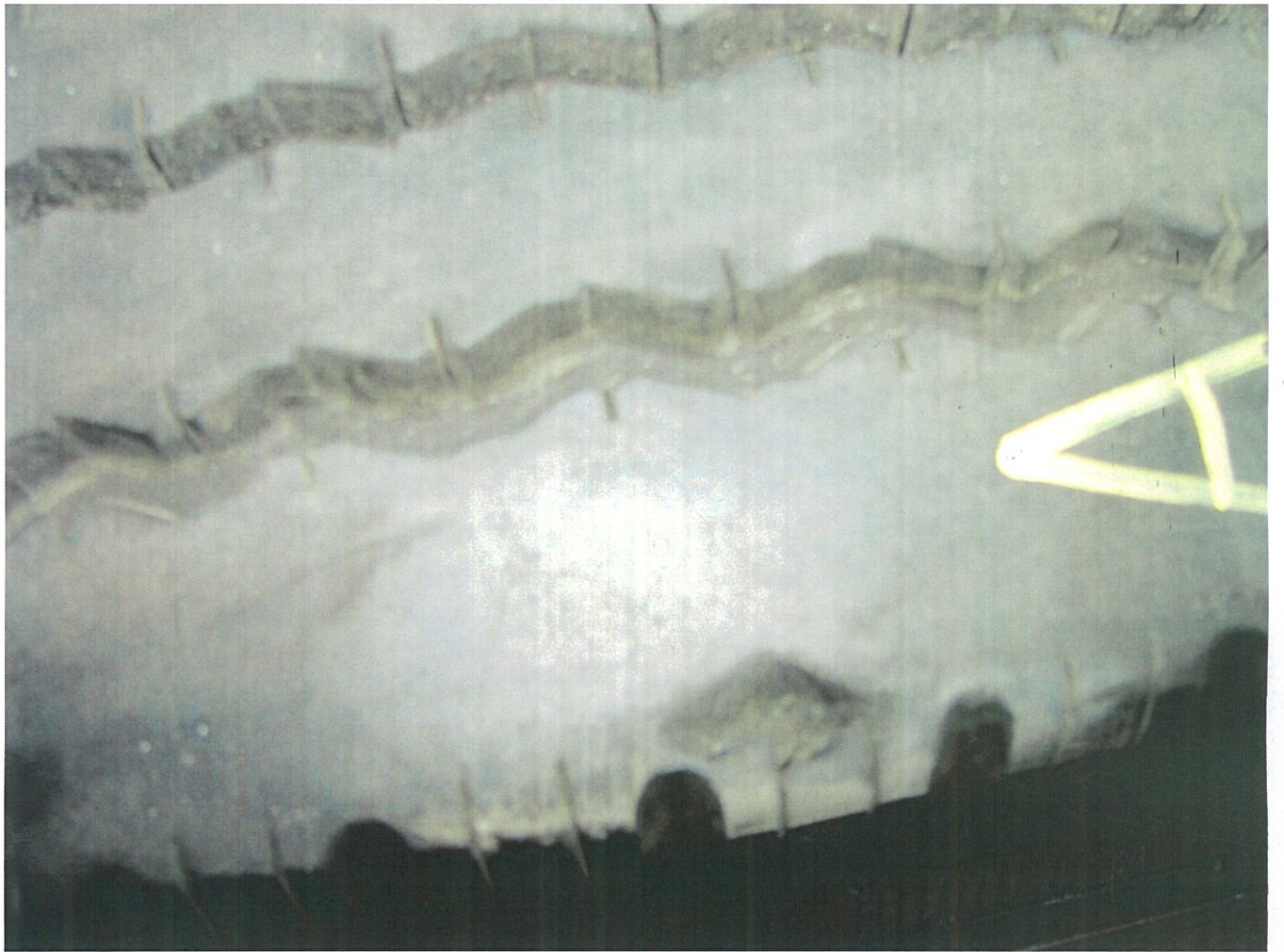
## - INSPECTION-

### Tire F – OBSERVATIONS AND IMAGES

TIRE OBSERVATIONS	0 DEG	30 DEG	60 DEG	90 DEG	120 DEG	150 DEG	180 DEG	210 DEG	240 DEG	270 DEG	300 DEG	330 DEG	Overall
<b>TIRE IDENTIFIERS</b>													
Groove 1 nearest to SS													
Groove 2													
Groove 3													
Groove 4													
Tread Block 1 nearest to SS							"LR OUT" grooved in						
Tread Block 2													
Tread Block 3													
Tread Block 4													
Tread Block 5													
Tread crown area													
<b>TIRE OBSERVATIONS</b>													
Groove 1 nearest to SS													
Groove 2													
Groove 3													
Groove 4													
Tread Block 1 nearest to SS													
Tread Block 2													
Tread Block 3													
Tread Block 4													
Tread Block 5										Tread chunk 1 inch			
Tread crown area													
Overall Tire													















# Appendix A

## - INSPECTION-

### Tire G Pre and Post Endurance Test- OBSERVATIONS AND IMAGES

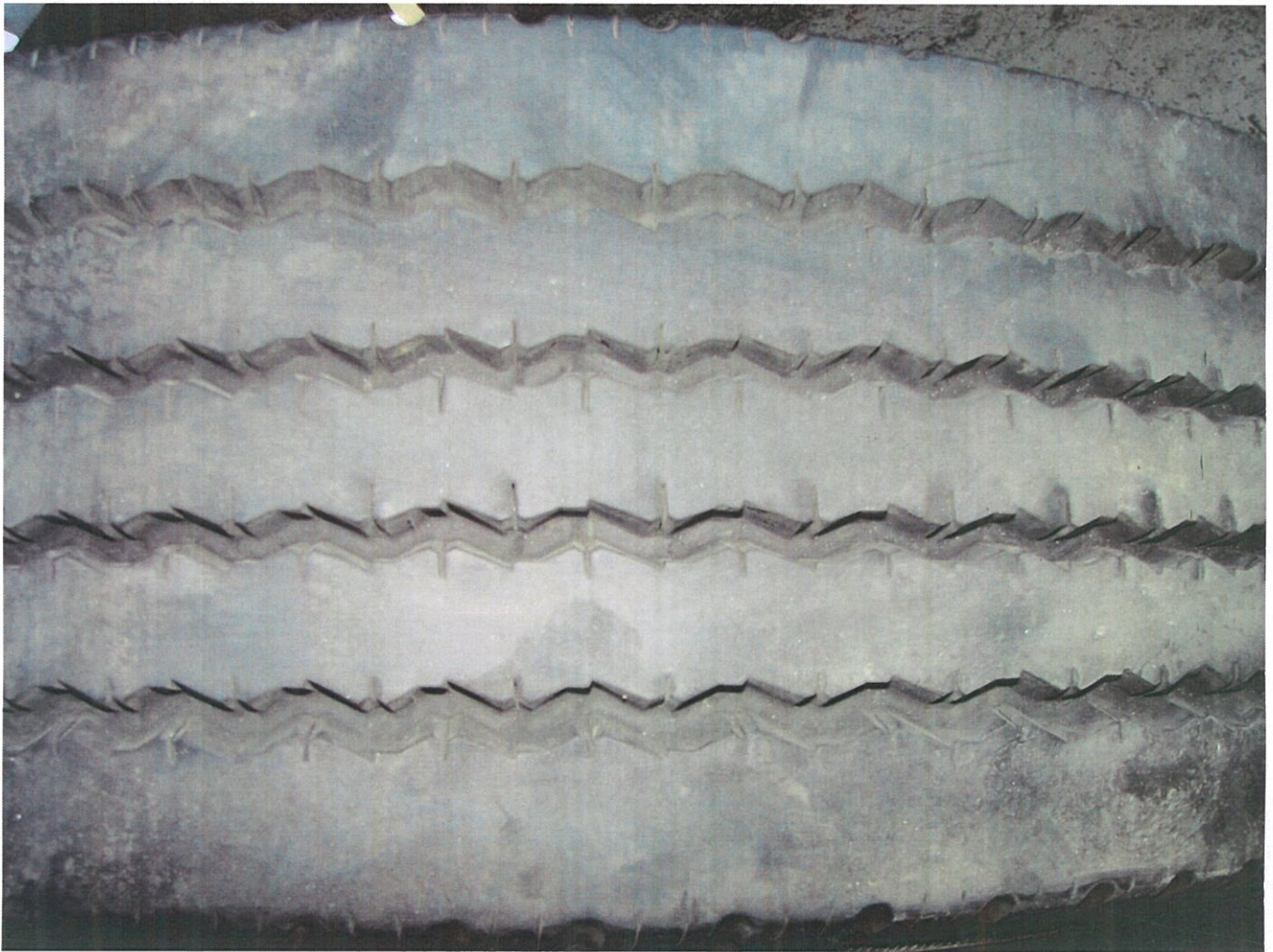
TIRE OBSERVATIONS	0 DEG	30 DEG	60 DEG	90 DEG	120 DEG	150 DEG	180 DEG	210 DEG	240 DEG	270 DEG	300 DEG	330 DEG	Overall
<b>TIRE IDENTIFIERS</b>													
Groove 1 nearest to SS													
Groove 2													
Groove 3													
Groove 4													
Tread Block 1 nearest to SS													
Tread Block 2													
Tread Block 3													
Tread Block 4													
Tread Block 5													
Tread crown area													
<b>TIRE OBSERVATIONS</b>													
Groove 1 nearest to SS													
Groove 2													
Groove 3													
Groove 4													
Tread Block 1 nearest to SS										"RR OUT" grooved in the tread block			
Tread Block 2													
Tread Block 3													
Tread Block 4													
Tread Block 5													
Tread crown area													









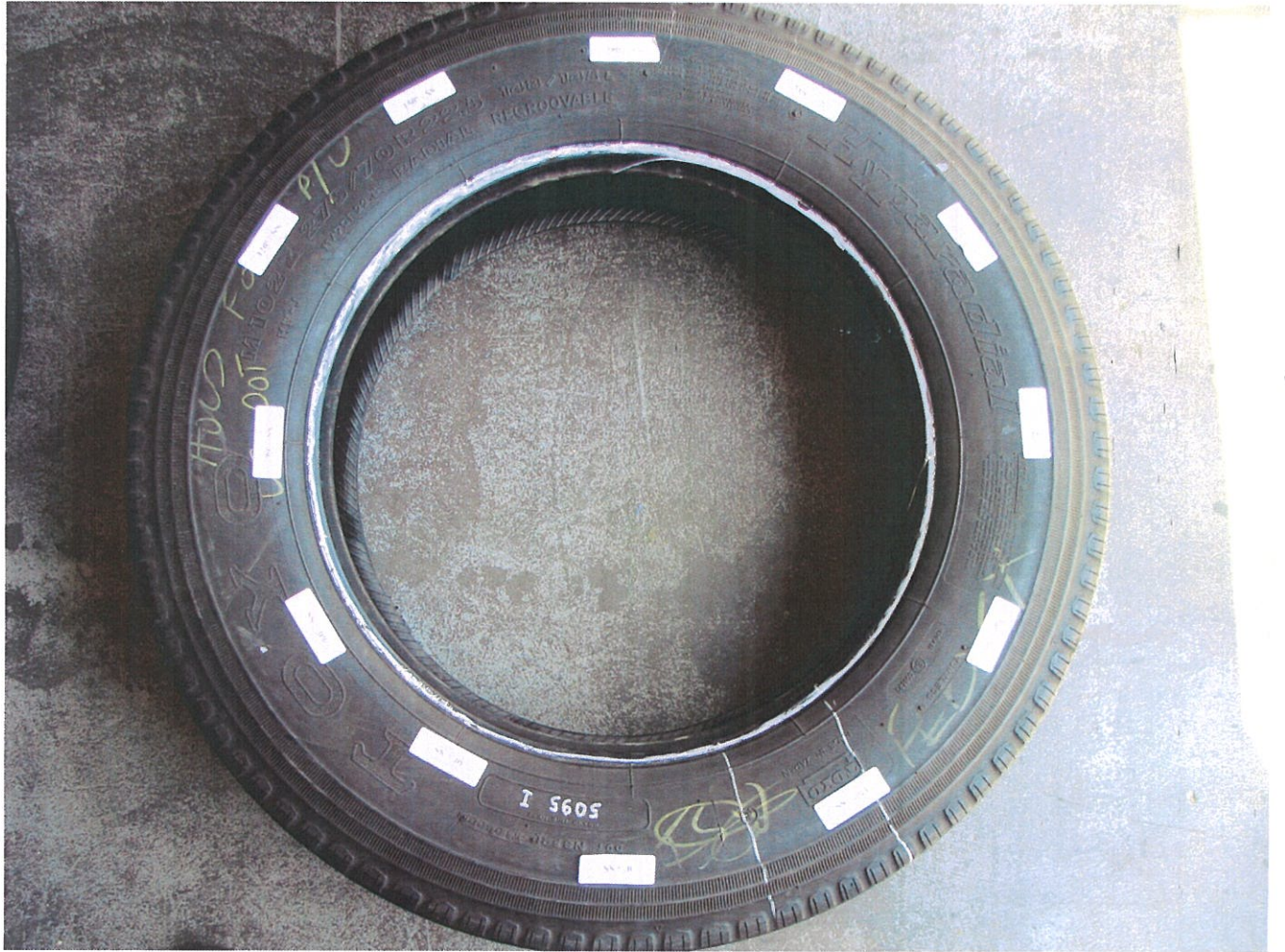


# Appendix A - INSPECTION- Tire H – OBSERVATIONS

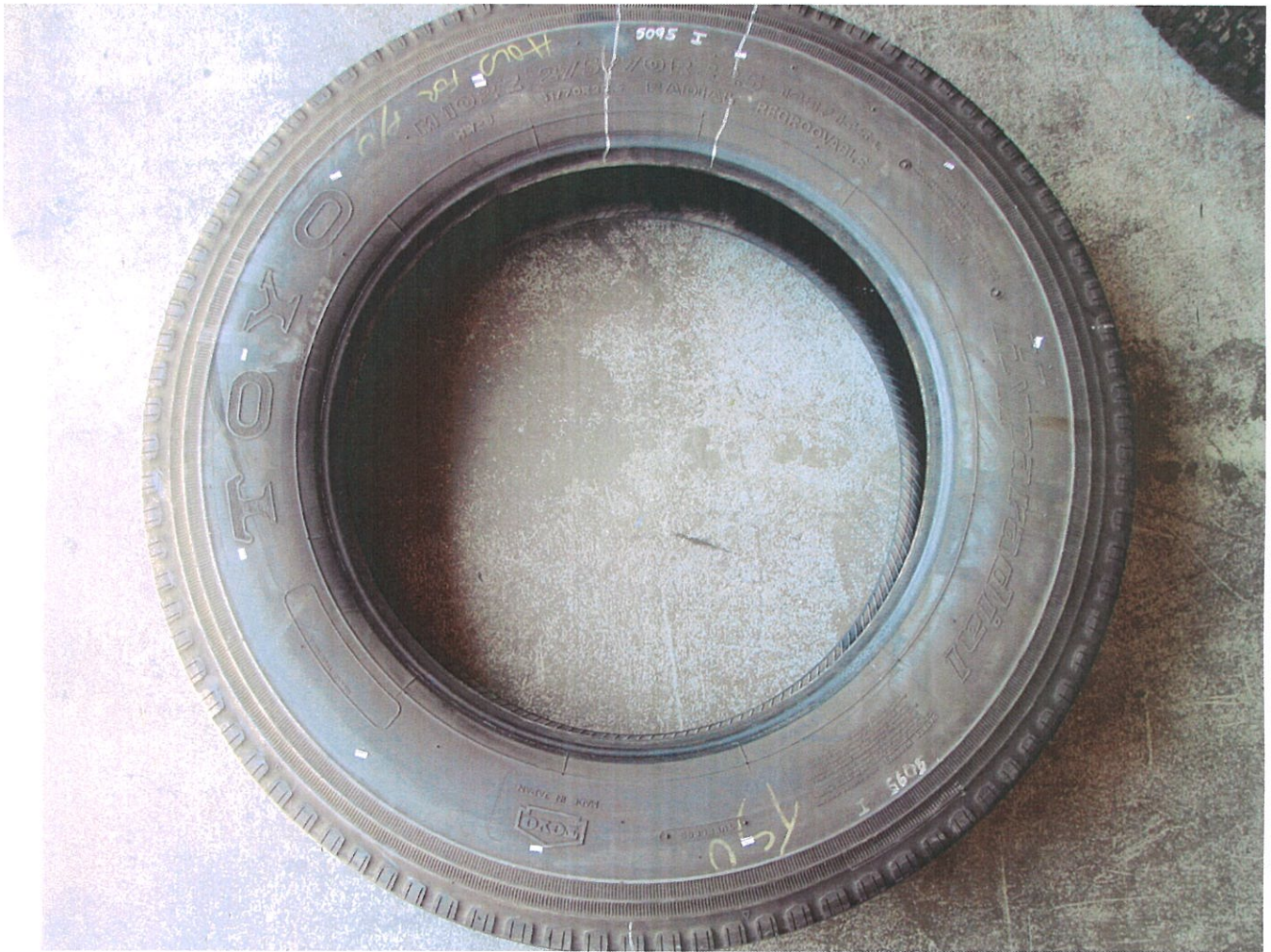
TIRE OBSERVATIONS	0 DEG	30 DEG	60 DEG	90 DEG	120 DEG	150 DEG	180 DEG	210 DEG	240 DEG	270 DEG	300 DEG	330 DEG	Overall
<b>TIRE IDENTIFIERS</b>													
Groove 1 nearest to SS													
Groove 2													
Groove 3													
Groove 4													
Tread Block 1 nearest to SS													
Tread Block 2													
Tread Block 3													
Tread Block 4													
Tread Block 5													
Tread crown area													tire size label stuck on tread area
<b>TIRE OBSERVATIONS</b>													
Groove 1 nearest to SS													
Groove 2											4MM GOLGE @320DE G		
Groove 3													
Groove 4													
Tread Block 1 nearest to SS													
Tread Block 2													
Tread Block 3													
Tread Block 4													
Tread Block 5													
Tread crown area													

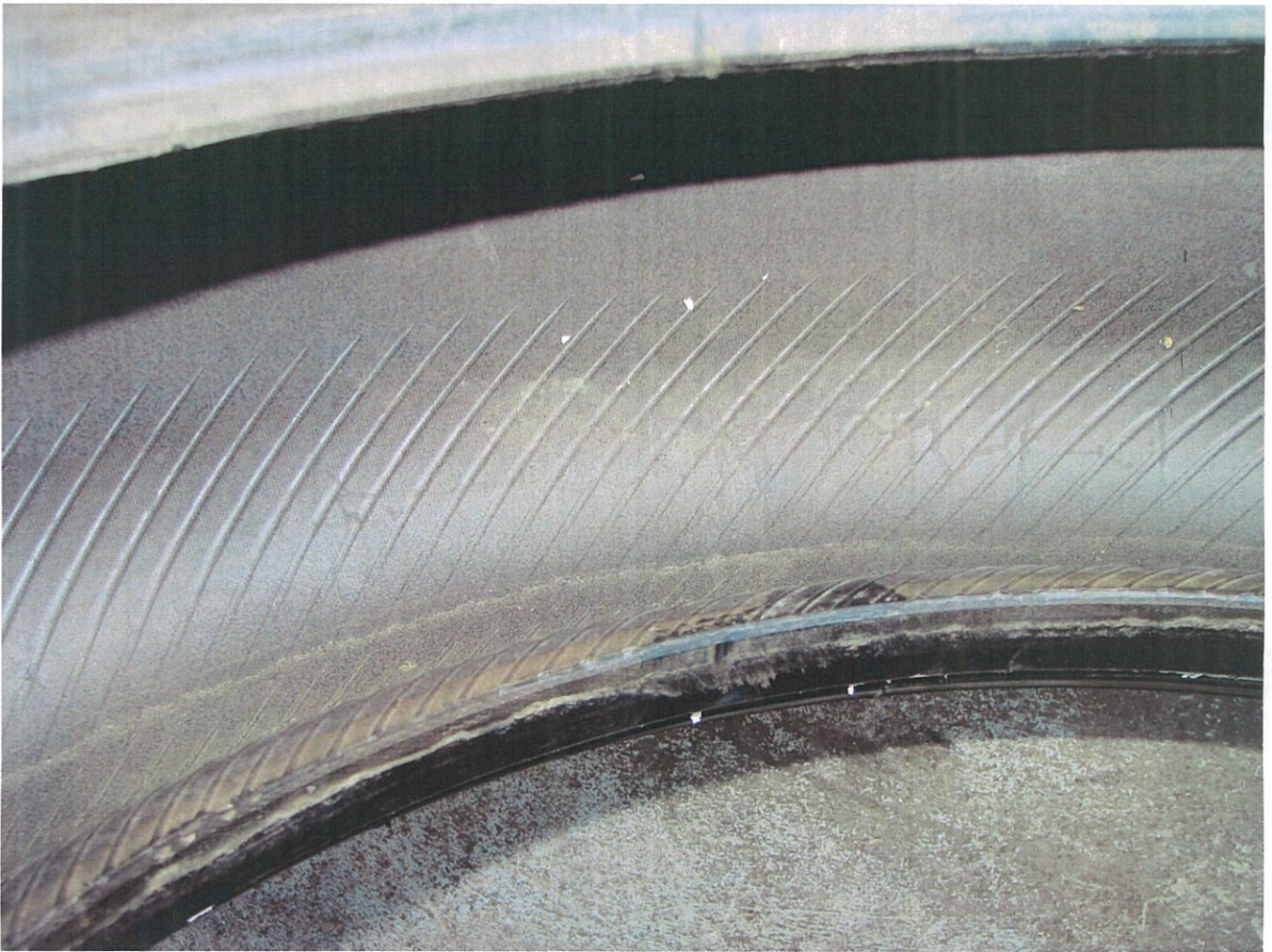
# Appendix A - INSPECTION- Tire I – images and observations

TIRE OBSERVATIONS	0 DEG	30 DEG	60 DEG	90 DEG	120 DEG	150 DEG	180 DEG	210 DEG	240 DEG	270 DEG	300 DEG	330 DEG
TIRE IDENTIFIERS												
Groove 1 nearest to SS												
Groove 2												
Groove 3												
Groove 4												
Tread Block 1 nearest to SS												
Tread Block 2												
Tread Block 3												
Tread Block 4												
Tread Block 5												
Tread crown area												
TIRE OBSERVATIONS												
Groove 1 nearest to SS												
Groove 2												
Groove 3												
Groove 4												
Tread Block 1 nearest to SS			1.5 inch cut									
Tread Block 2												
Tread Block 3												
Tread Block 4												
Tread Block 5												
Tread crown area												















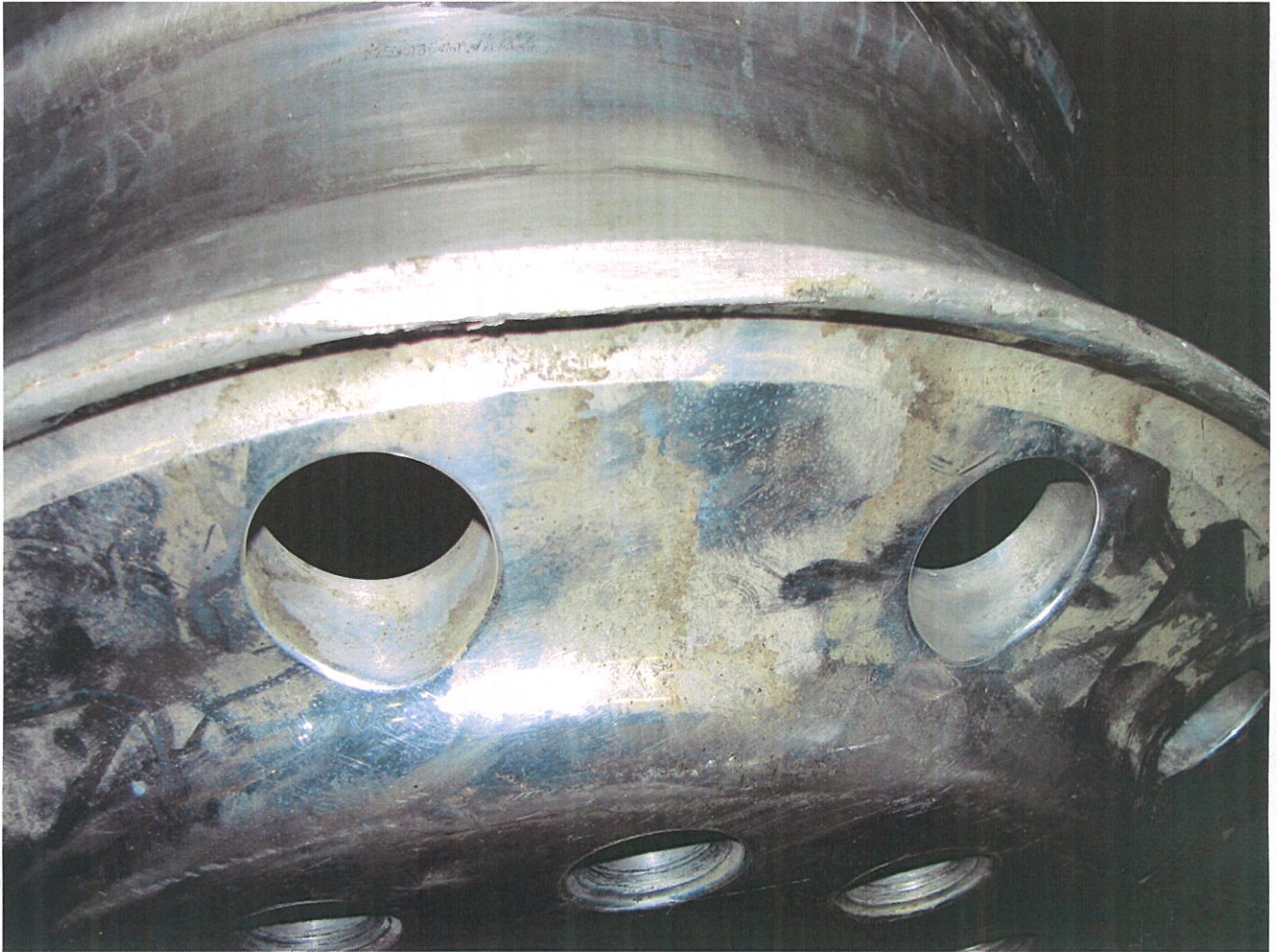
# Appendix A

## - INSPECTION-

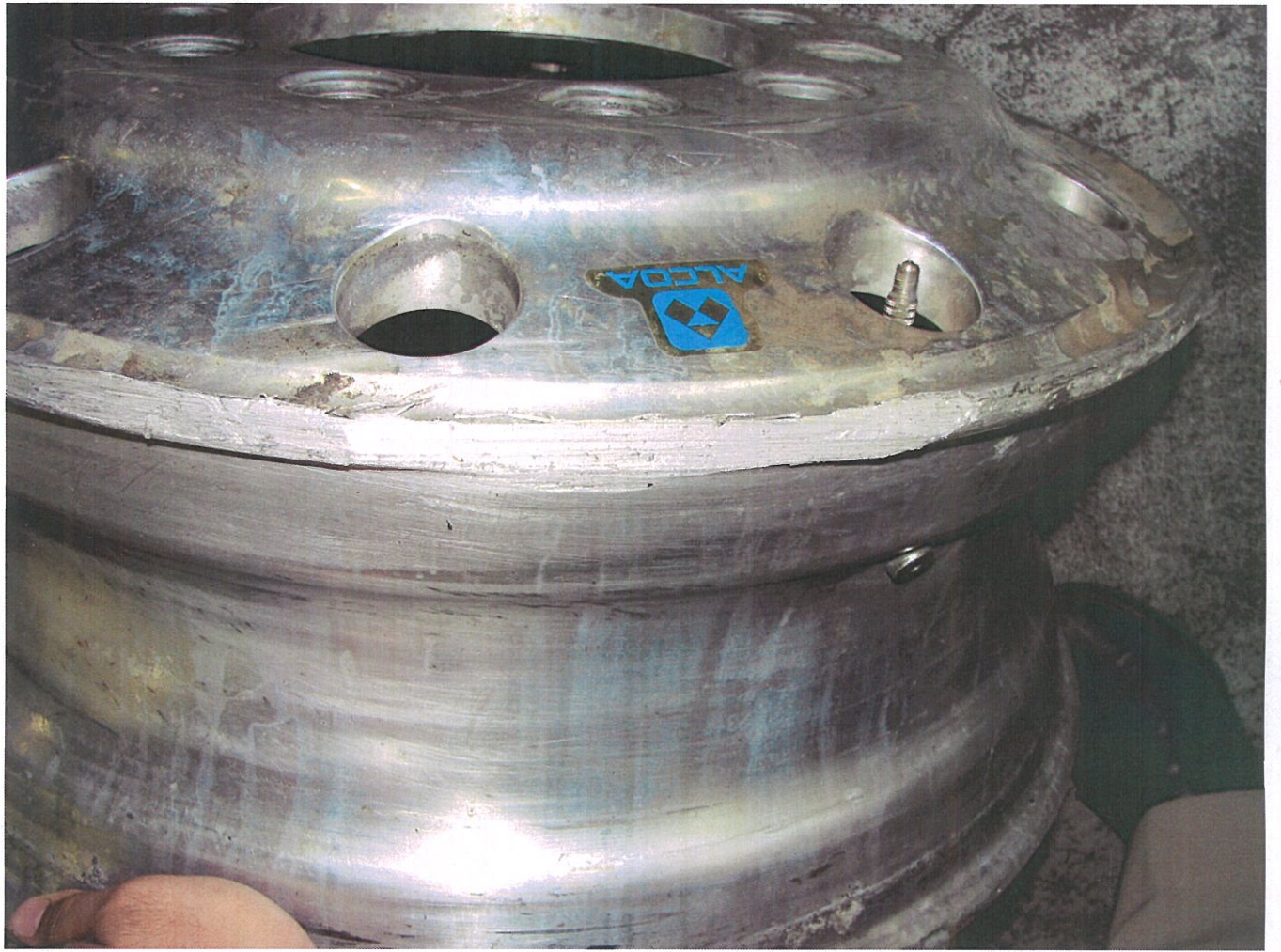
### Tire J – OBSERVATIONS AND IMAGES

VISUAL OBSERVATIONS	0 DEG	30 DEG	60 DEG	90 DEG	120 DEG	150 DEG	180 DEG	210 DEG	240 DEG	270 DEG	300 DEG	330 DEG
Tread Block 1 nearest to SS	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing
Tread Block 2	Missing	Missing	Missing	Missing	Missing	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Tread Block 3	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing
Tread Block 4	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing
Tread Block 5	Missing	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Tread crown area												
Steel belt 0 - Radial Plies	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Rubber between steel belt 0 and 1	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Steel belt 1	Missing	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Rubber between steel belt 1 and 2	Missing	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Steel belt 2	Missing	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Rubber between steel belt 2 and 3	Missing	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Steel belt 3	Missing	Missing	Missing	Missing	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Rubber between steel belt 3 and 4	Missing	Missing	Missing	Missing	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible
Steel belt 4	Missing	Missing	Missing	Missing	Visible	Visible	Visible	Visible	Visible	Visible	Visible	Visible













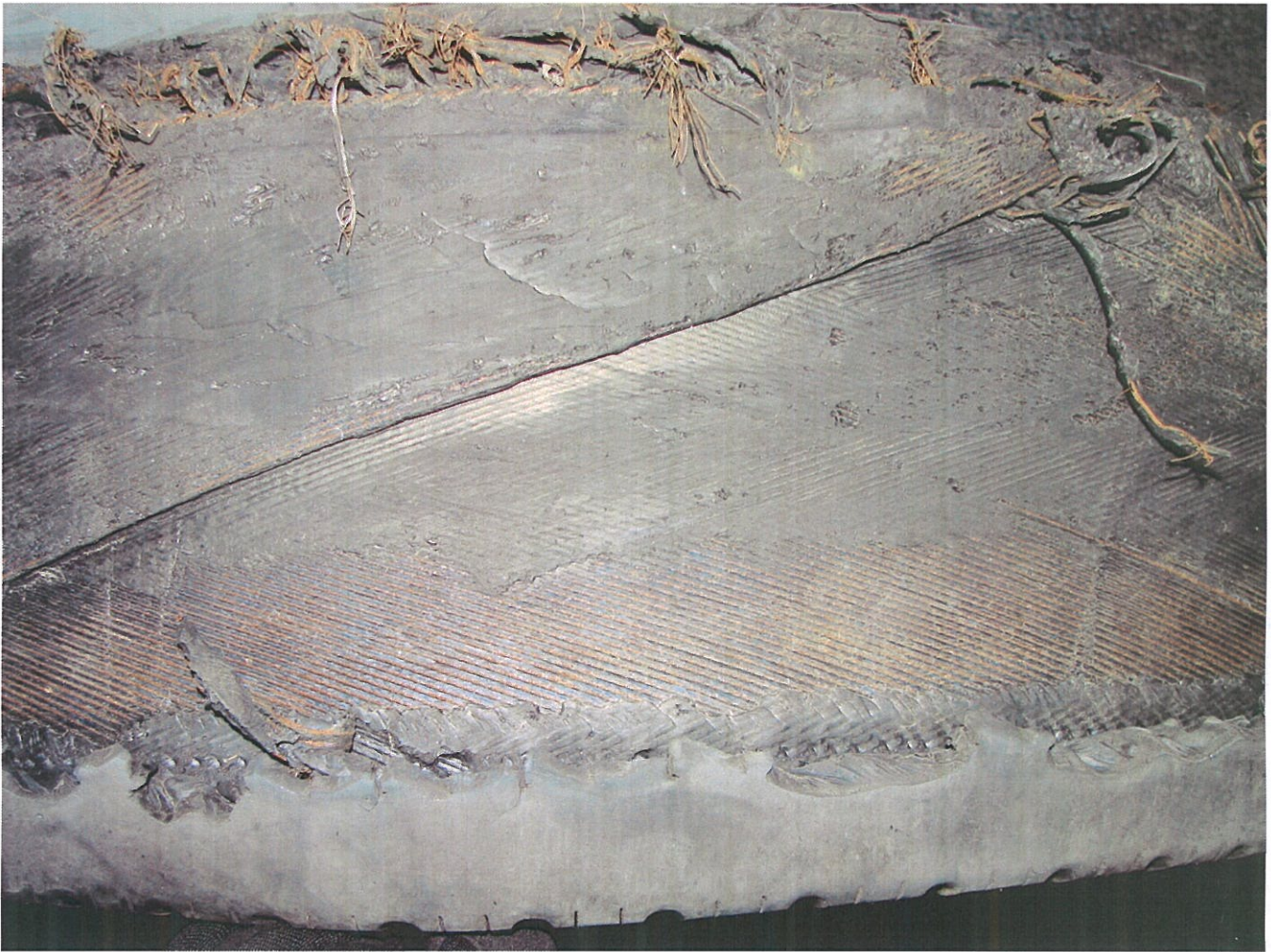


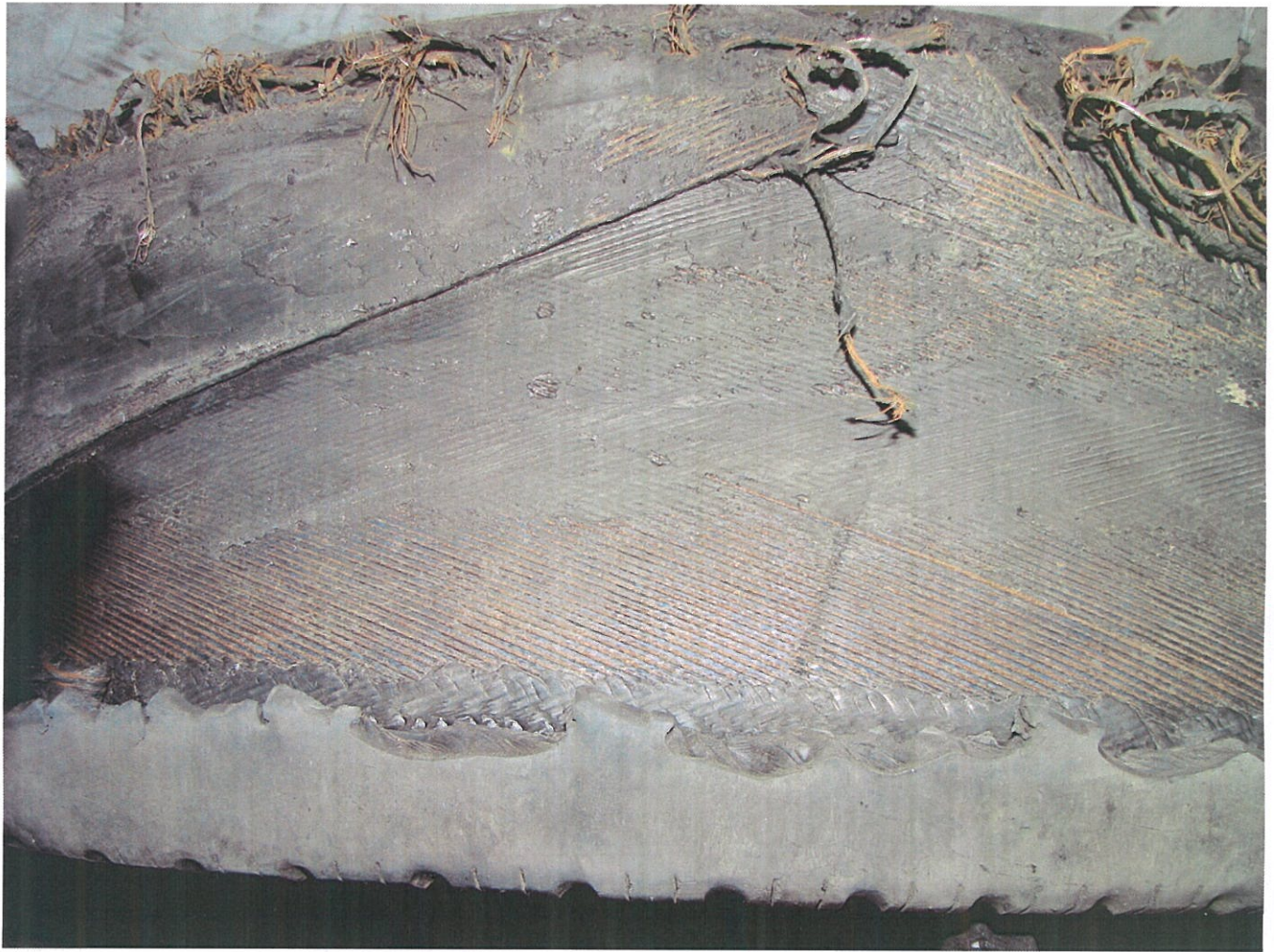
































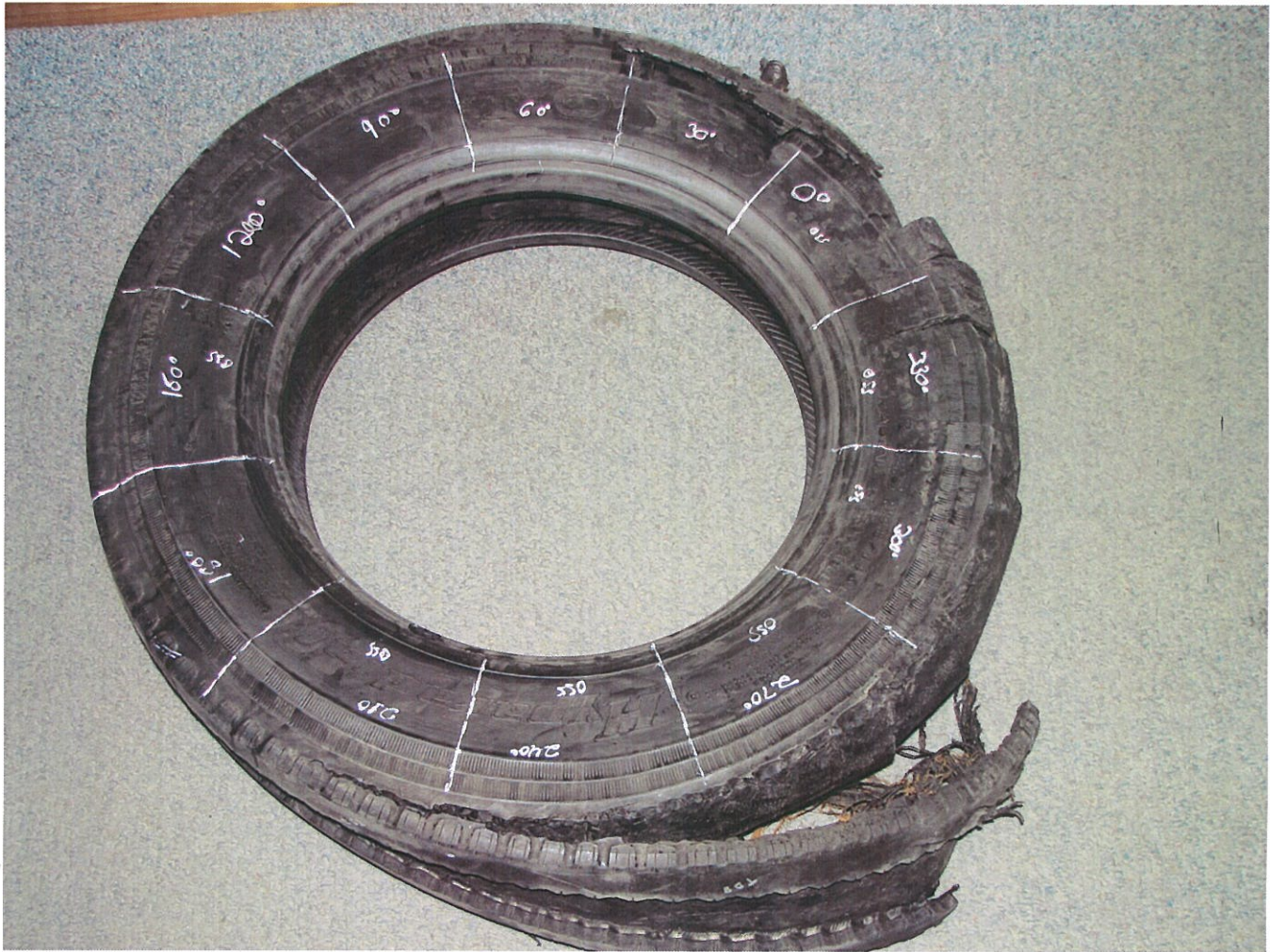


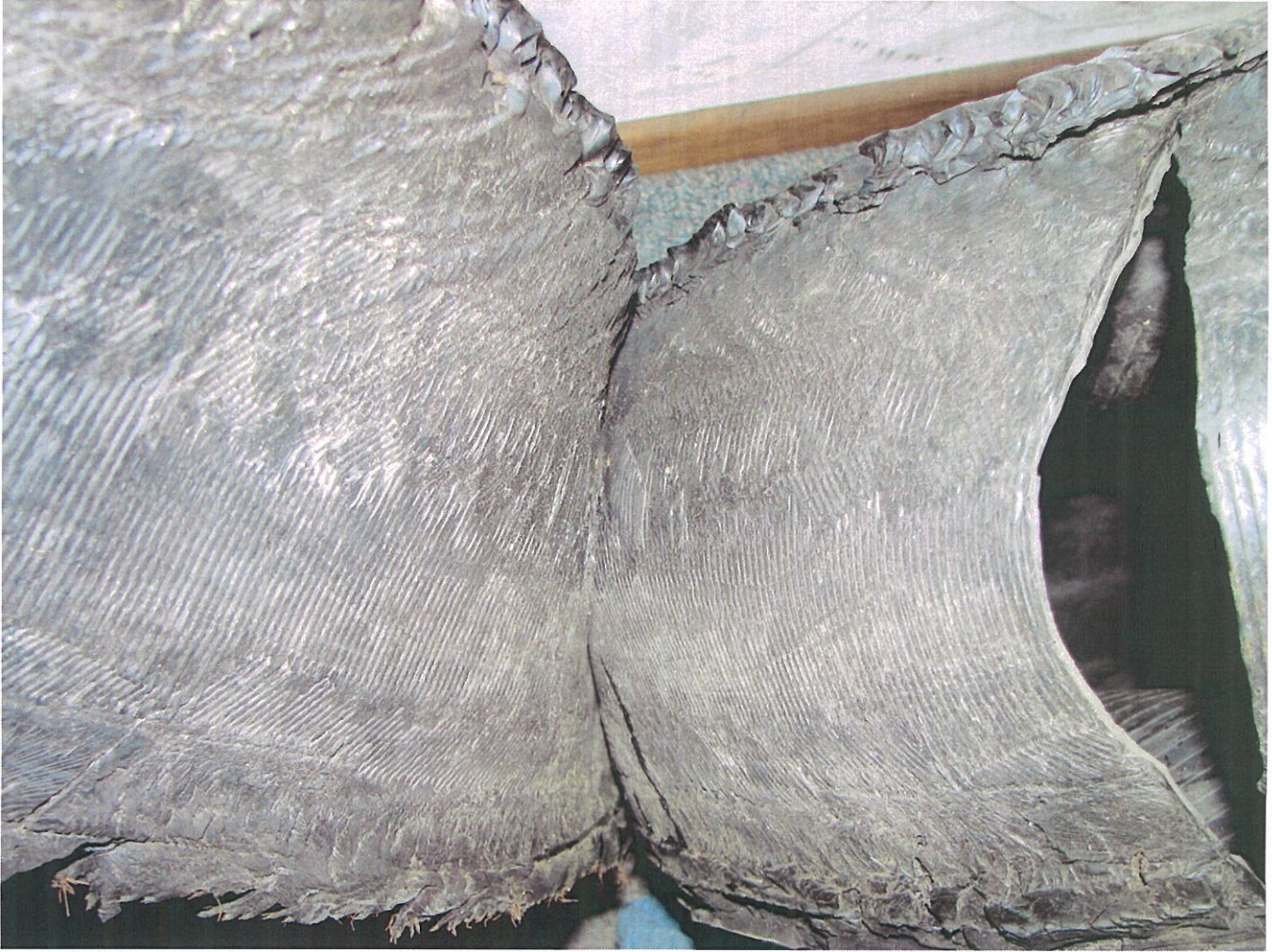




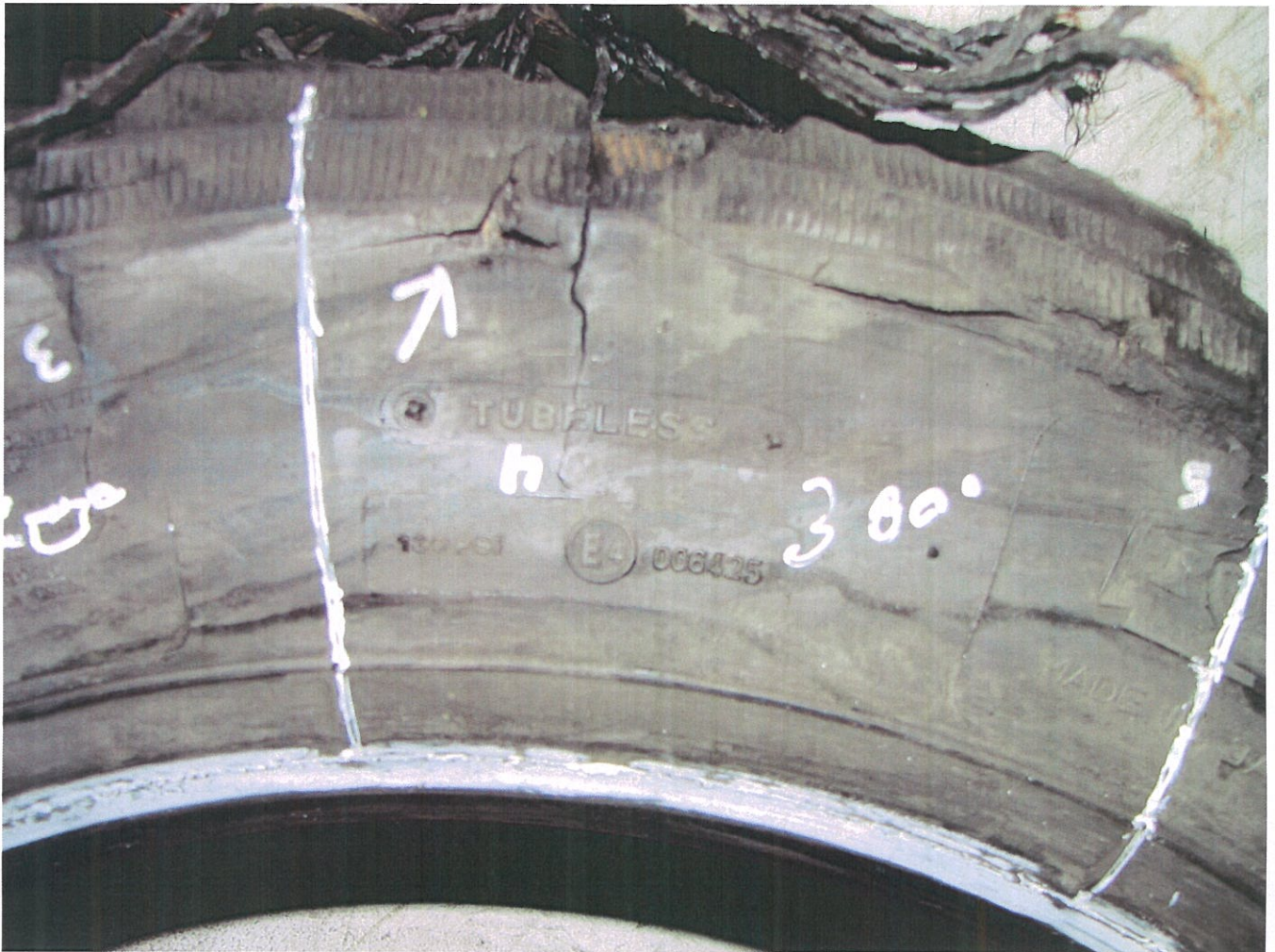






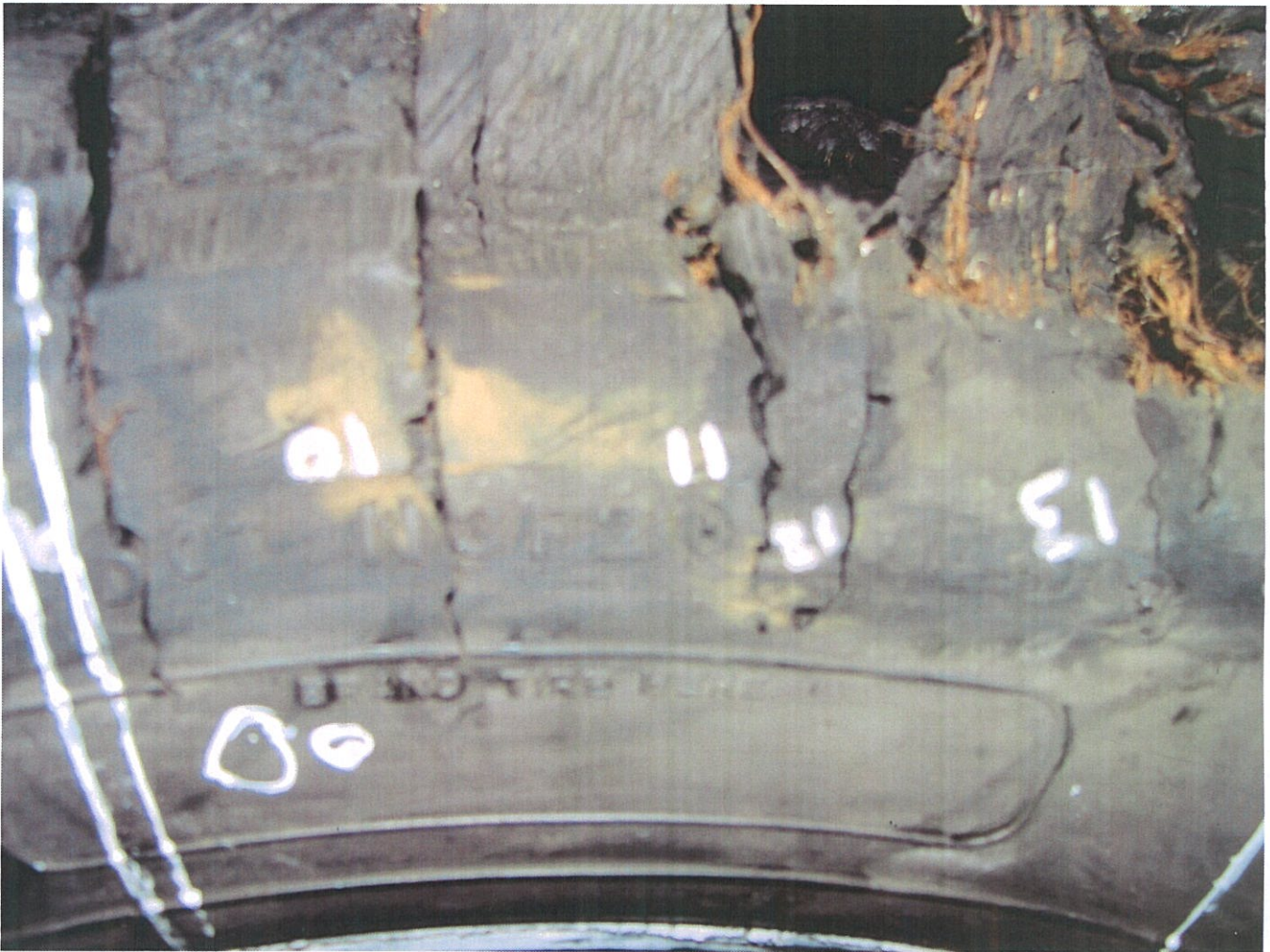






























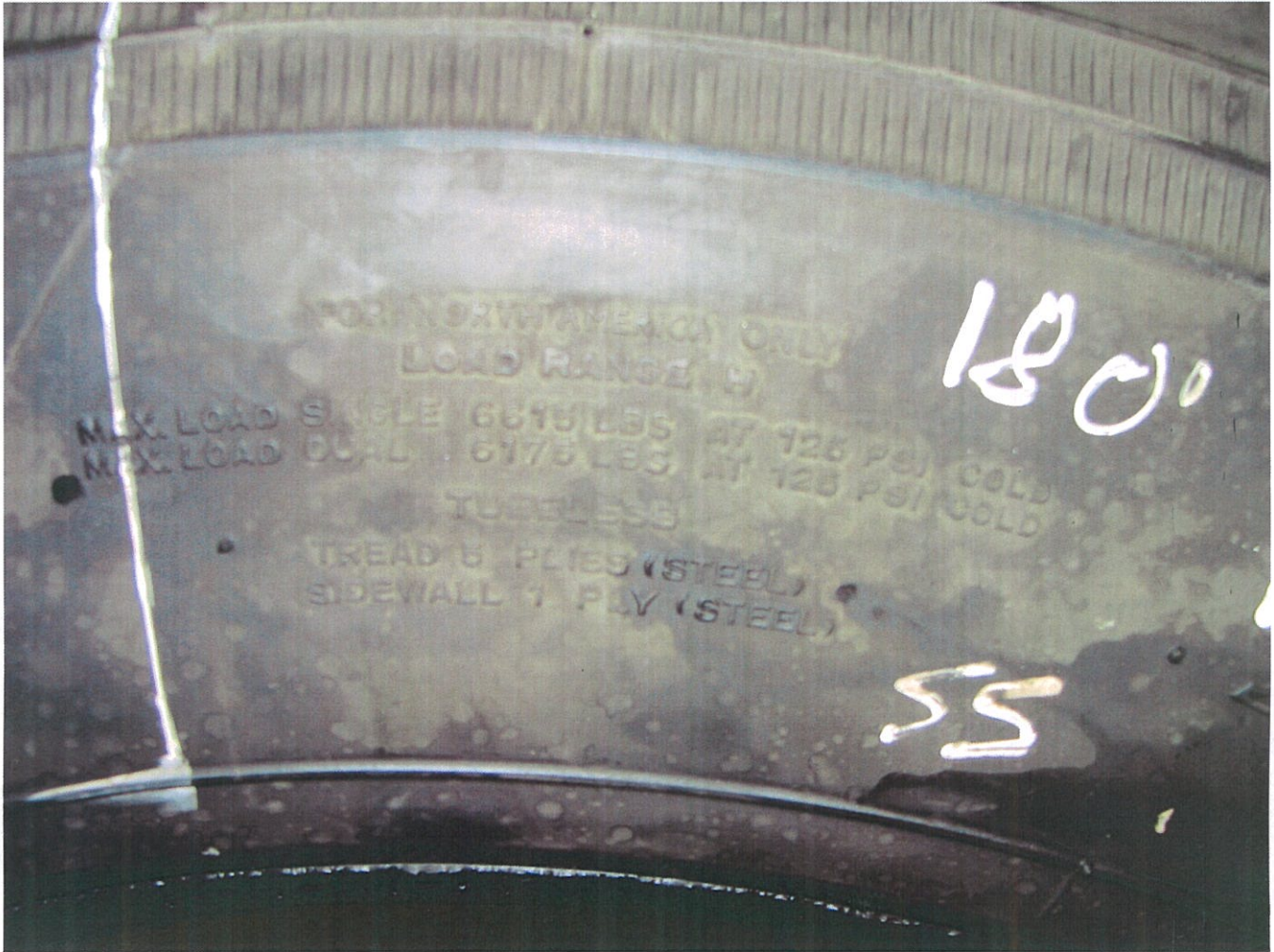






Appendix A  
- INSPECTION-  
Tire K – OBSERVATIONS AND IMAGES

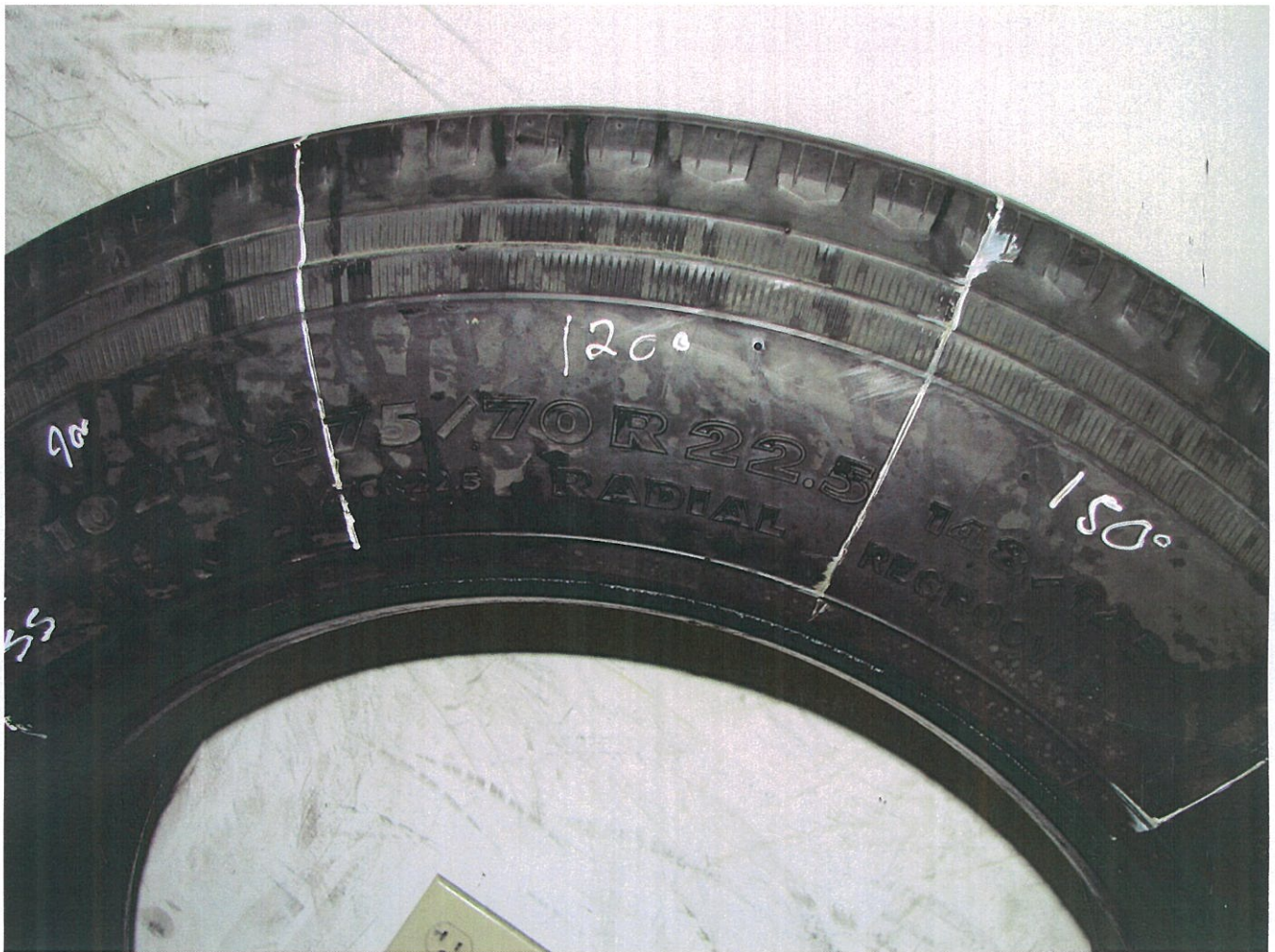




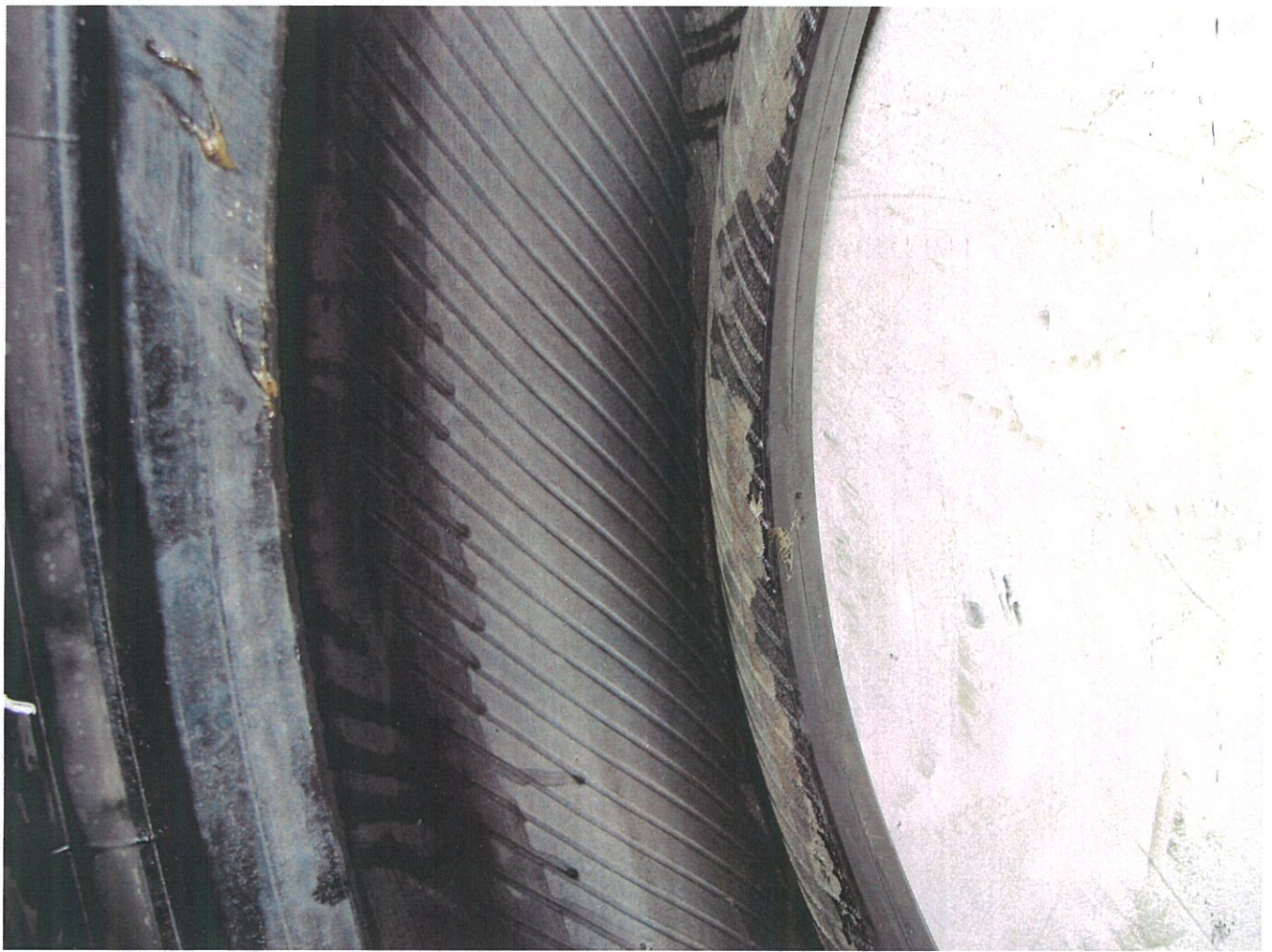


























# Appendix B

## - Tread Depth-

Tire A

Tire B Pre and Post Endurance

Tire C

Tire F

Tire G Pre and Post Endurance

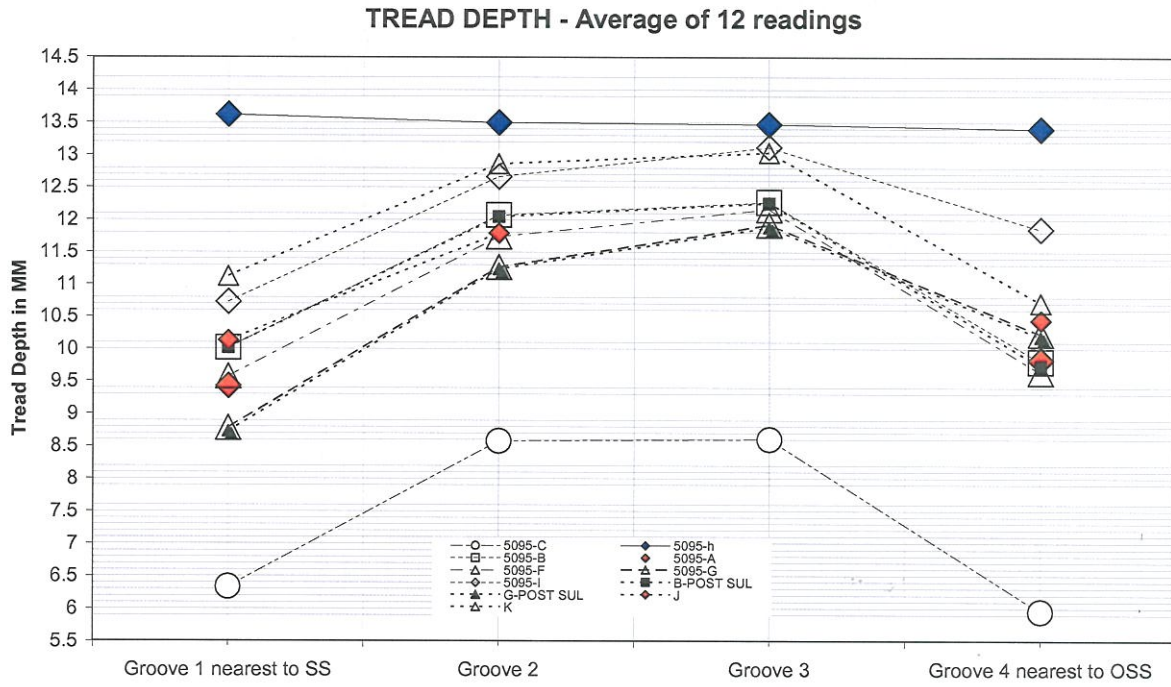
Tire H

Tire I

Tire J

Tire K

# Appendix B



Tire ID	Tread Depth in MM	0 DEG	30 DEG	60 DEG	90 DEG	120 DEG	150 DEG	180 DEG	210 DEG	240 DEG	270 DEG	300 DEG	330 DEG	Average
5095-A	Groove 1 nearest to SS	NA	9.6	9.5	9.4	NA	NA	NA	NA	NA	NA	9.2	NA	9.4
	Groove 2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Groove 3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Groove 4	NA	NA	NA	10.1	NA	NA	NA	10.9	NA	9.1	9.2	NA	9.8
5095-B	Groove 1 nearest to SS	9.9	10.1	10.2	9.8	10.4	10.4	9.1	9.3	10.5	9.8	10.3	10.4	10.0
	Groove 2	12.8	12.1	12.1	12.1	12.2	12.0	12.0	11.1	12.0	12.0	12.1	12.3	12.1
	Groove 3	12.5	12.2	12.4	12.0	12.5	12.3	12.3	12.2	12.1	12.1	12.1	12.5	12.3
	Groove 4	9.7	9.8	10.2	9.9	9.7	9.1	9.8	9.8	10.0	9.7	9.9	10.0	9.8
B-POST RUN	Groove 1 nearest to SS	10.5	10.0	10.0	9.9	10.0	10.0	9.9	10.0	10.1	10.0	10.0	9.9	10.0
	Groove 2	12.5	12.1	12.5	12.1	12.2	12.2	12.0	12.1	11.9	10.3	12.3	12.4	12.0
	Groove 3	12.9	12.5	12.5	12.4	12.5	12.6	12.5	12.2	11.9	10.6	12.1	12.4	12.3
	Groove 4	10.1	10.4	10.1	9.6	9.5	9.8	9.6	9.5	9.6	9.7	9.8	9.2	9.7
5095-C	Groove 1 nearest to SS	6.7	6.6	6.2	6.8	6.7	6.5	5.4	5.9	5.9	6.1	6.3	6.9	6.3
	Groove 2	8.7	8.8	8.7	8.8	8.8	8.5	8.7	8.0	8.0	8.6	8.7	8.6	8.6
	Groove 3	8.9	8.8	8.9	8.7	8.3	8.4	8.3	8.0	8.2	9.0	9.0	8.7	8.6
	Groove 4 nearest to OSS	6.2	6.2	6.0	6.1	5.4	5.6	5.4	5.9	5.6	6.0	6.4	6.6	6.0
5095-F	Groove 1 nearest to SS	8.9	9.8	9.8	9.5	9.8	9.1	9.6	9.8	9.8	9.8	9.3	9.8	9.7
	Groove 2	11.7	12.1	11.8	11.5	11.6	11.6	11.8	11.6	11.8	11.3	12.2	11.8	11.7
	Groove 3	12.2	12.2	12.2	12.0	12.0	12.0	12.0	12.2	12.2	12.8	11.9	12.2	12.2
	Groove 4 nearest to OSS	9.8	9.8	9.9	9.8	9.5	9.1	9.6	9.8	9.7	9.4	9.7	9.5	9.6
5095-G	Groove 1 nearest to SS	8.7	8.6	8.8	9.6	8.9	8.5	9.3	9.2	8.6	8.7	8.2	8.3	8.8
	Groove 2	11.1	11.1	11.3	11.7	11.1	11.5	11.8	11.5	11.1	11.0	11.0	11.0	11.3
	Groove 3	12.0	12.1	11.7	12.3	12.4	12.3	12.2	11.7	11.7	11.6	11.5	11.5	11.9
	Groove 4 nearest to OSS	10.1	10.6	10.7	11.0	10.7	10.7	10.4	10.0	9.8	9.5	9.6	9.6	10.2
G-POST RUN	Groove 1 nearest to SS	8.2	8.5	8.6	8.8	8.5	8.6	9.0	9.0	8.9	9.3	8.5	9.0	8.7
	Groove 2	11.1	11.1	11.2	11.6	11.2	11.6	11.2	11.2	11.1	11.2	11.2	11.3	11.2
	Groove 3	11.4	11.6	12.3	12.4	12.6	12.3	12.0	11.6	11.4	11.4	12.0	11.9	11.9
	Groove 4 nearest to OSS	10.5	10.6	9.9	10.0	10.2	10.2	10.3	10.1	10.0	9.9	10.1	10.6	10.2
5095-H	Groove 1 nearest to SS	13.7	13.2	13.7	13.8	13.7	13.6	13.7	13.7	13.4	13.8	13.5	13.6	13.6
	Groove 2	13.5	13.4	13.7	13.7	13.6	13.4	13.6	13.6	13.4	13.5	13.1	13.4	13.5
	Groove 3	13.5	13.4	13.3	13.6	13.4	13.6	13.4	13.5	13.4	13.4	13.2	13.9	13.5
	Groove 4	13.2	13.8	13.2	13.6	13.3	13.3	13.1	13.4	13.4	13.5	13.2	13.7	13.4
5095-I	Groove 1 nearest to SS	10.7	10.7	10.8	10.7	10.8	10.8	10.5	10.9	10.7	10.8	10.4	10.9	10.7
	Groove 2	12.6	12.6	12.7	12.7	12.8	12.6	12.8	12.3	12.9	12.2	13.0	12.7	12.7
	Groove 3	13.1	13.1	13.1	13.0	13.2	13.3	13.2	13.2	12.9	13.1	13.1	13.1	13.1
	Groove 4 nearest to OSS	12.2	12.1	12.2	11.6	11.9	12.0	11.6	11.3	11.7	12.0	11.7	11.9	11.9
J	Groove 1 nearest to SS	NA	NA	NA	NA	NA	9.6	NA	NA	10.7	10.2	NA	NA	10.1
	Groove 2	NA	NA	NA	NA	NA	12.3	12.1	11.0	11.6	12.2	11.6	NA	11.8
	Groove 3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Groove 4	NA	10.9	0.0	0.0	NA	9.8	10.1	10.6	10.6	10.3	10.8	NA	8.1
K	Groove 1 nearest to SS	10.7	11.3	11.1	10.9	11.1	11.1	11.2	11.1	11.2	11.3	11.1	11.3	11.1
	Groove 2	12.6	13.0	12.7	12.7	12.9	13.0	12.9	12.9	12.8	13.0	12.9	12.9	12.9
	Groove 3	13.0	13.1	13.2	13.1	13.0	13.1	13.1	12.9	12.8	12.9	13.1	13.0	13.0
	Groove 4 nearest to OSS	10.7	11.0	10.8	10.6	10.4	10.5	10.8	10.6	10.8	10.9	10.7	10.8	10.7

# Appendix C

## - Tread Hardness-

Tire A

Tire B Pre and Post Endurance

Tire C

Tire F

Tire G Pre and Post Endurance

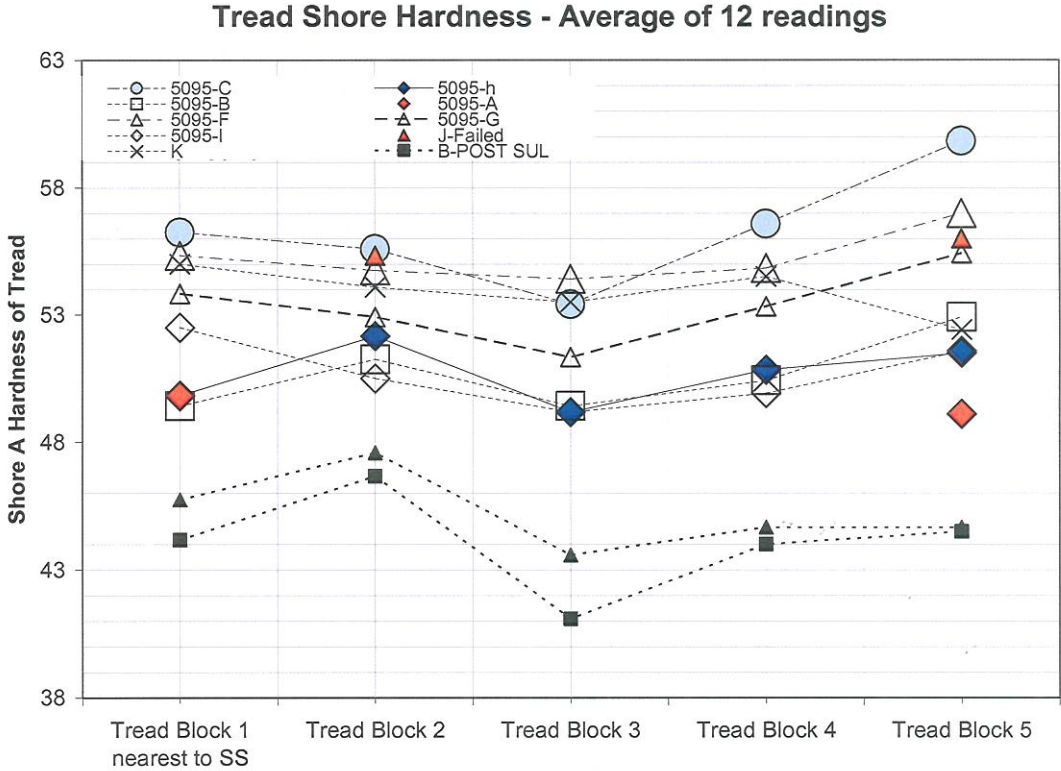
Tire H

Tire I

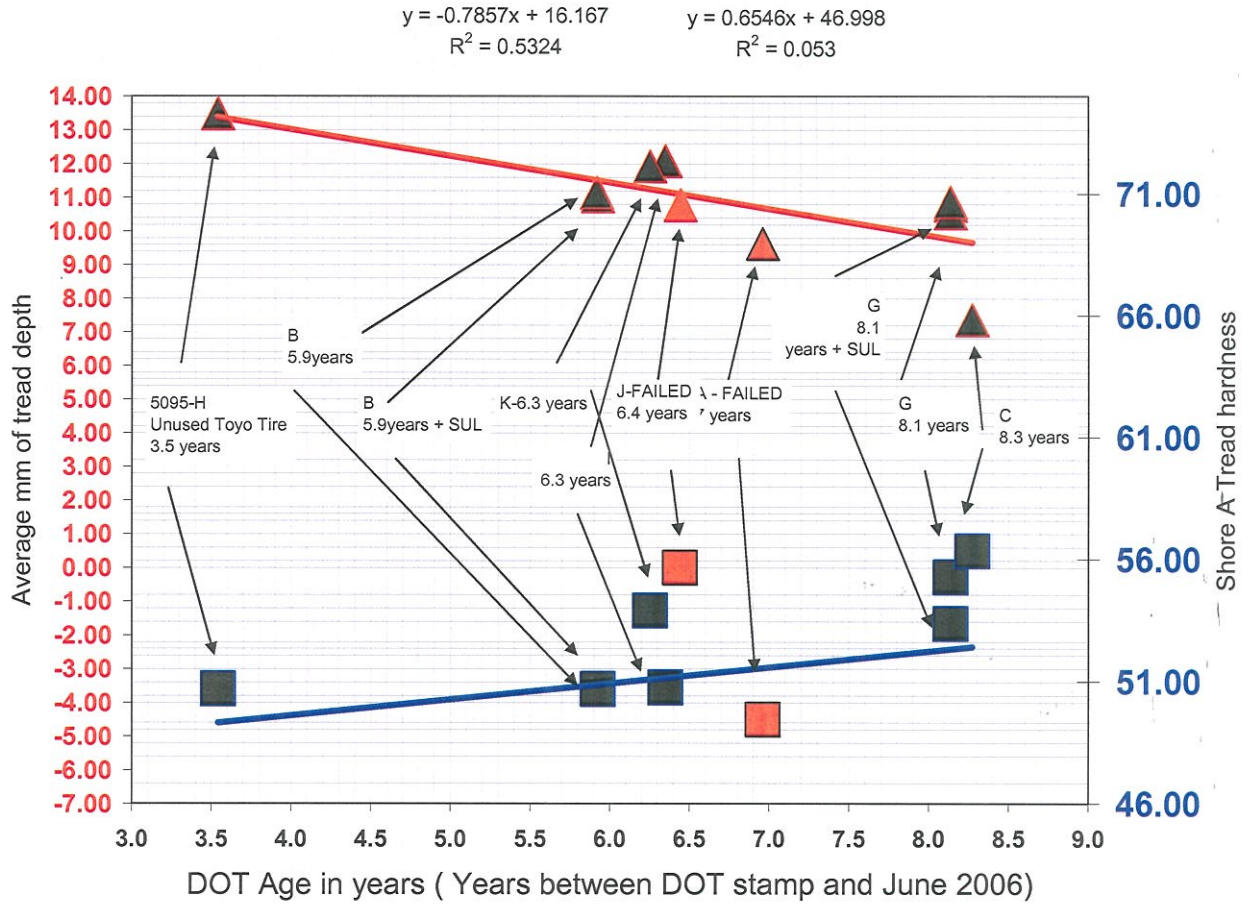
Tire J

Tire K

# Appendix C



Tire ID	SHORE A Tread Hardness	0 DEG	30 DEG	60 DEG	90 DEG	120 DEG	150 DEG	180 DEG	210 DEG	240 DEG	270 DEG	300 DEG	330 DEG	Average
5095-A	Tread Block 1 nearest to SS	54	53	49	46	47	NA	NA	NA	NA	NA	NA	NA	50
	Tread Block 2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Tread Block 3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Tread Block 4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Tread Block 5	53	47	48	45	49	NA	58	49	48	48	NA	46	49
5095-B	Tread Block 1 nearest to SS	51	47	46	48	48	53	50	51	52	46	54	47	49
	Tread Block 2	58	44	52	51	50	52	51	52	53	48	53	51	51
	Tread Block 3	58	46	50	46	47	51	44	46	51	52	51	51	49
	Tread Block 4	51	54	51	51	50	56	46	46	46	52	50	52	50
	Tread Block 5	59	50	52	52	50	52	51	52	49	53	58	57	53
B-POST RUN	Tread Block 1 nearest to SS	45	43	47	49	38	43	46	44	44	42	46	43	44
	Tread Block 2	44	43	44	50	52	44	47	50	50	46	43	47	47
	Tread Block 3	44	40	44	42	37	41	38	42	42	50	38	35	41
	Tread Block 4	44	36	48	43	42	45	47	43	43	46	45	46	44
	Tread Block 5	45	42	44	50	46	45	41	43	43	47	45	43	45
5095-C	Tread Block 1 nearest to SS	55	55	61	53	58	55	59	56	59	56	56	52	56
	Tread Block 2	55	57	53	54	62	57	55	59	54	54	53	54	58
	Tread Block 3	56	56	56	55	50	56	53	49	54	52	51	53	53
	Tread Block 4	57	59	55	58	62	56	61	55	56	52	54	54	57
	Tread Block 5	60	59	58	62	63	58	62	62	61	56	54	63	60
5095-F	Tread Block 1 nearest to SS	52	56	56	52	50	57	58	56	58	58	56	55	55
	Tread Block 2	54	53	55	53	57	58	52	58	52	56	57	52	55
	Tread Block 3	54	59	57	53	56	52	53	54	52	53	52	58	54
	Tread Block 4	54	52	60	52	58	53	55	55	55	55	53	56	55
	Tread Block 5	58	55	55	61	60	54	58	53	56	58	59	57	57
5095-G	Tread Block 1 nearest to SS	51	55	56	50	57	53	57	58	50	53	52	54	54
	Tread Block 2	52	53	54	52	53	55	54	54	52	55	48	53	53
	Tread Block 3	54	52	50	53	54	54	52	50	48	51	45	53	51
	Tread Block 4	58	52	51	54	53	51	58	52	57	51	52	51	53
	Tread Block 5	60	56	55	57	54	53	59	56	52	56	49	58	55
G-POST RUN	Tread Block 1 nearest to SS	47	47	47	49	38	43	46	46	44	46	51	45	46
	Tread Block 2	48	46	44	50	52	44	47	47	50	47	48	48	48
	Tread Block 3	46	47	44	42	37	41	38	46	42	45	46	47	44
	Tread Block 4	44	44	48	43	42	45	47	44	43	41	47	48	45
	Tread Block 5	46	45	44	50	46	45	41	43	43	42	46	45	45
5095-H	Tread Block 1 nearest to SS	48	44	51	51	52	46	47	50	54	50	54	51	50
	Tread Block 2	52	51	53	52	52	53	50	52	52	53	54	52	52
	Tread Block 3	49	46	51	52	48	46	52	48	48	50	49	51	49
	Tread Block 4	48	52	54	55	47	44	52	51	52	46	56	53	51
	Tread Block 5	49	53	50	48	51	50	47	53	53	54	57	53	52
5095-I	Tread Block 1 nearest to SS	55	48	48	54	49	52	50	56	54	52	58	54	53
	Tread Block 2	49	51	49	54	52	47	52	56	50	50	49	47	51
	Tread Block 3	50	48	48	48	49	46	48	50	50	56	49	48	49
	Tread Block 4	46	47	46	55	50	49	54	49	48	51	52	52	50
	Tread Block 5	53	49	45	54	53	52	55	52	52	50	52	52	52
J	Tread Block 1 nearest to SS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Tread Block 2	NA	NA	NA	NA	NA	57	54	57	54	57	53	NA	55
	Tread Block 3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Tread Block 4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Tread Block 5	NA	49	53	60	59	59	58	57	57	56	52	NA	56
K	Tread Block 1 nearest to SS	57	59	54	54	53	60	57	54	54	53	53	52	55
	Tread Block 2	58	57	56	54	53	57	54	53	51	54	53	49	54
	Tread Block 3	56	60	50	53	53	51	58	51	57	57	50	46	54
	Tread Block 4	56	58	54	54	53	57	53	54	57	58	52	48	55
	Tread Block 5	51	52	50	53	54	55	57	53	53	53	51	47	52
Z	Tread Block 1 nearest to SS	47	46	49	43	49	50	48	48	52	44	48	46	48
	Tread Block 2	45	49	51	48	48	49	50	46	47	47	51	48	48
	Tread Block 3	46	47	48	47	51	51	47	49	46	46	50	48	48
	Tread Block 4	45	48	50	48	49	46	47	49	47	46	48	48	48
	Tread Block 5	44	46	48	47	47	48	47	46	49	45	46	46	47



## Appendix D

### -Tire XRAY images-

Tire A - X-ray images

Tire B Pre and Post Endurance- X-ray images

Tire C - X-ray images

Tire G Pre and Post Endurance - X-ray images

Tire F - X-ray images

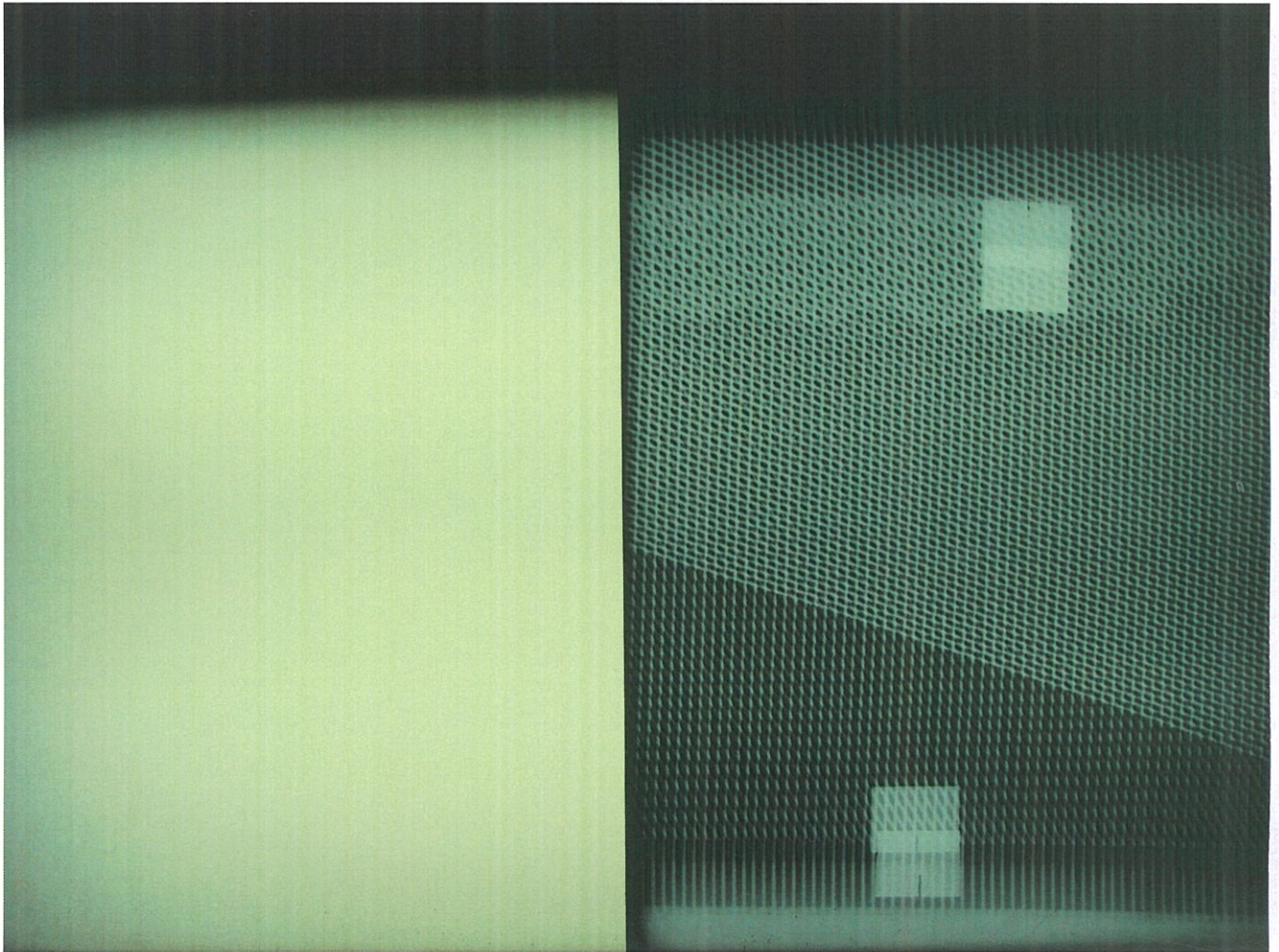
Tire H - X-ray images

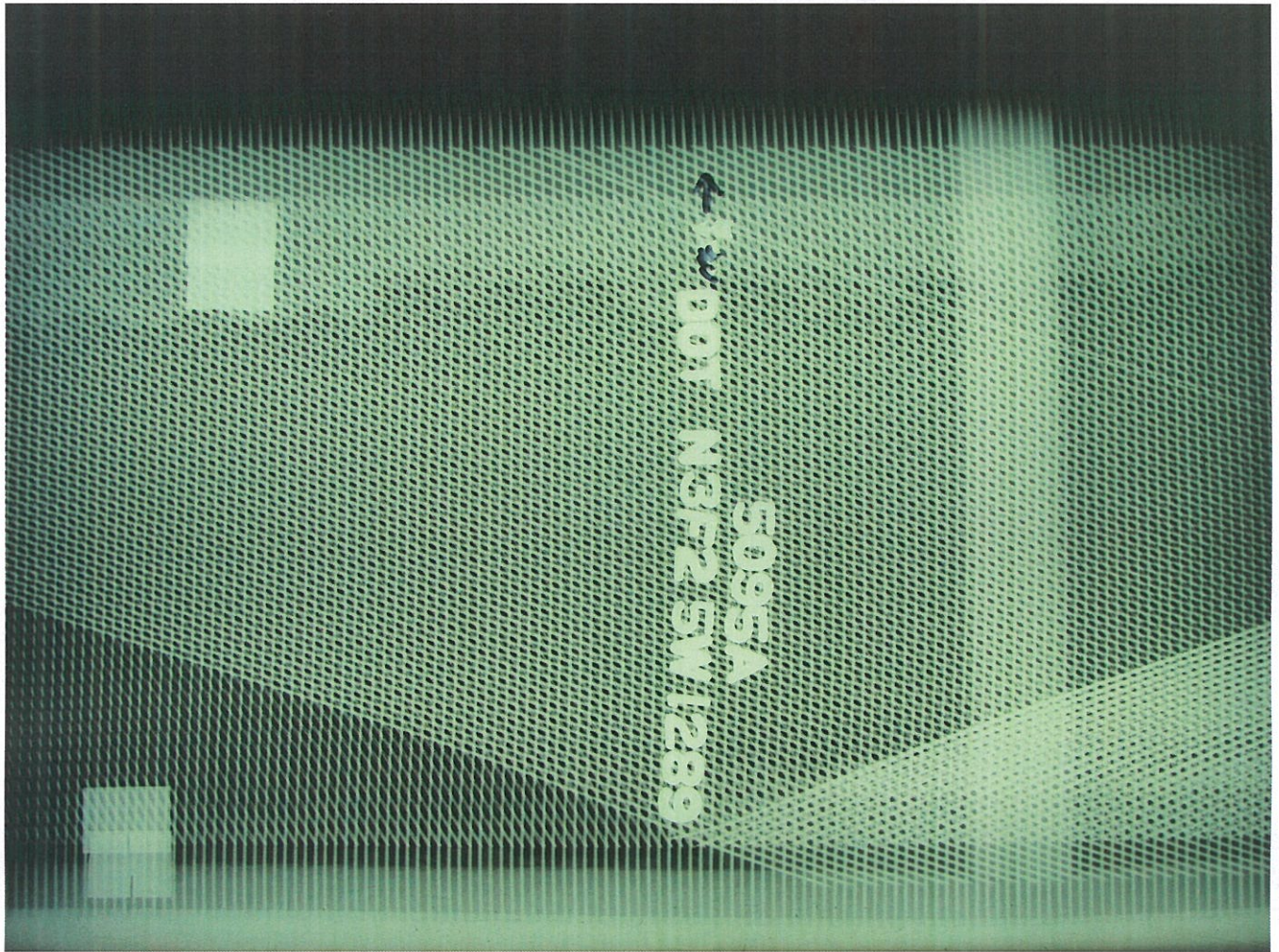
Tire I - X-ray images

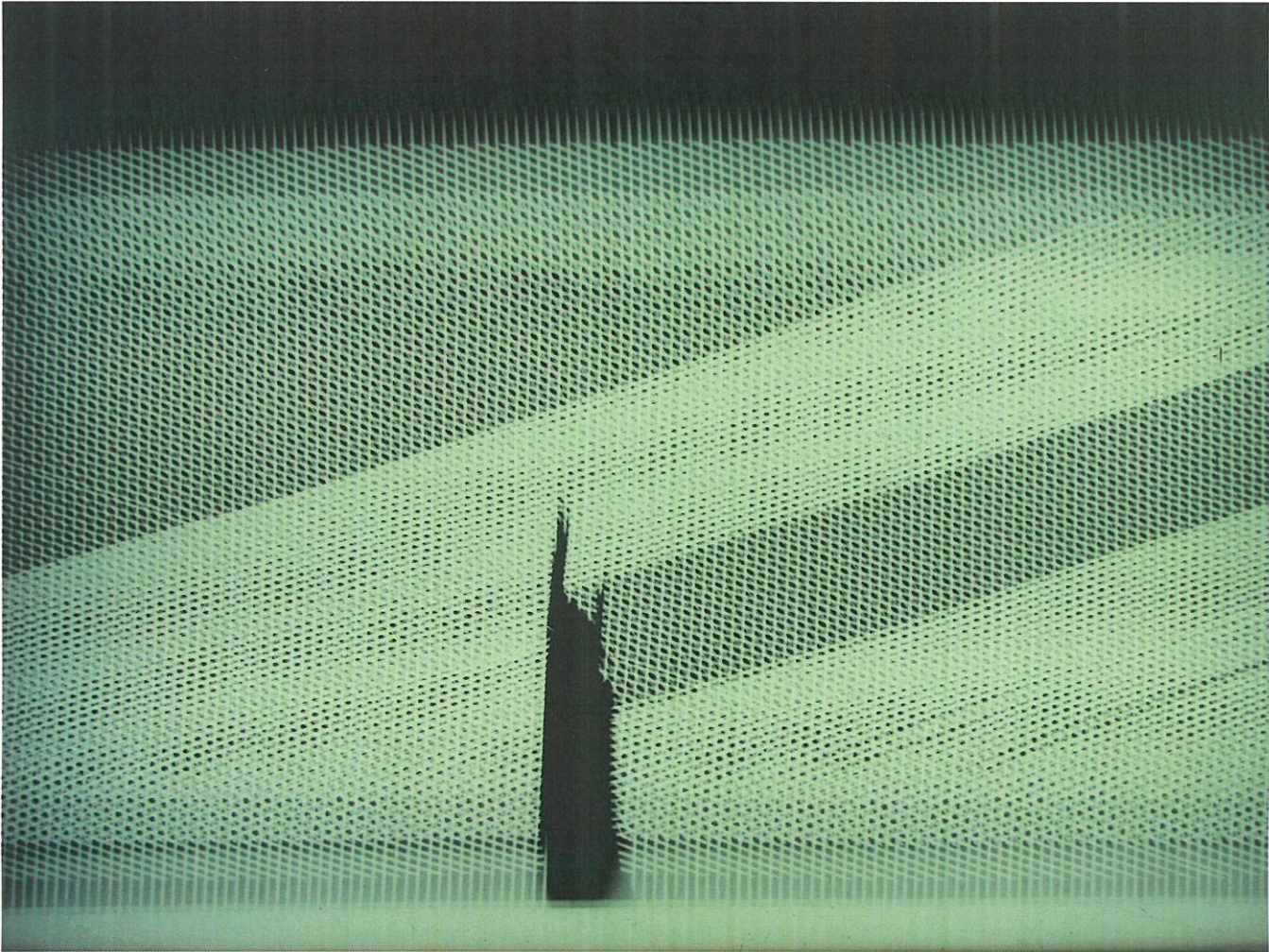
Tire J - X-ray images

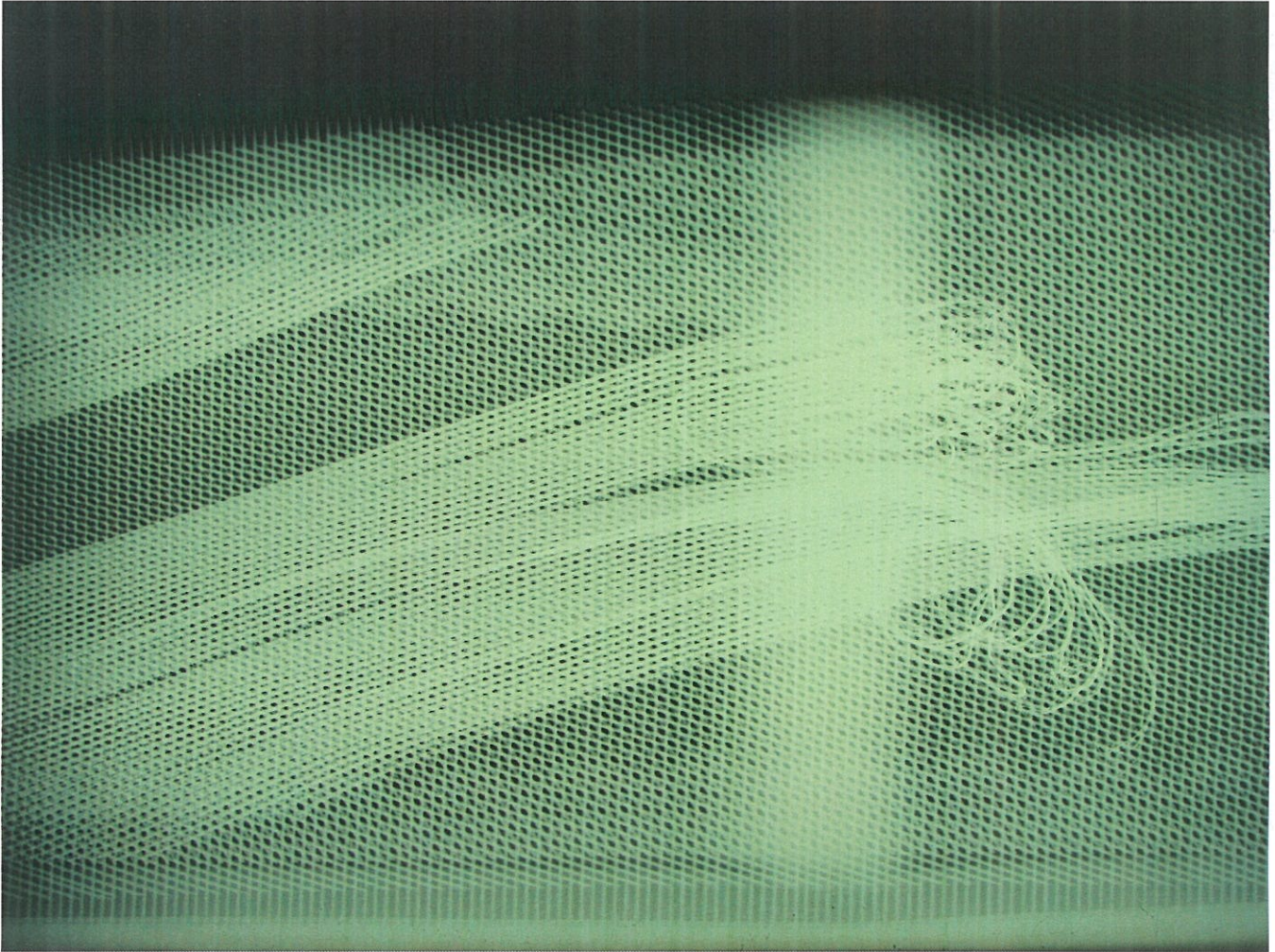
Tire K - X-ray images

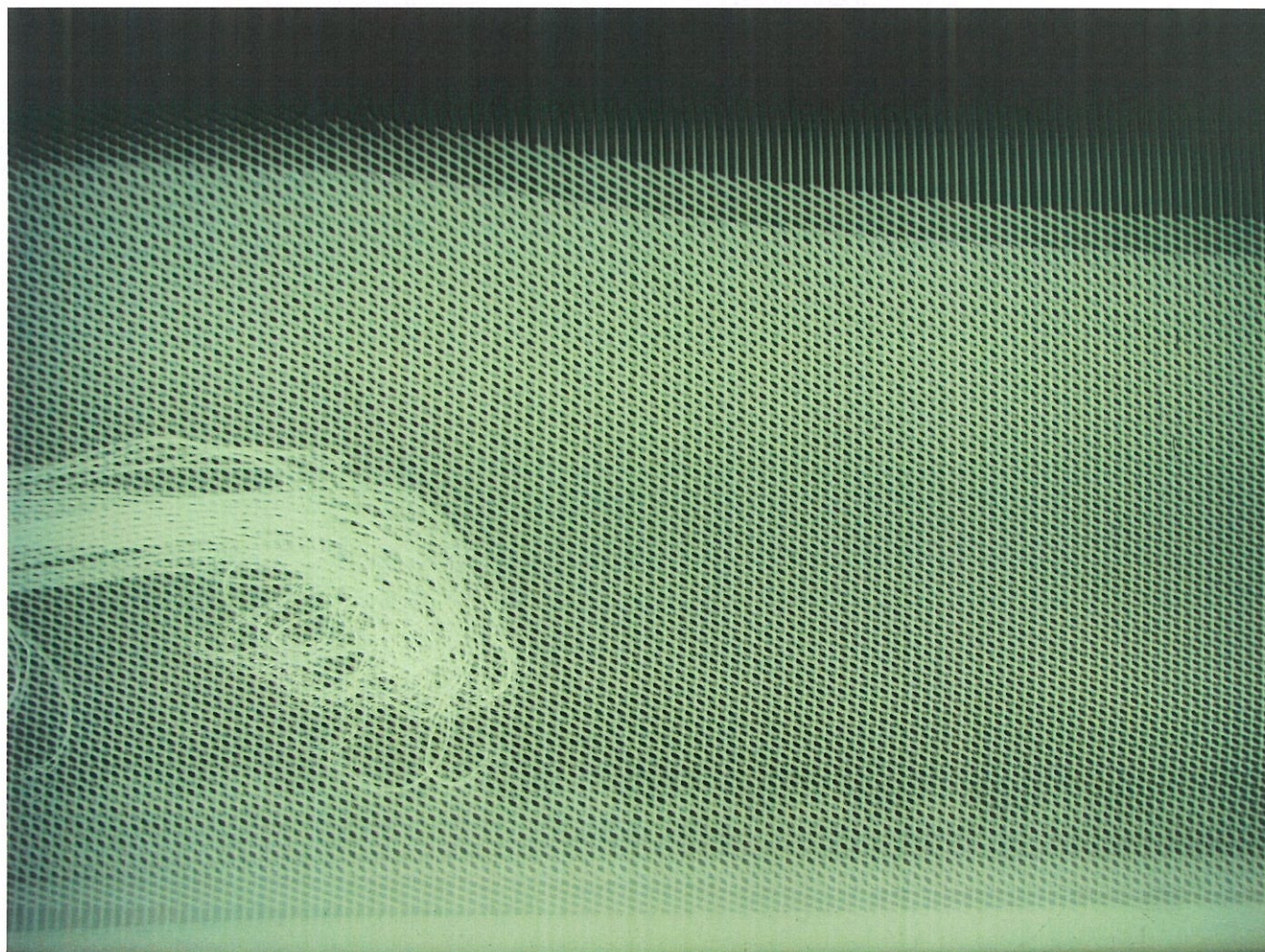
# Tire A - X-ray Images

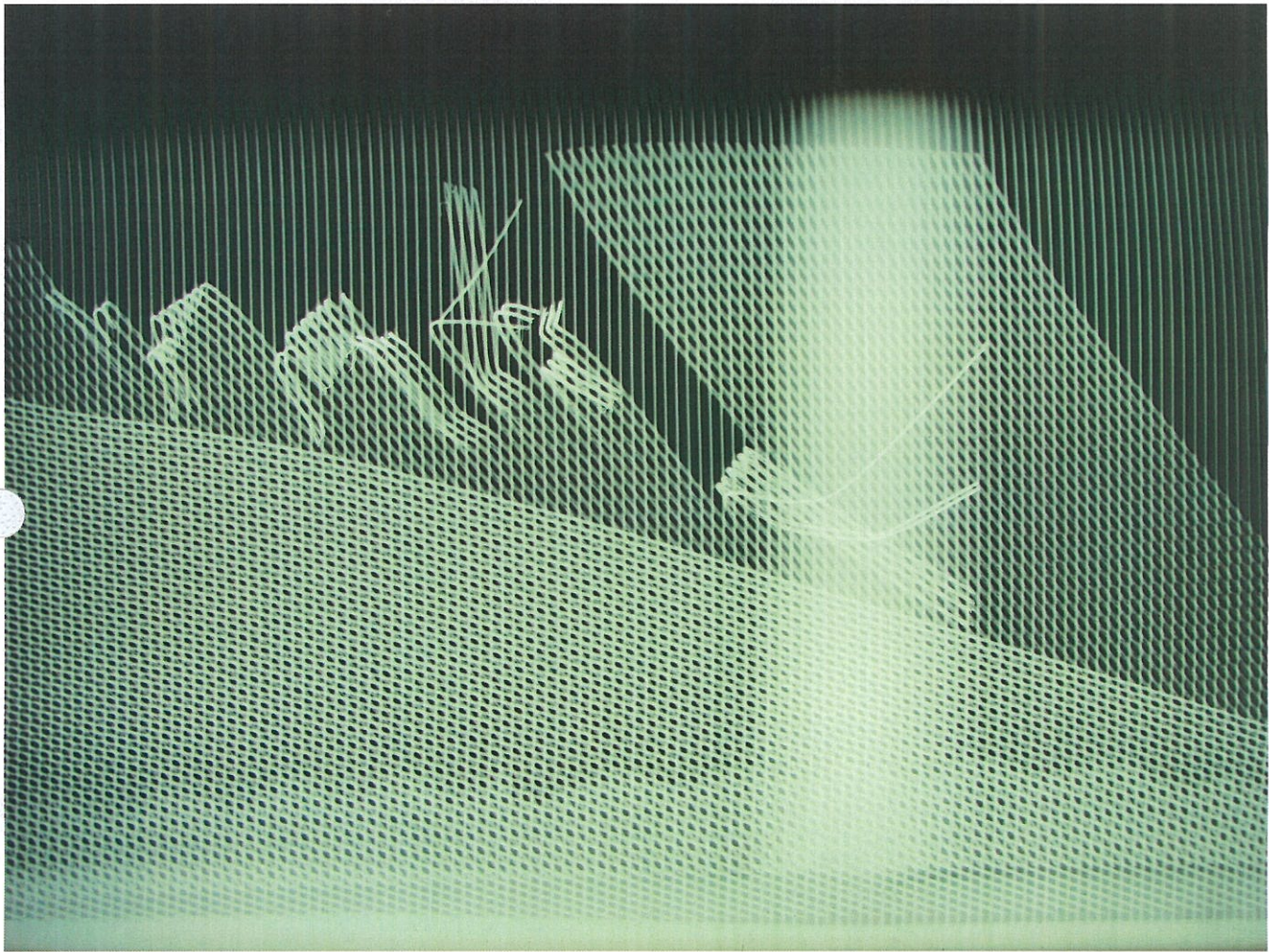


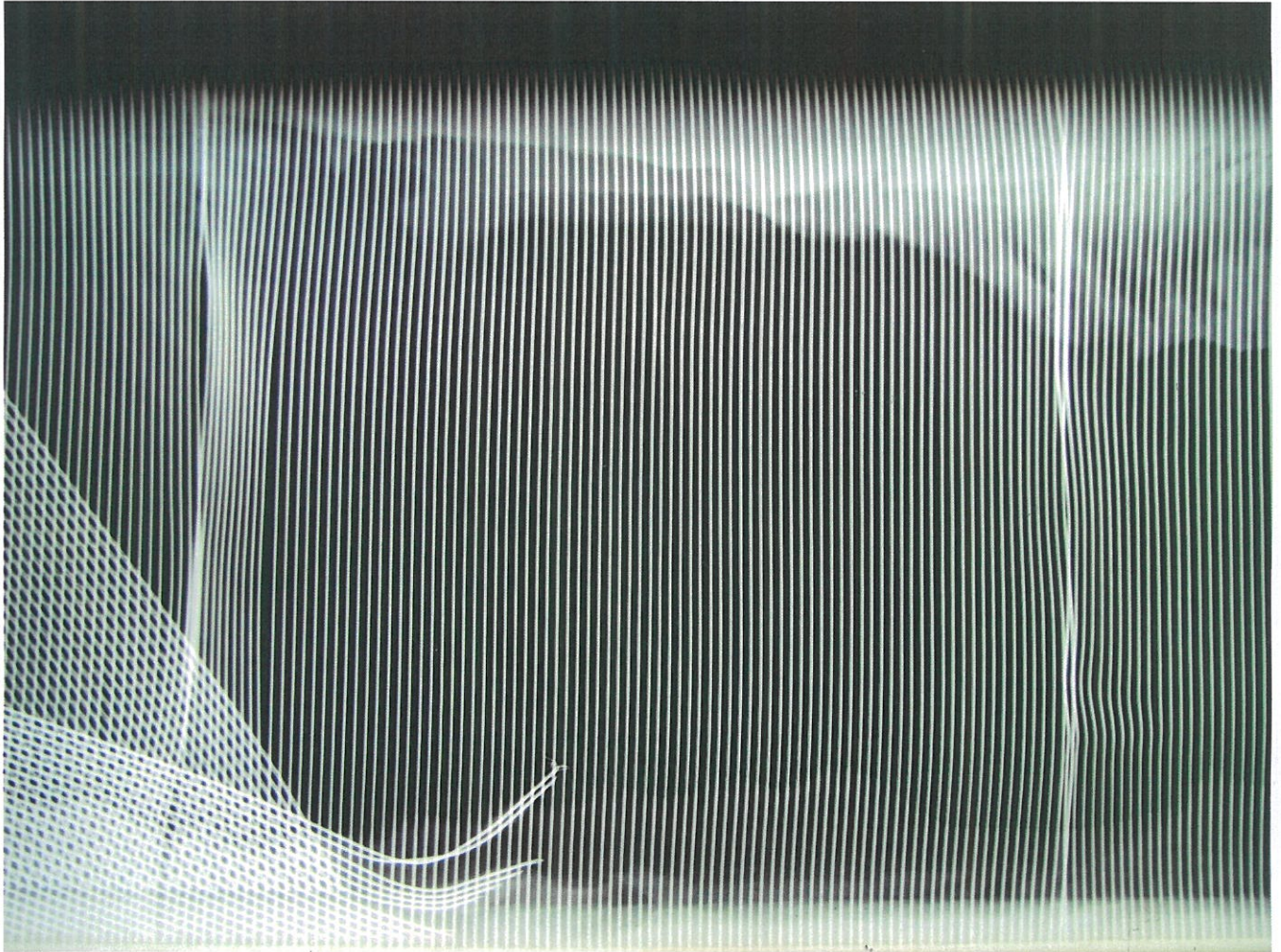


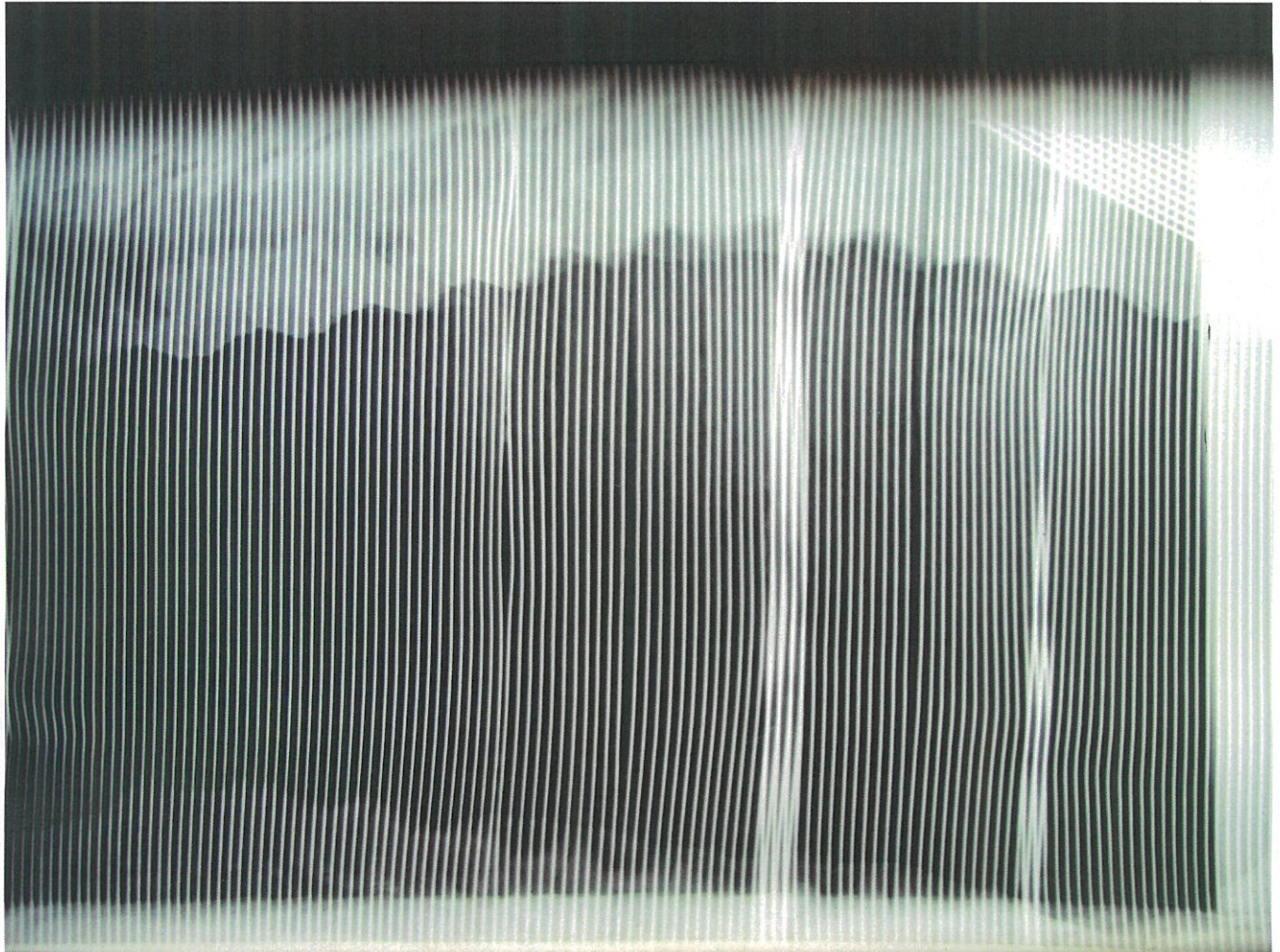


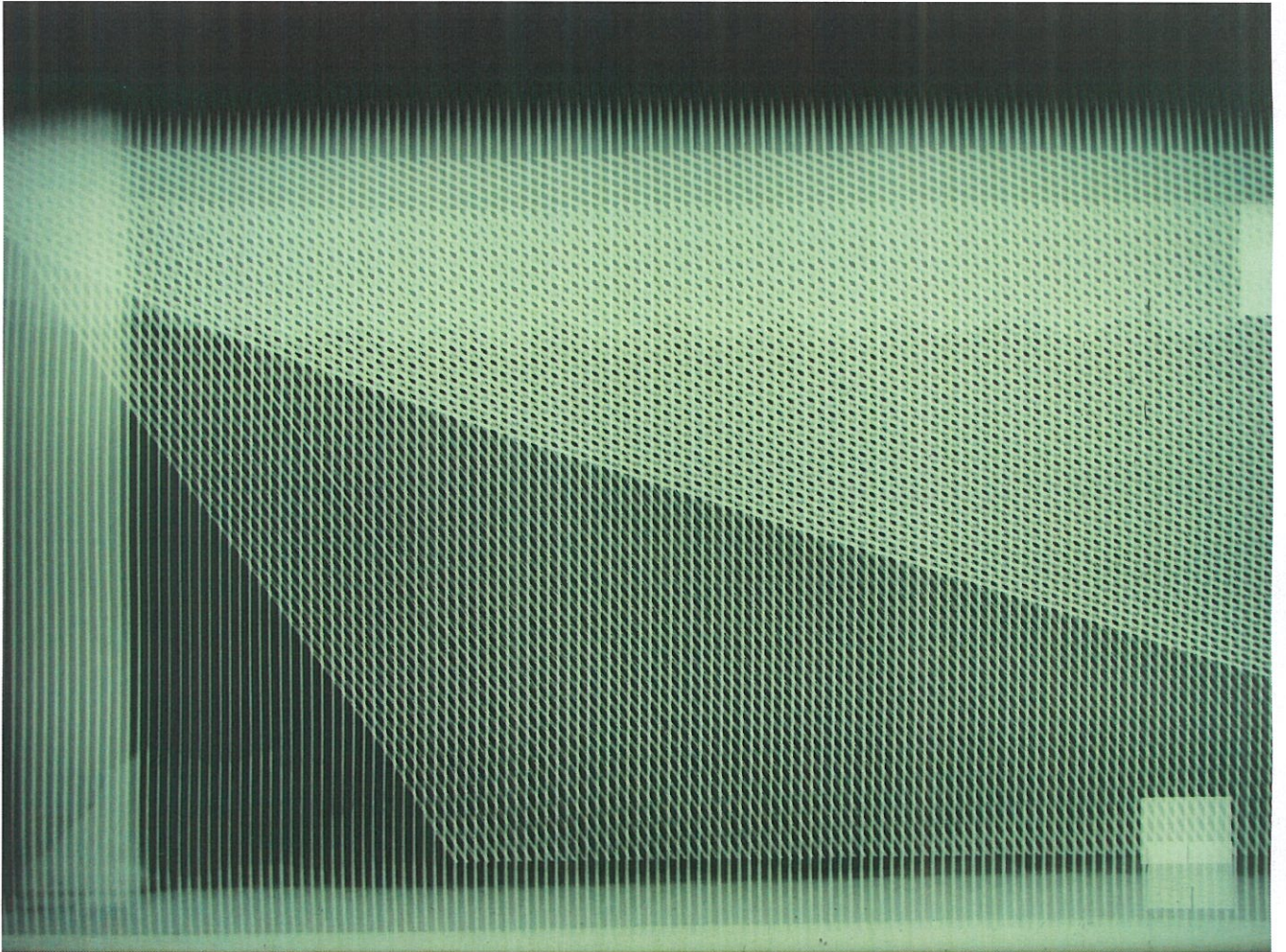


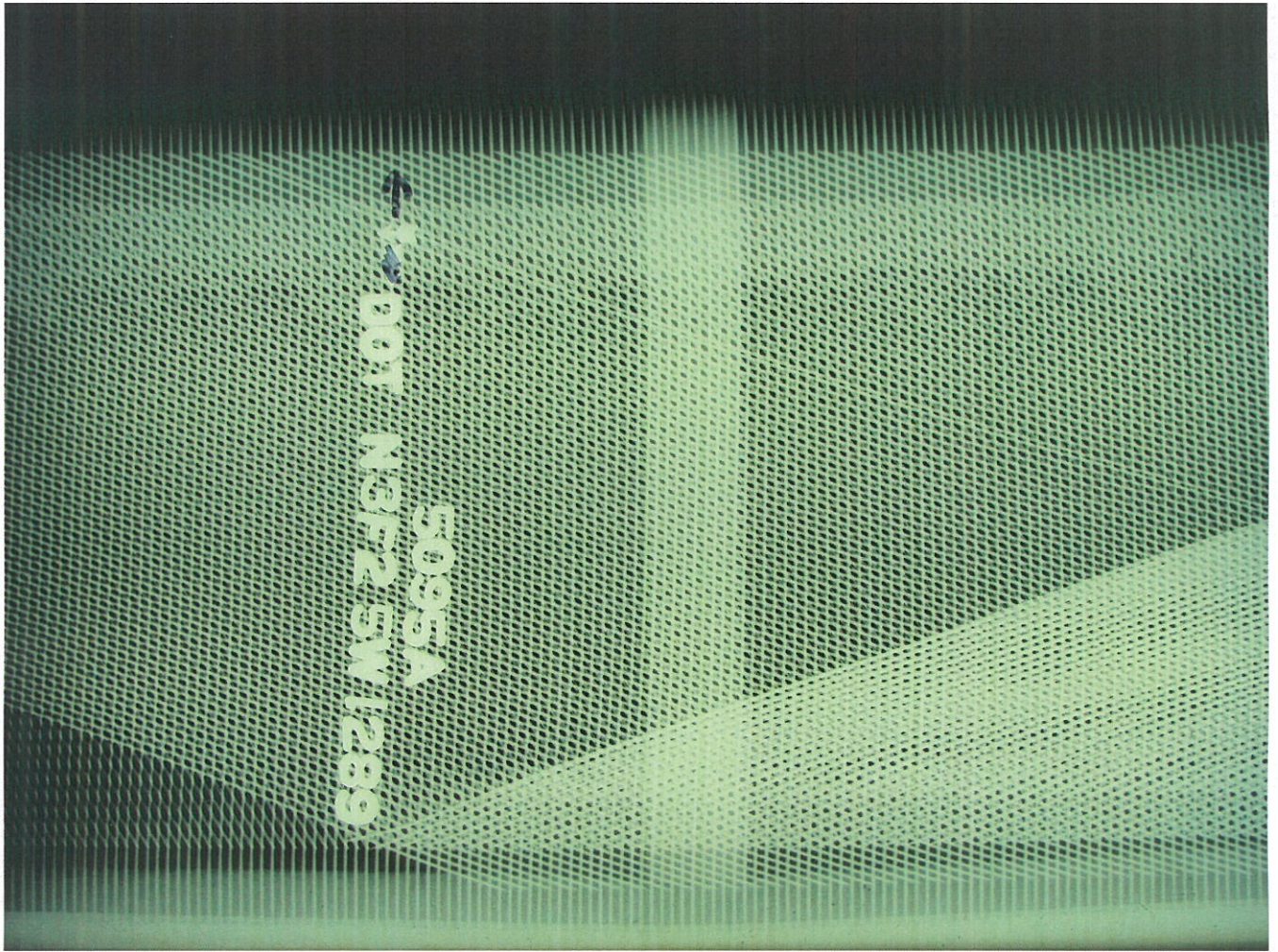


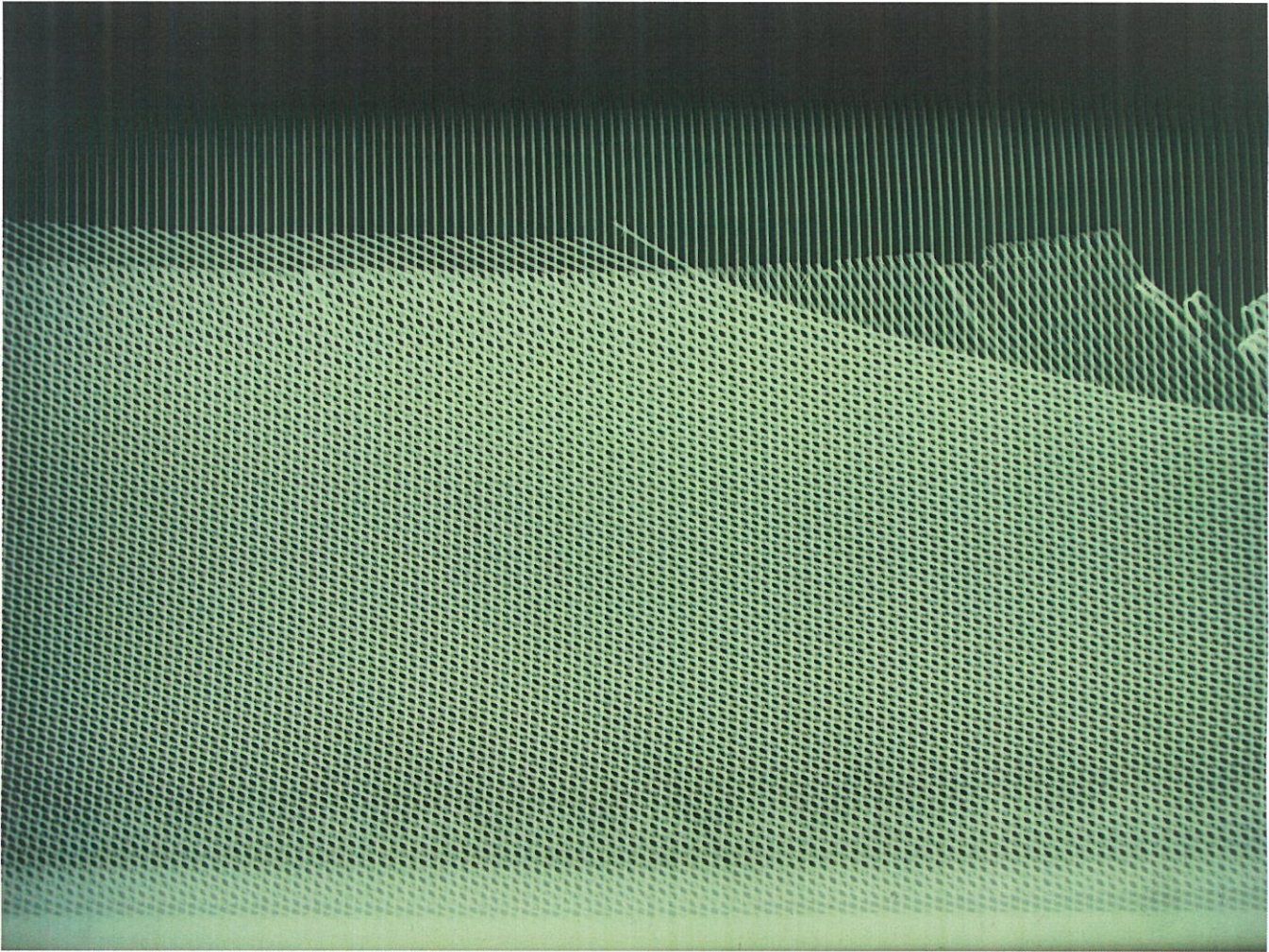




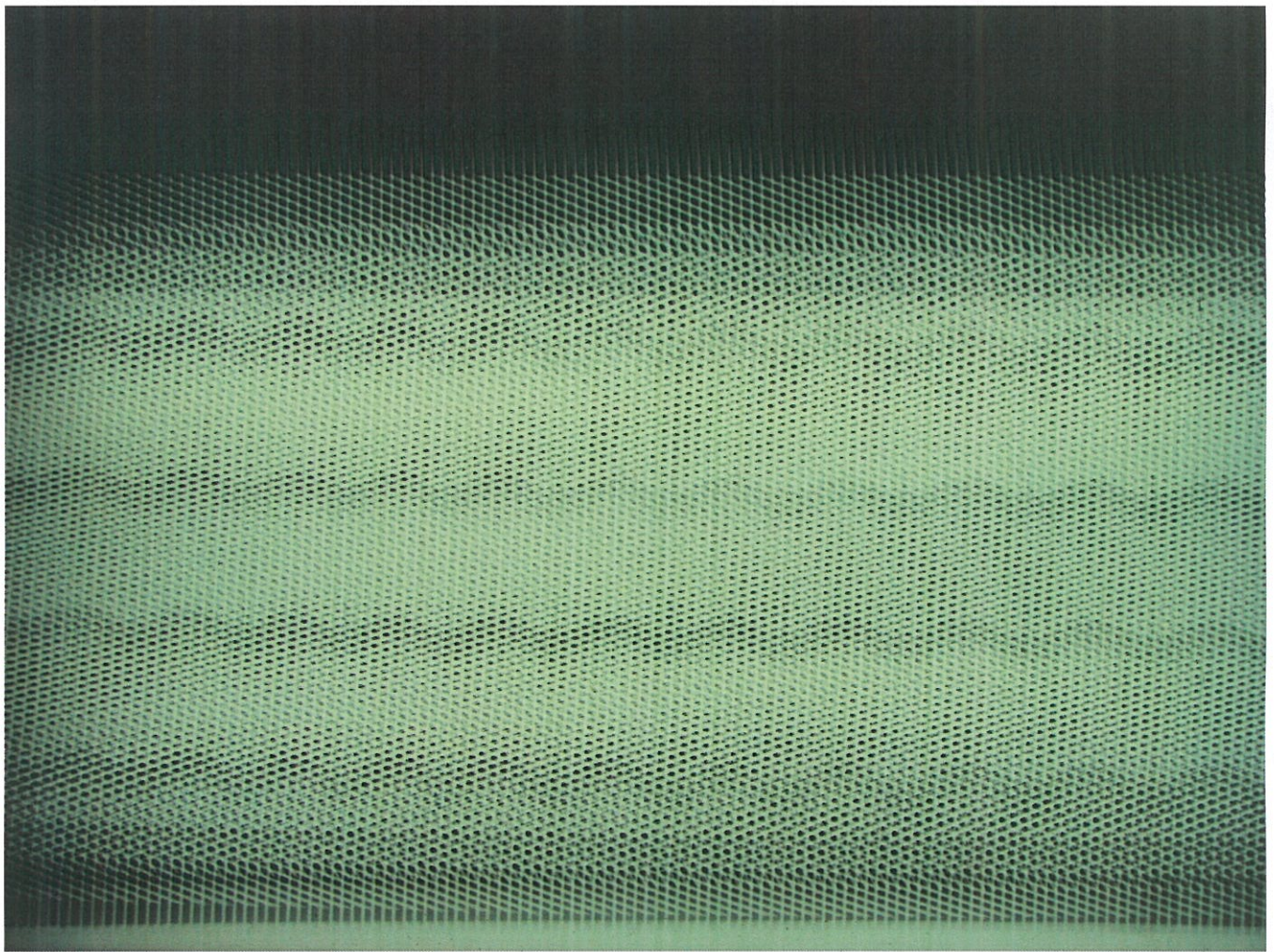


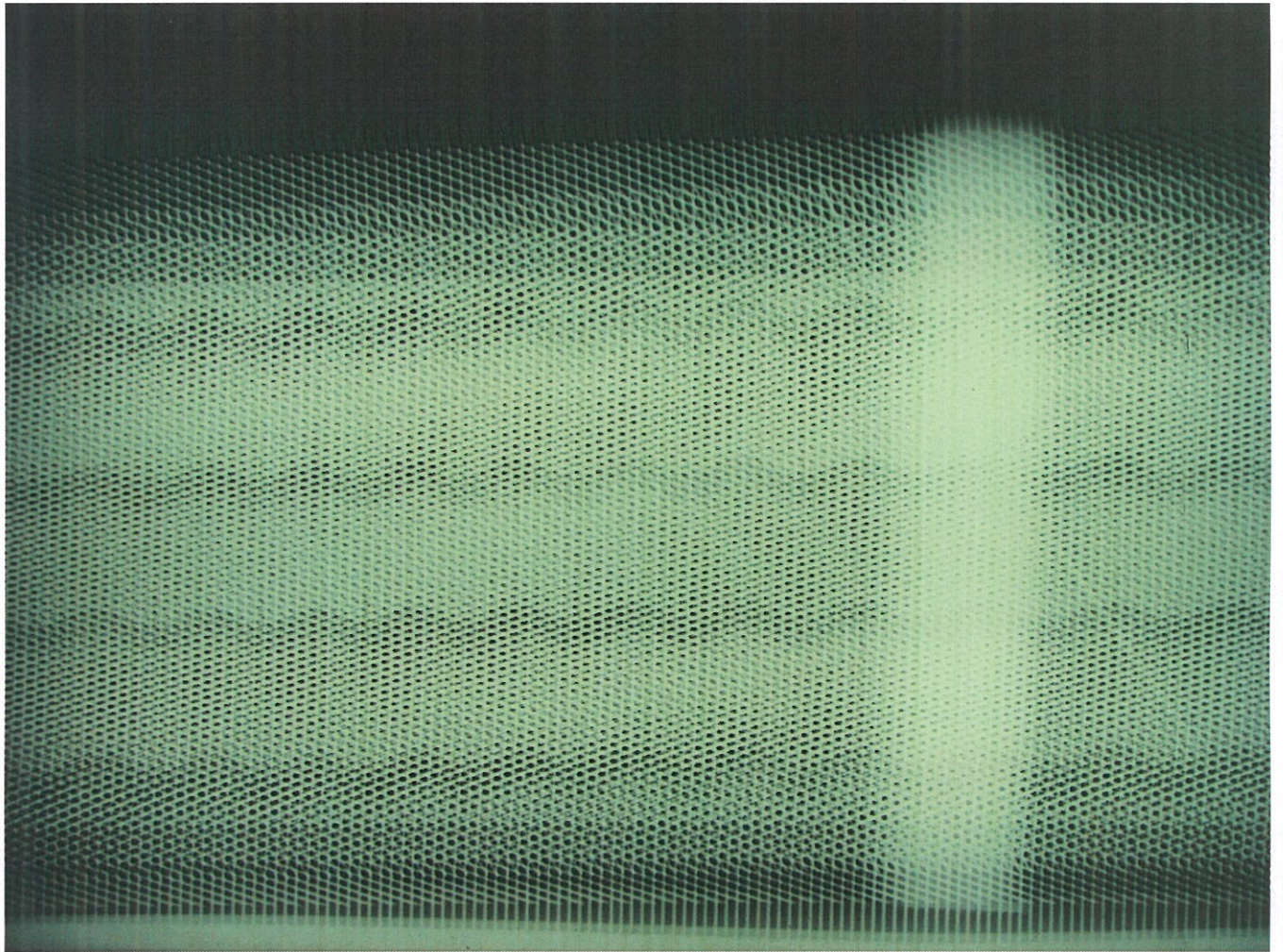


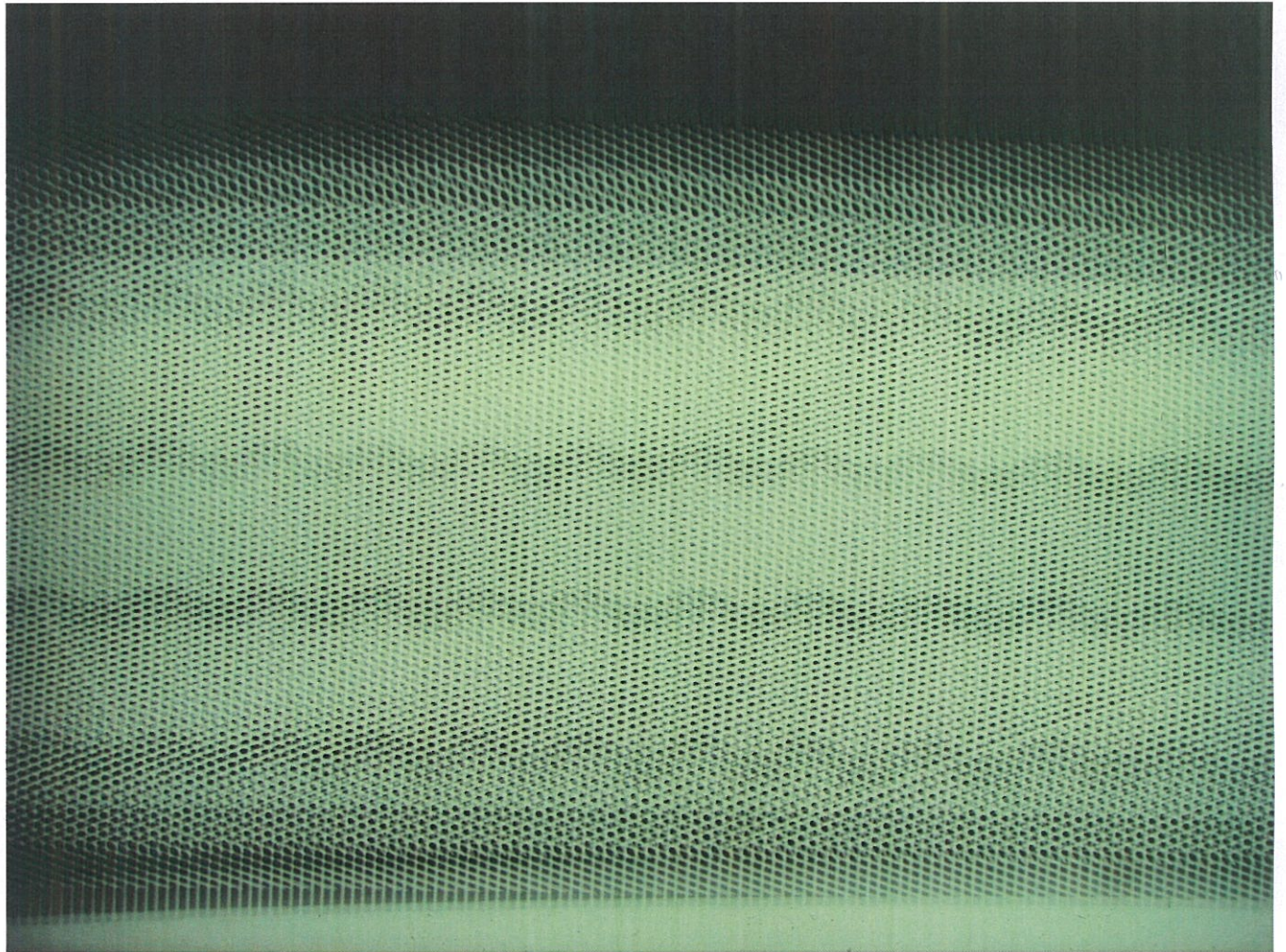


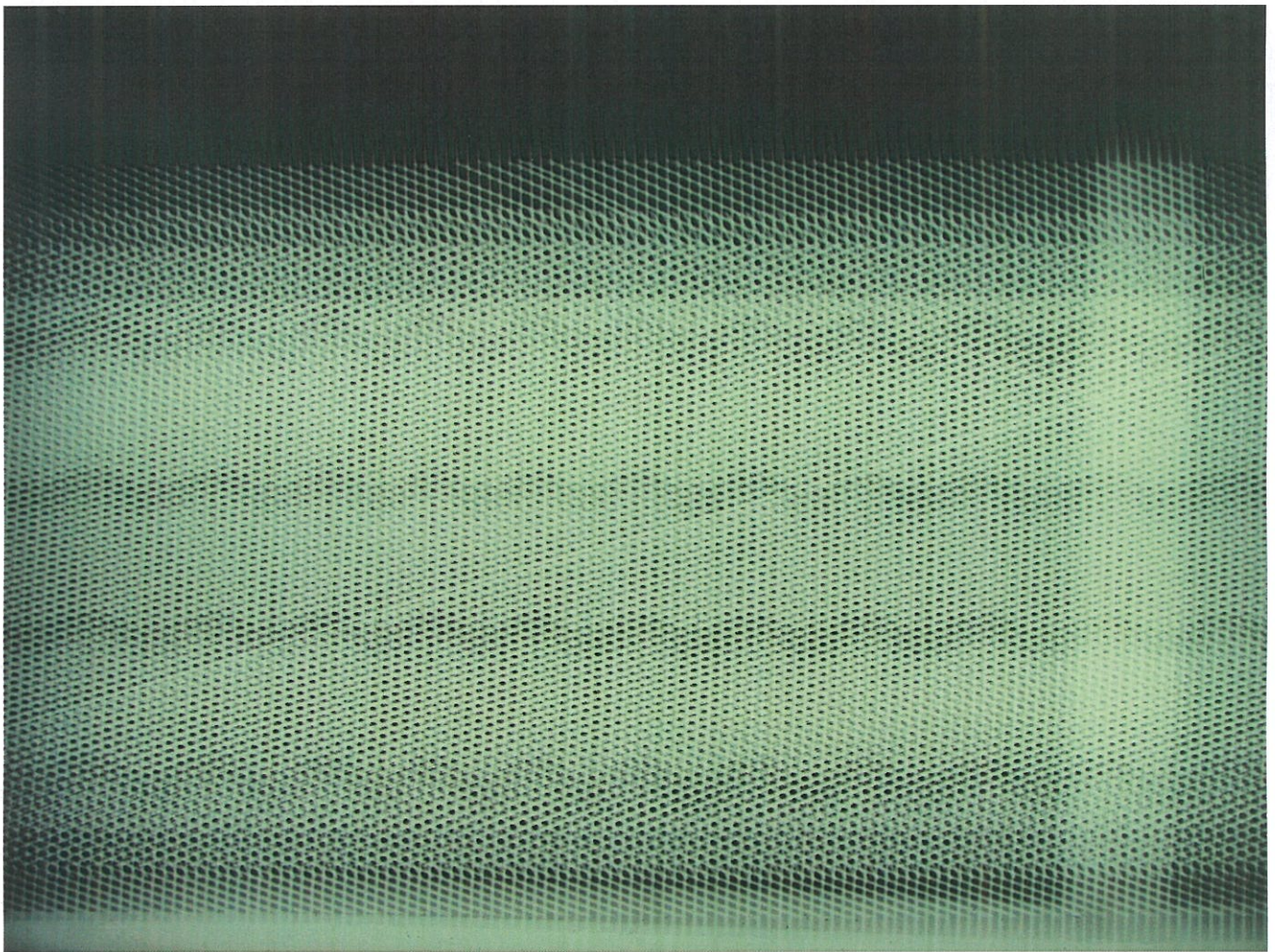




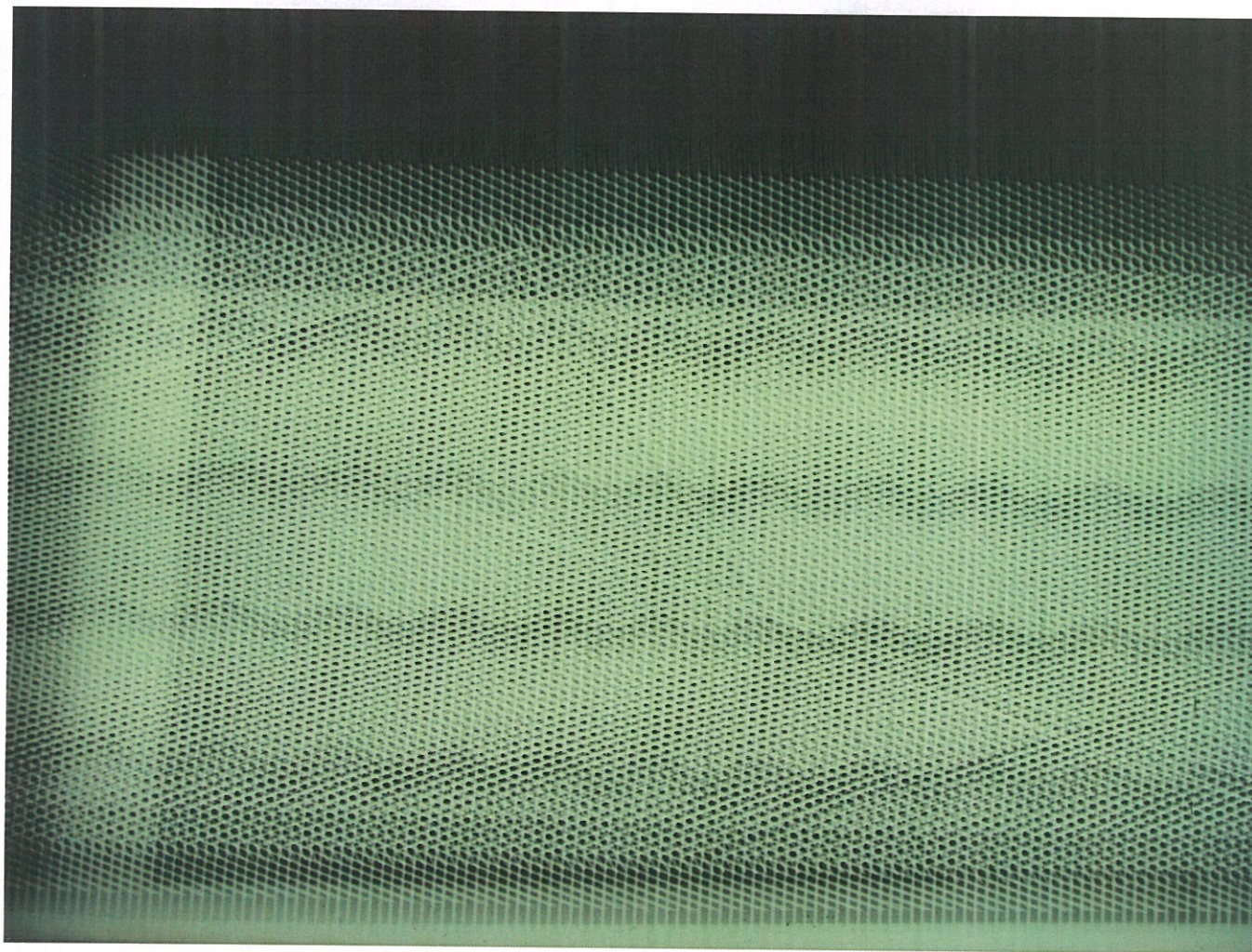


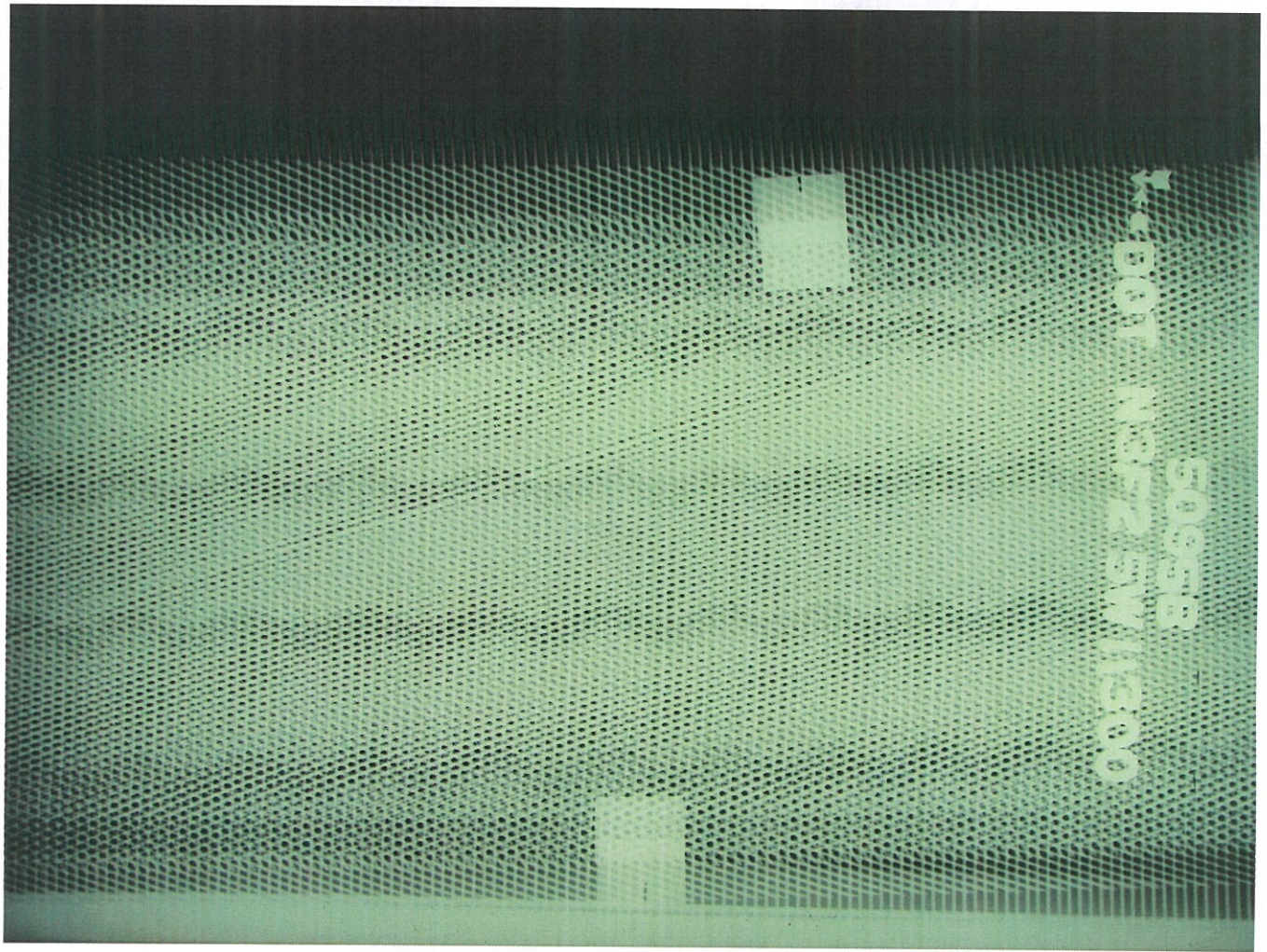


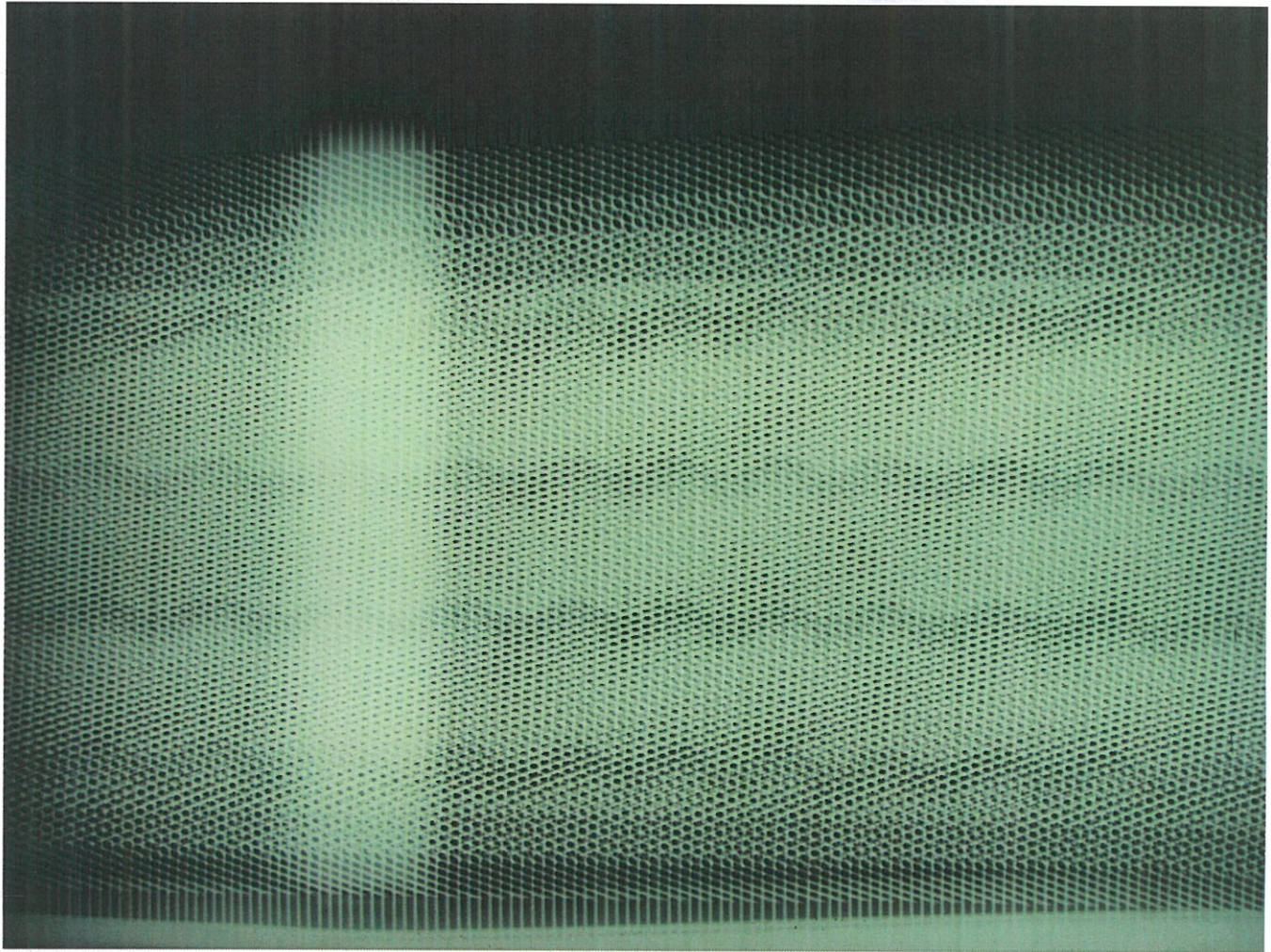


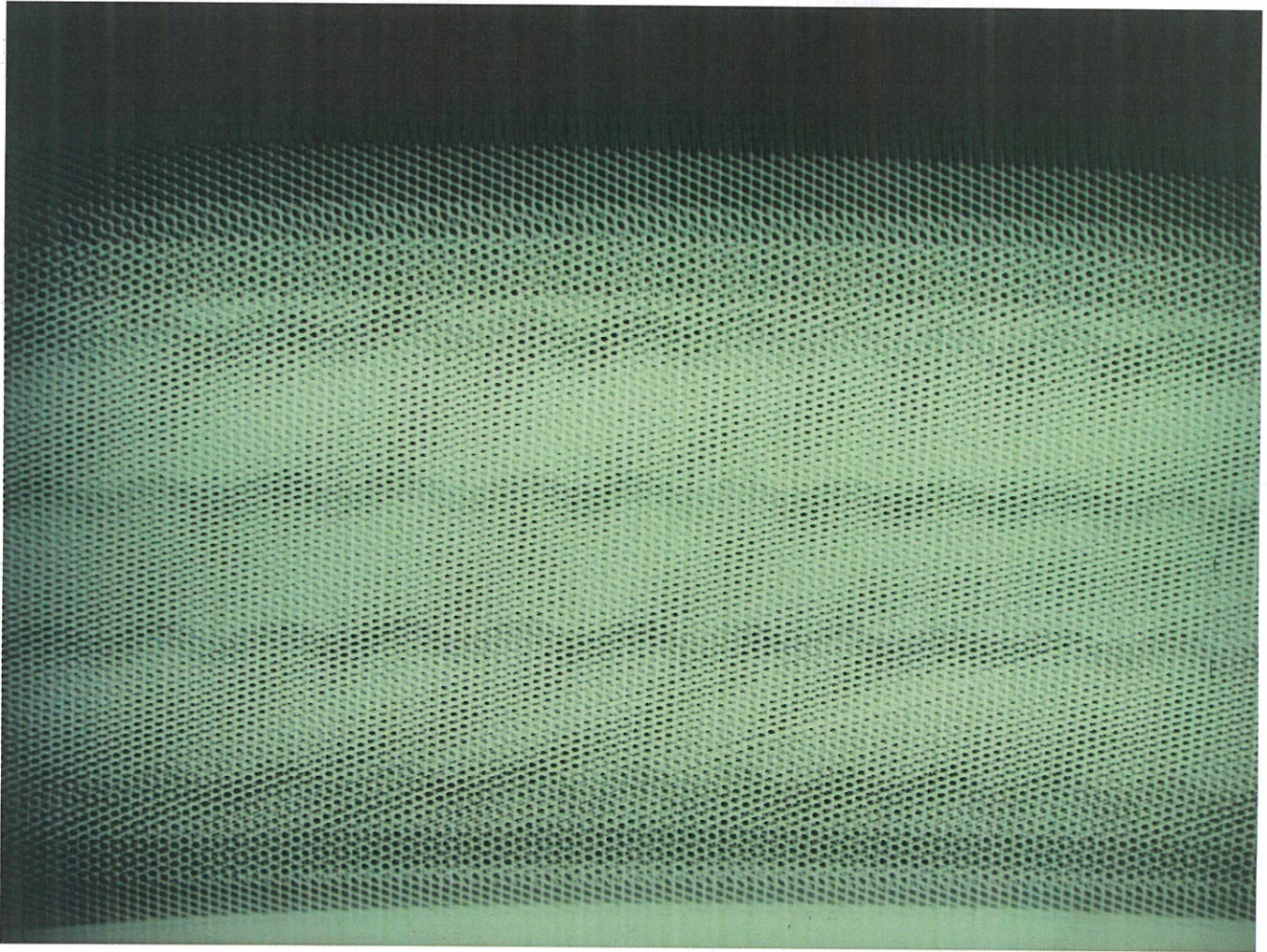


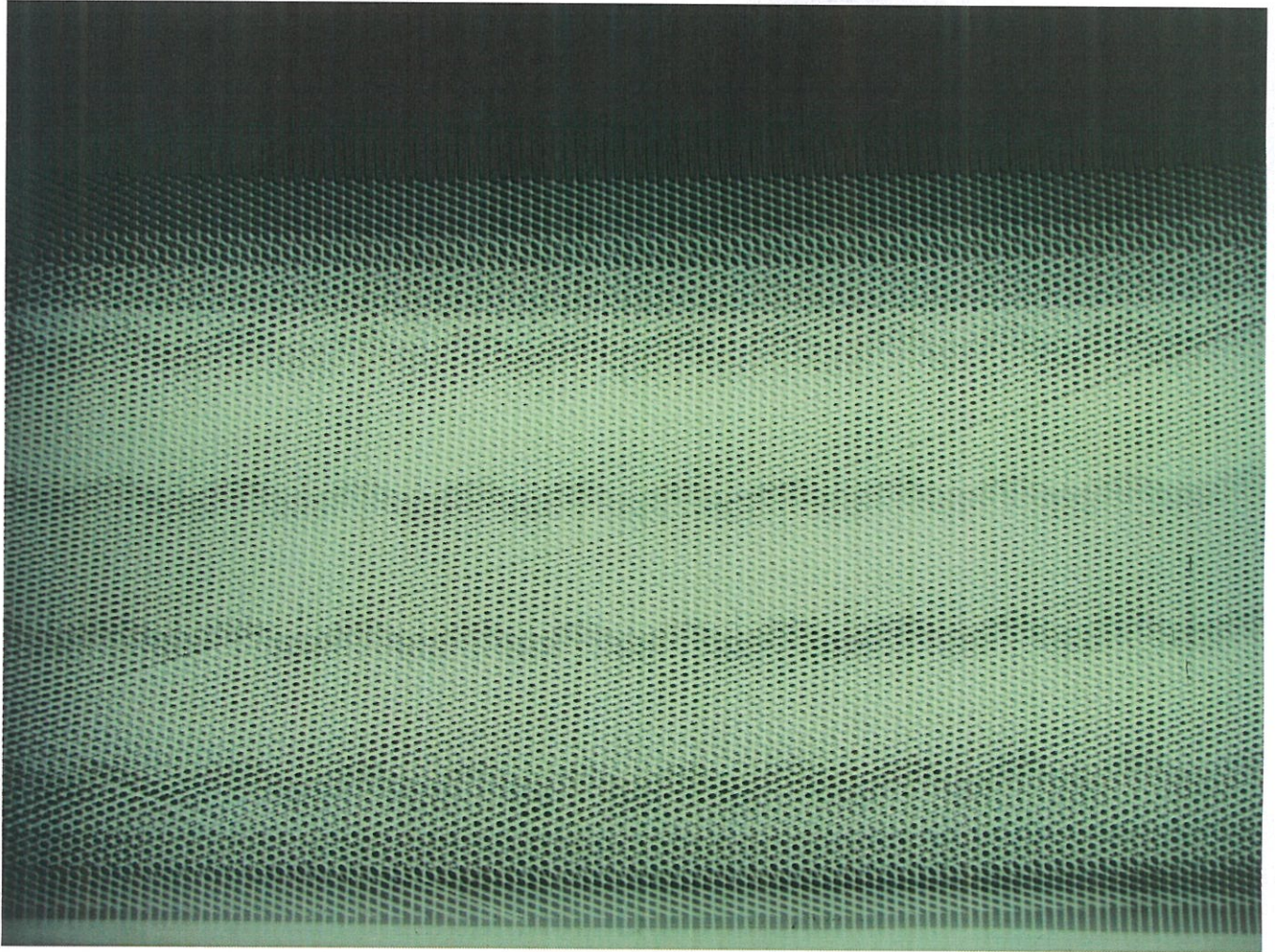




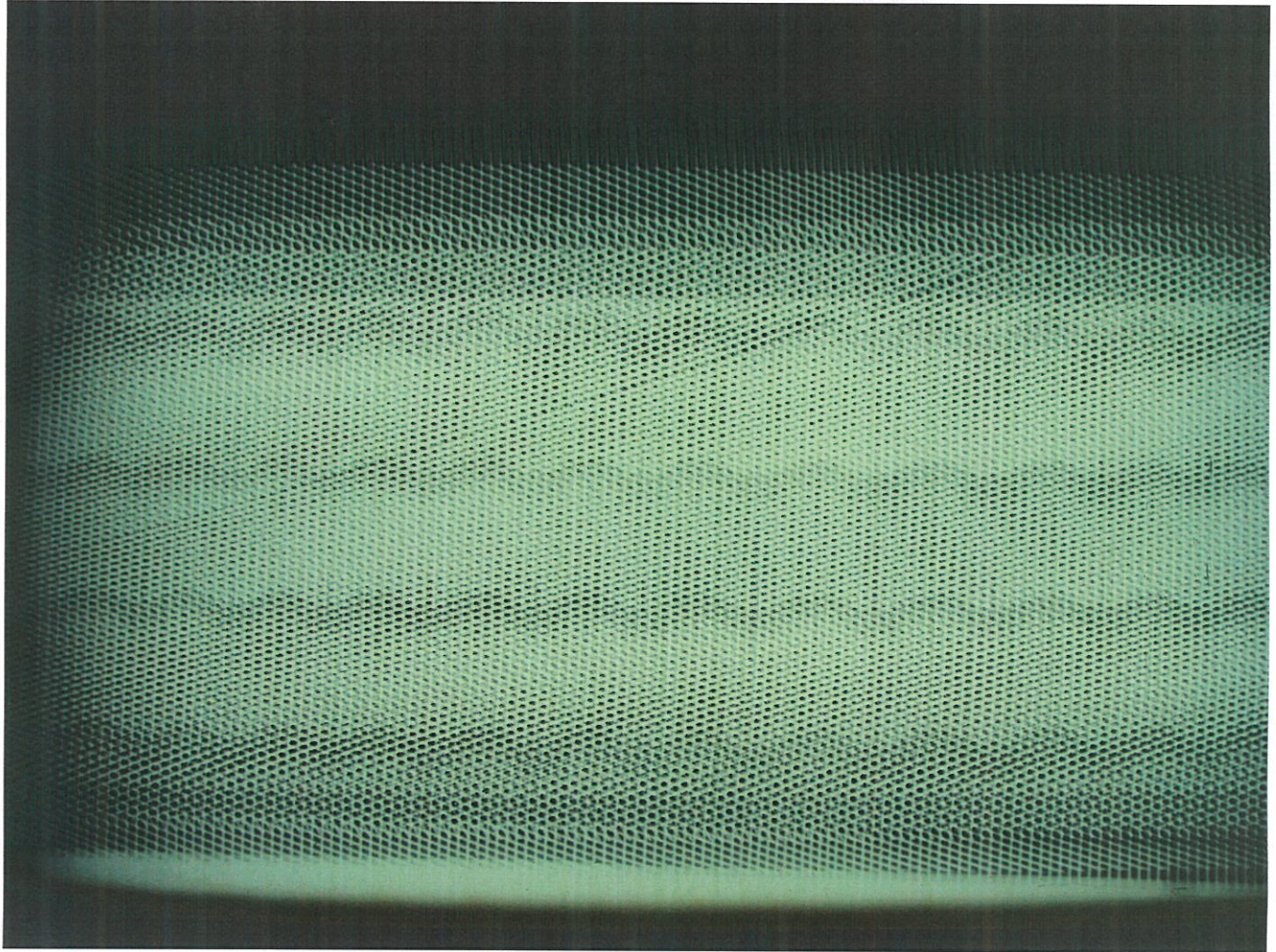


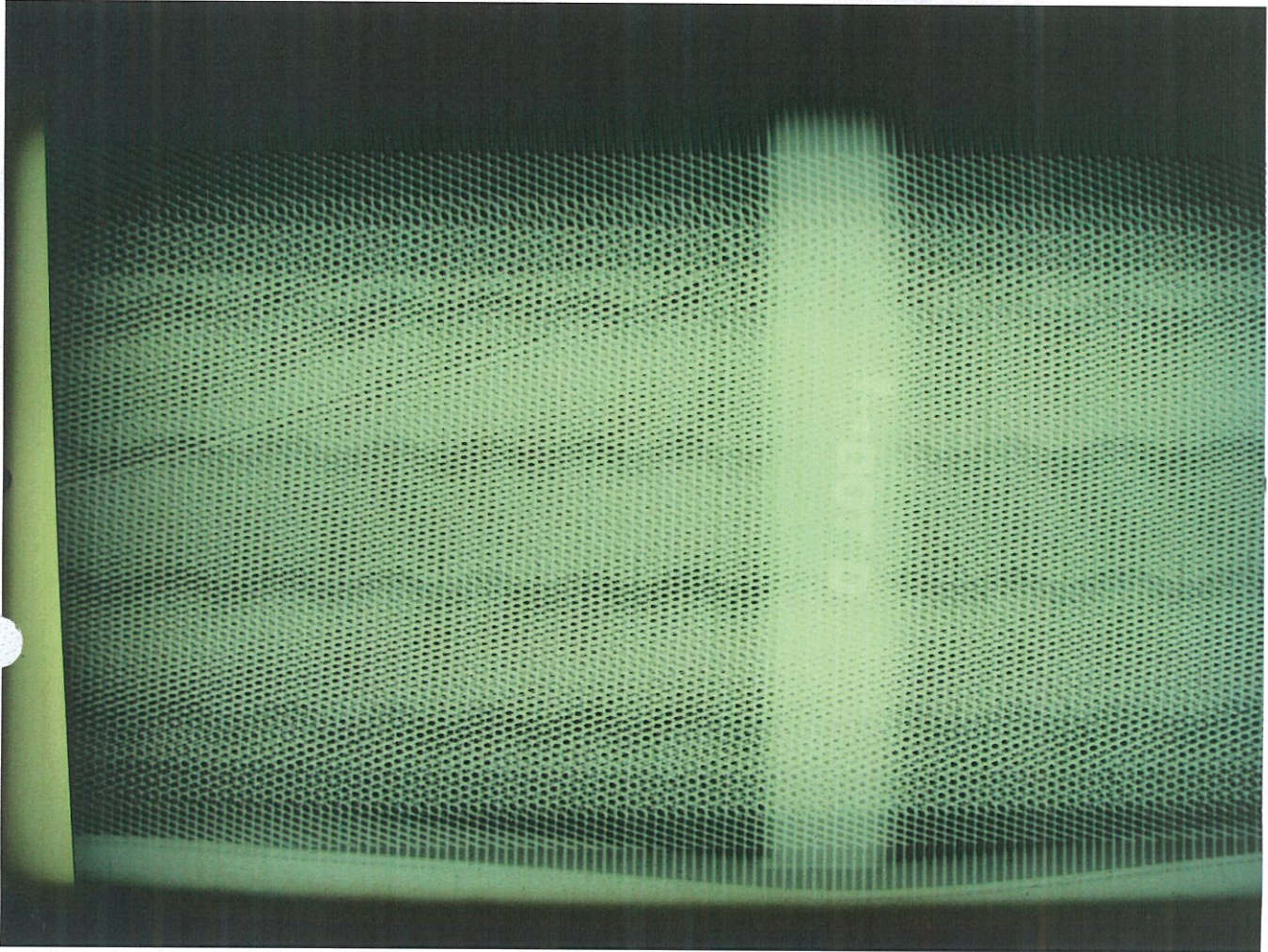


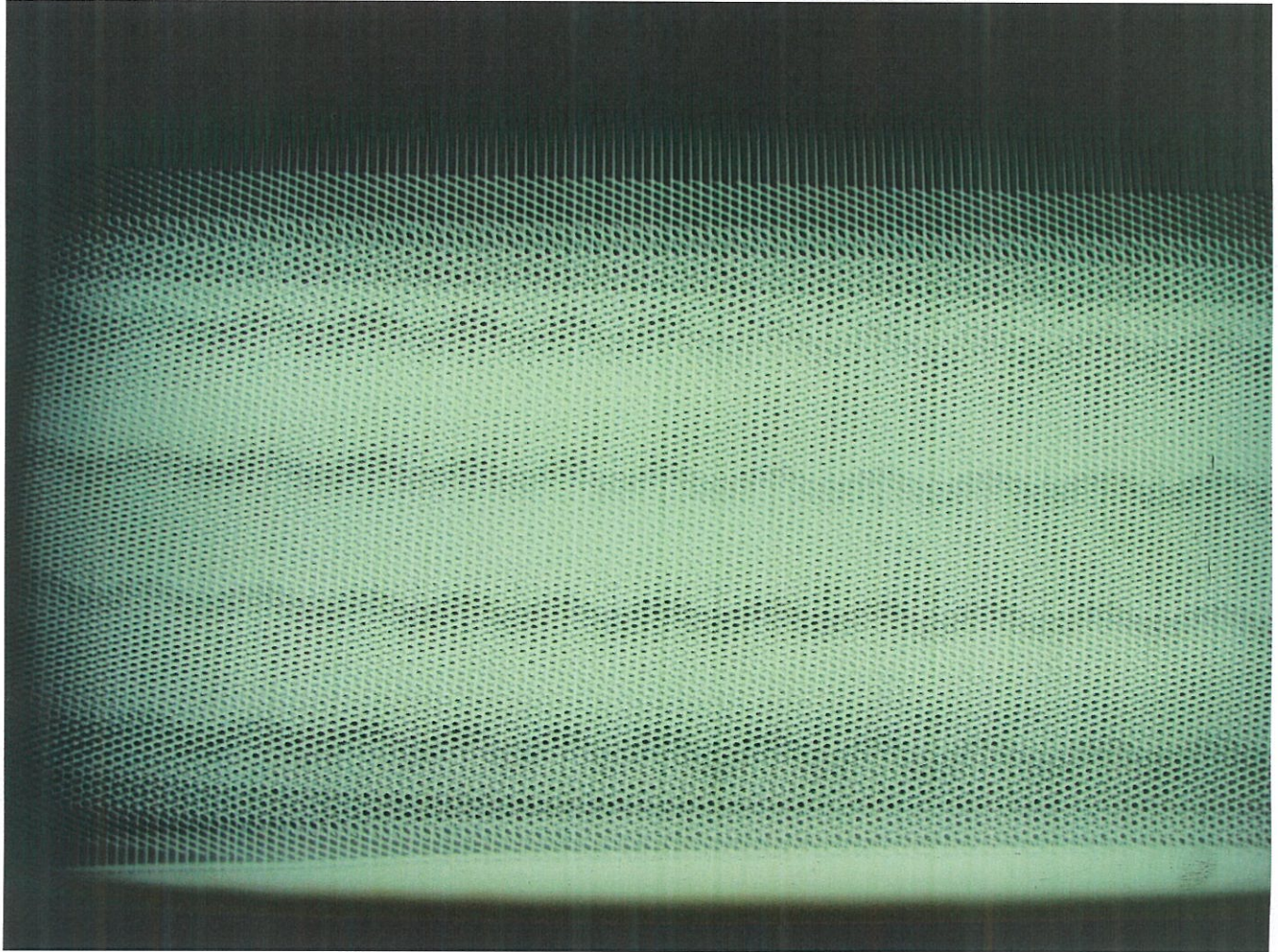


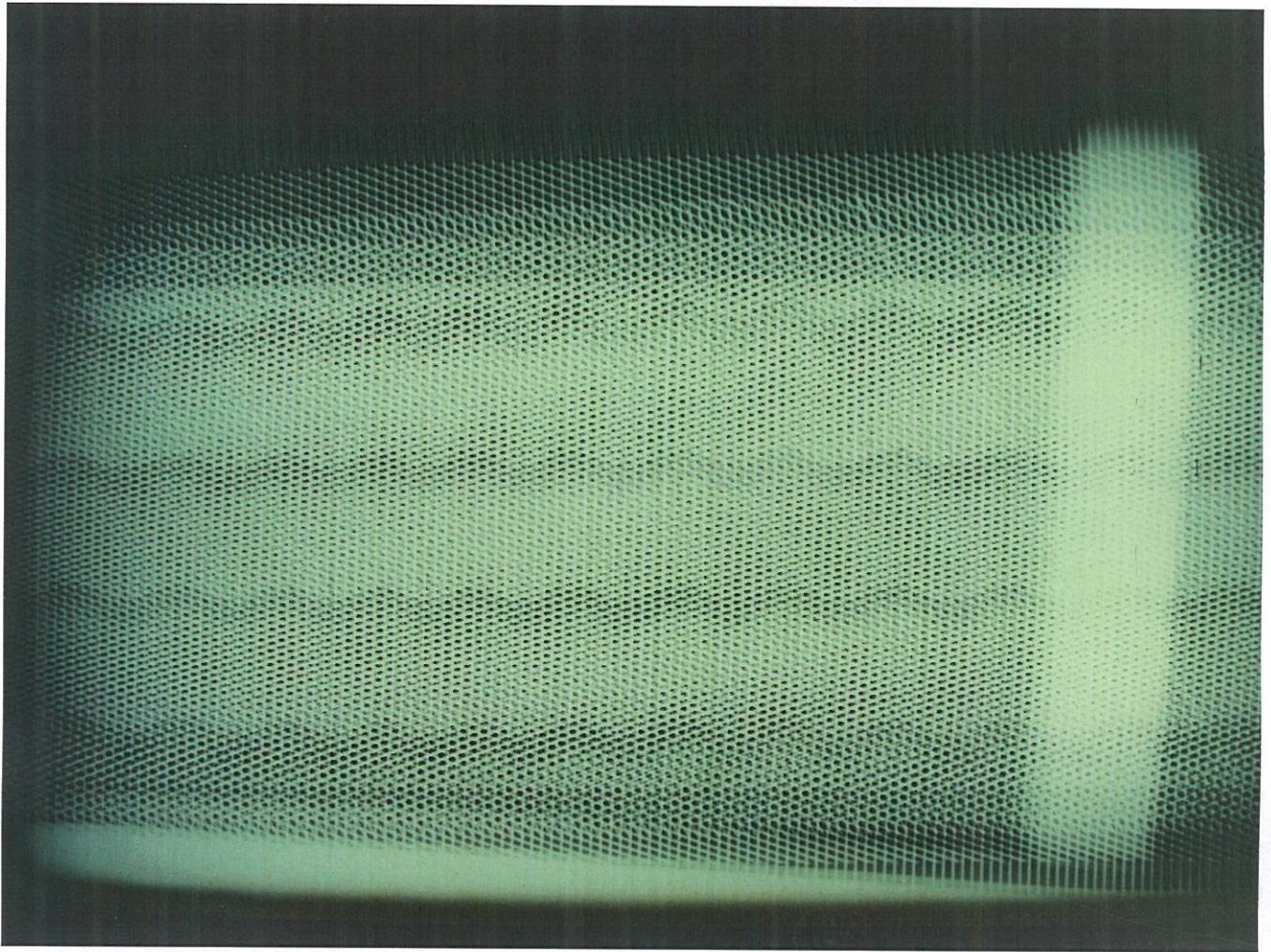


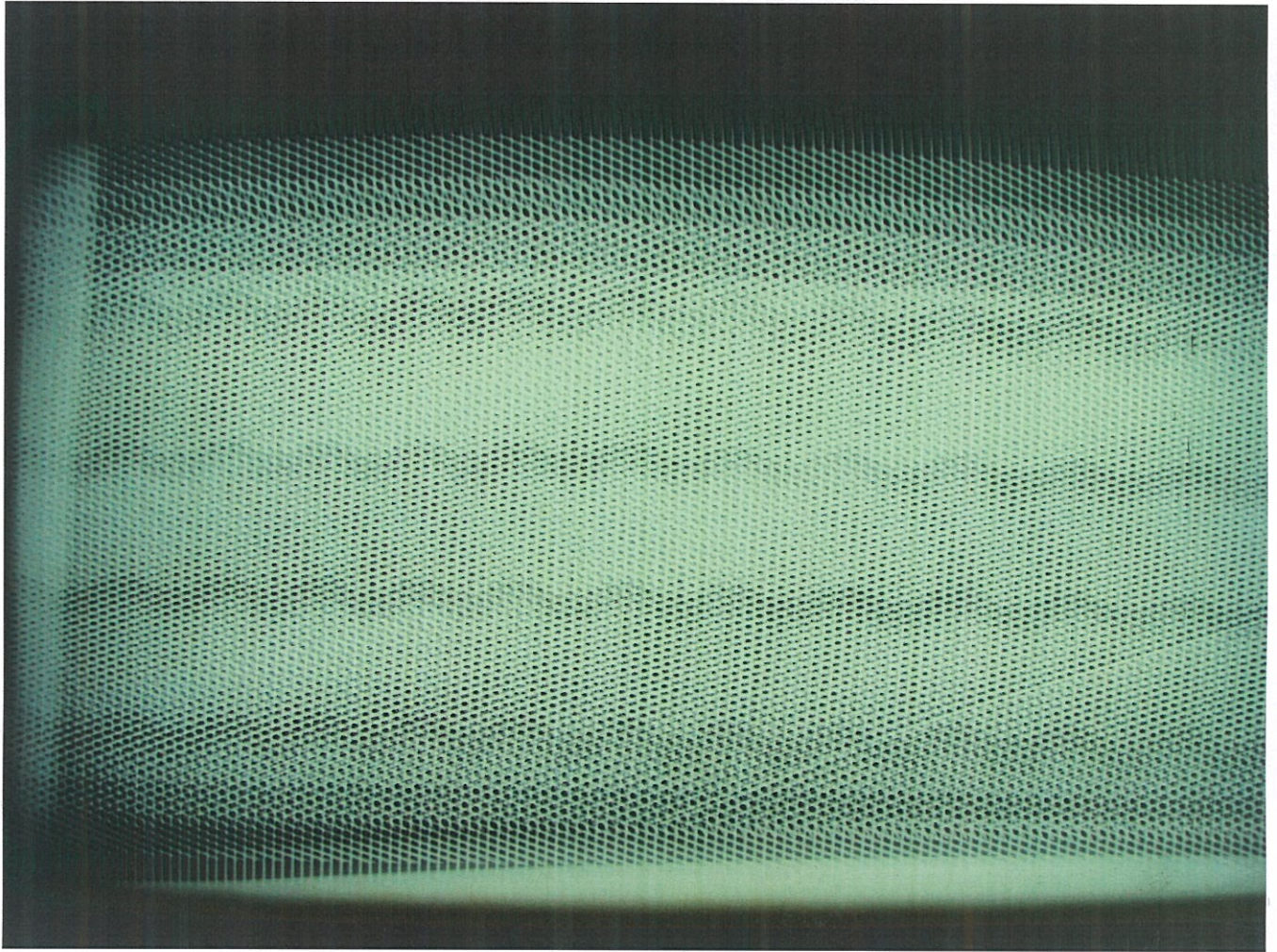
## Tire B Post Endurance Test - X-ray Images

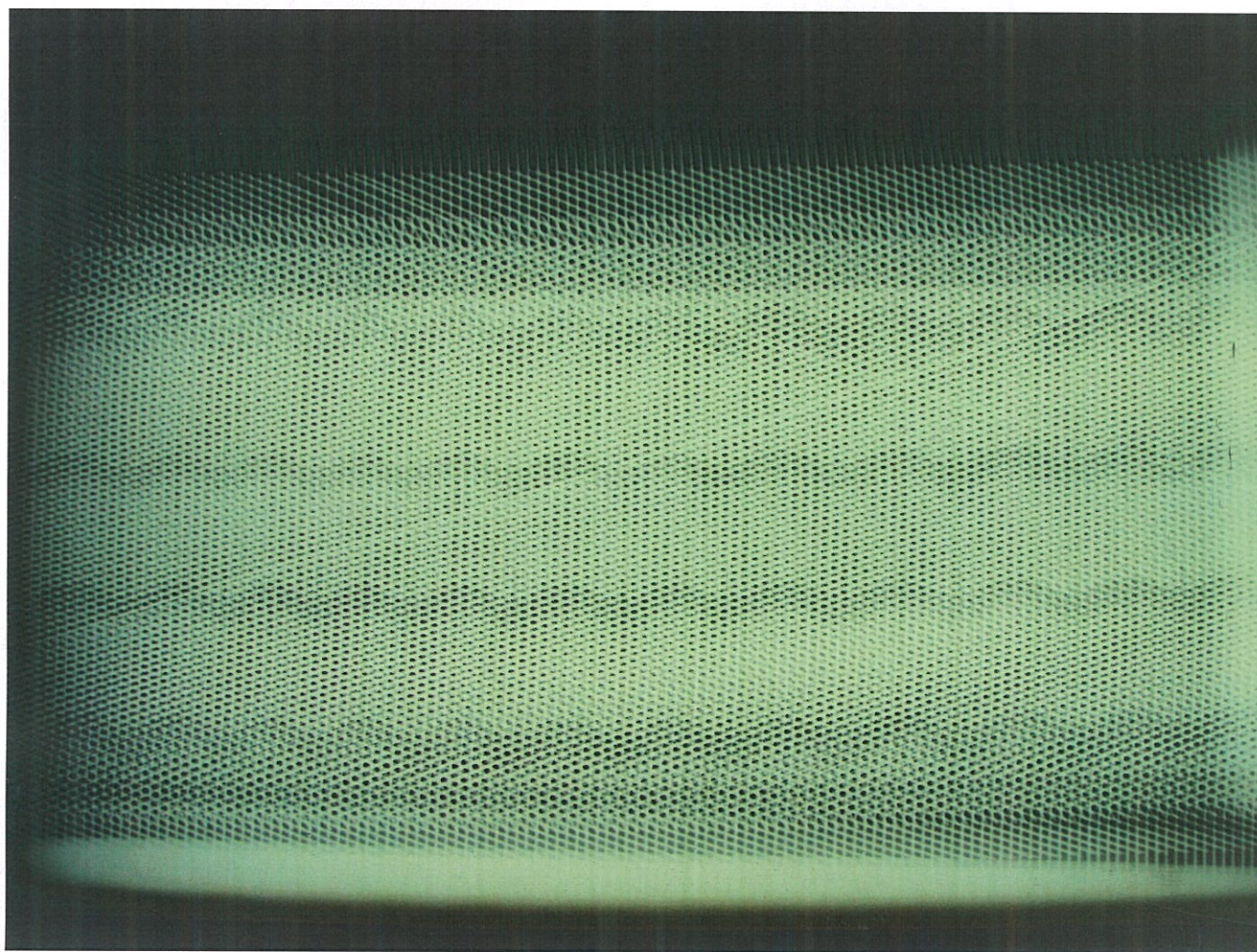


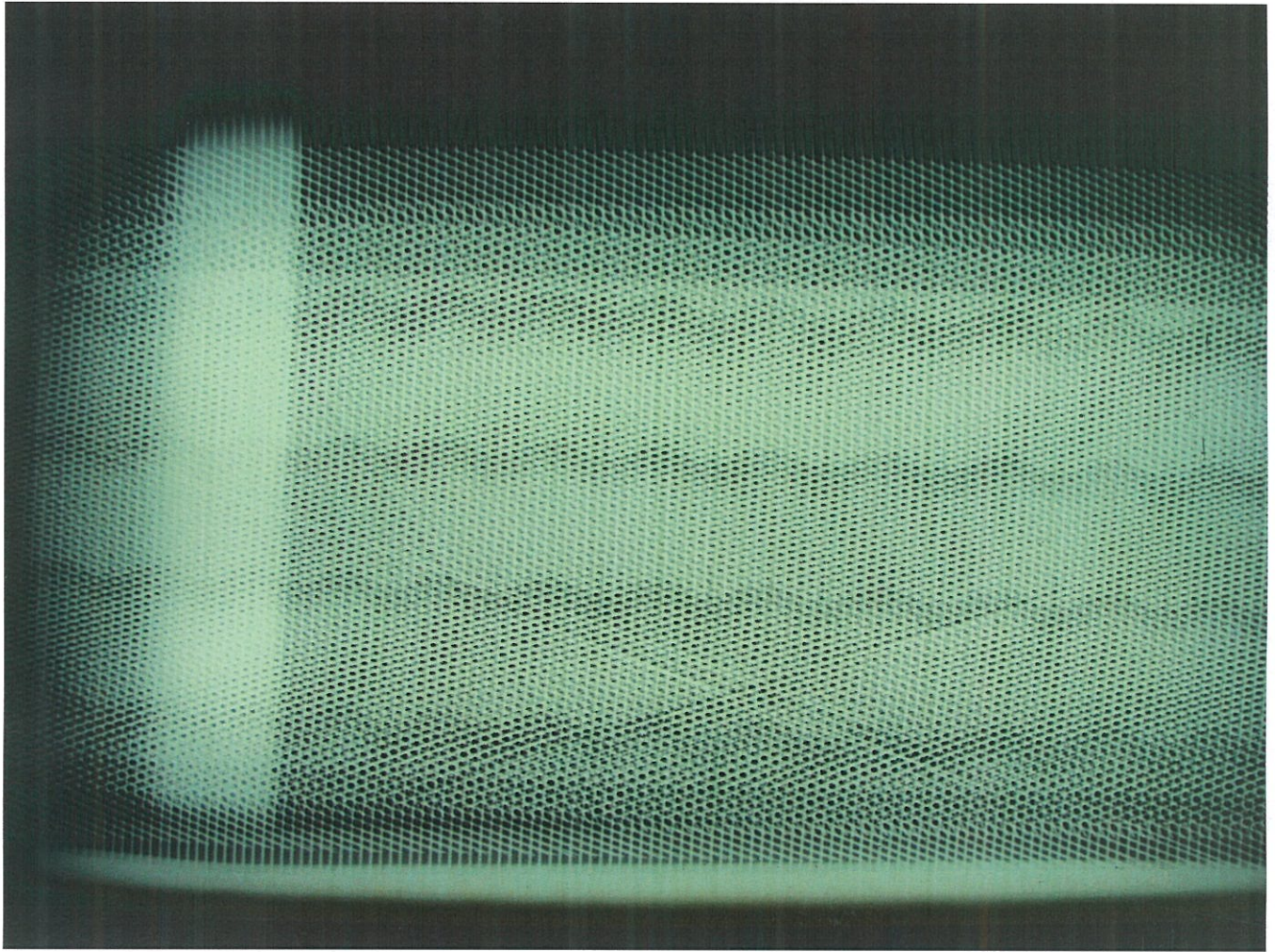


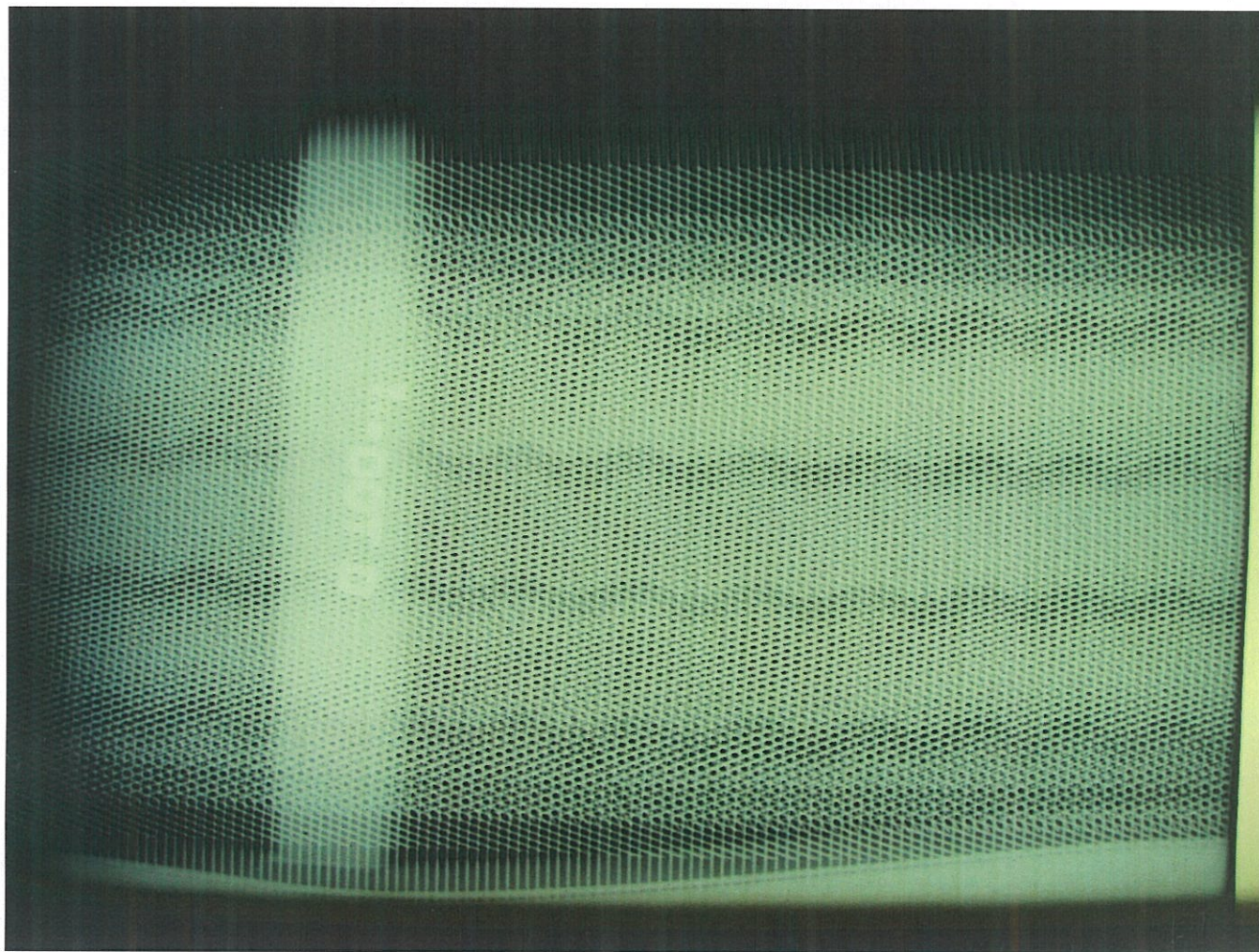


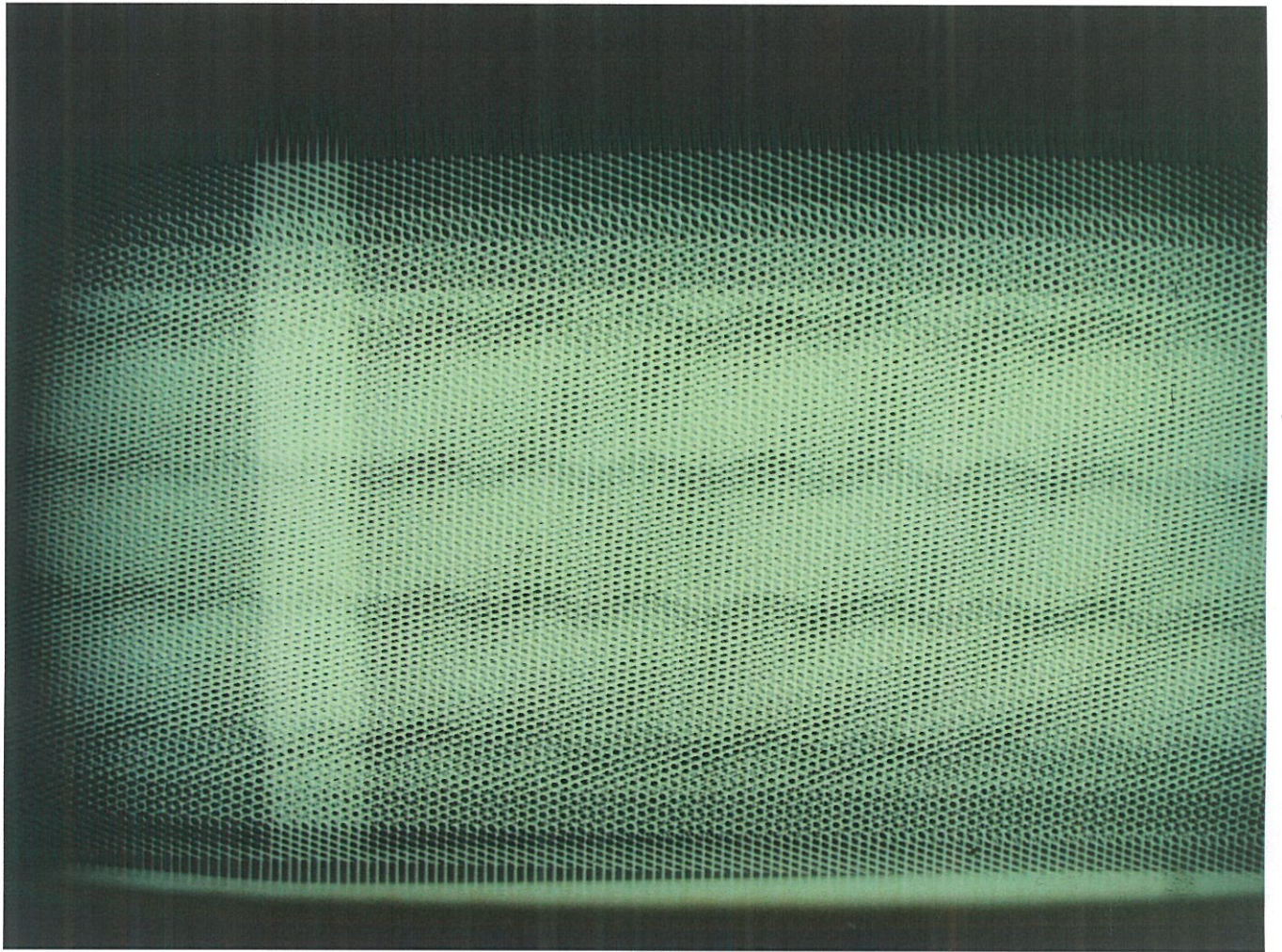


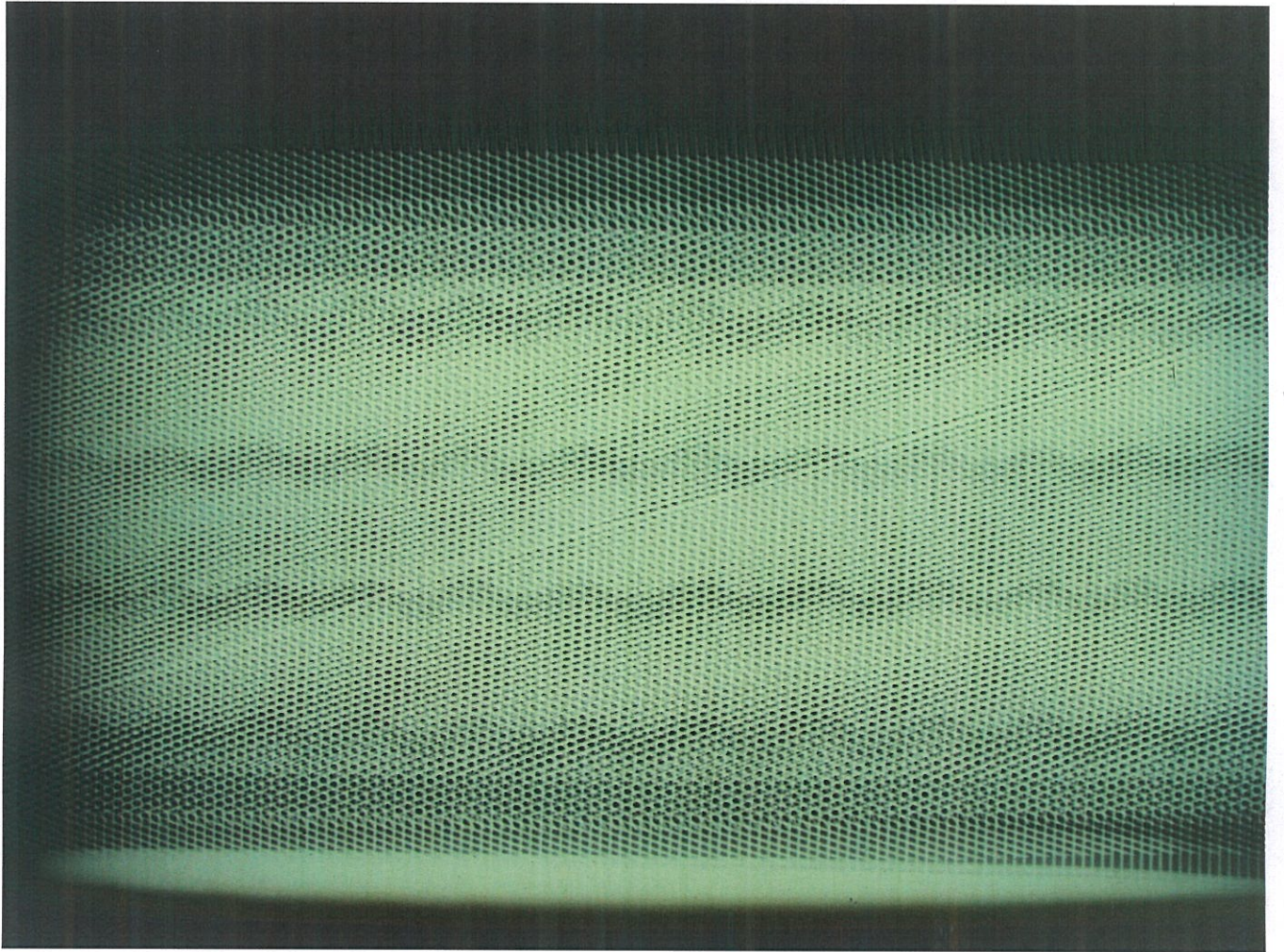




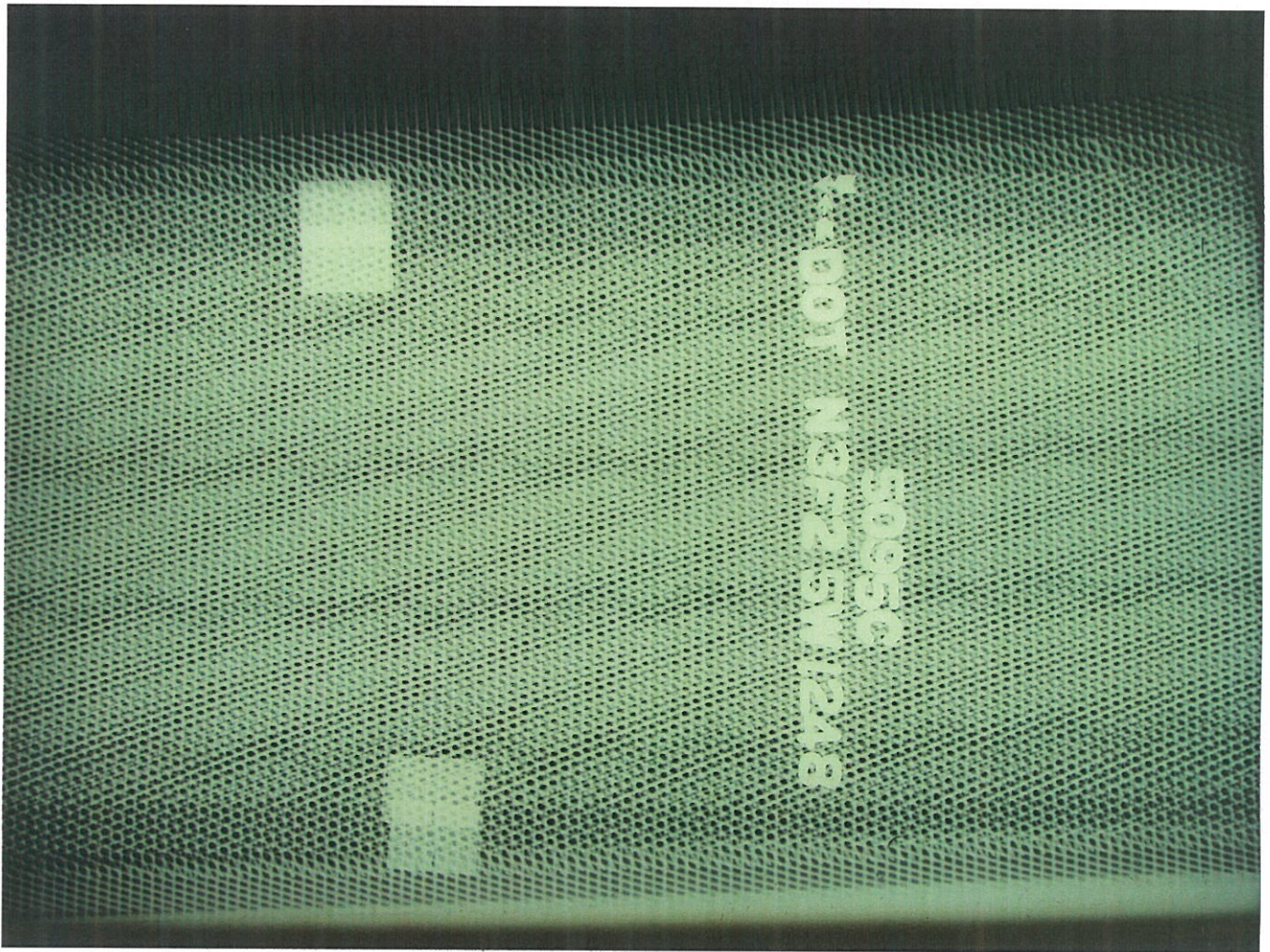


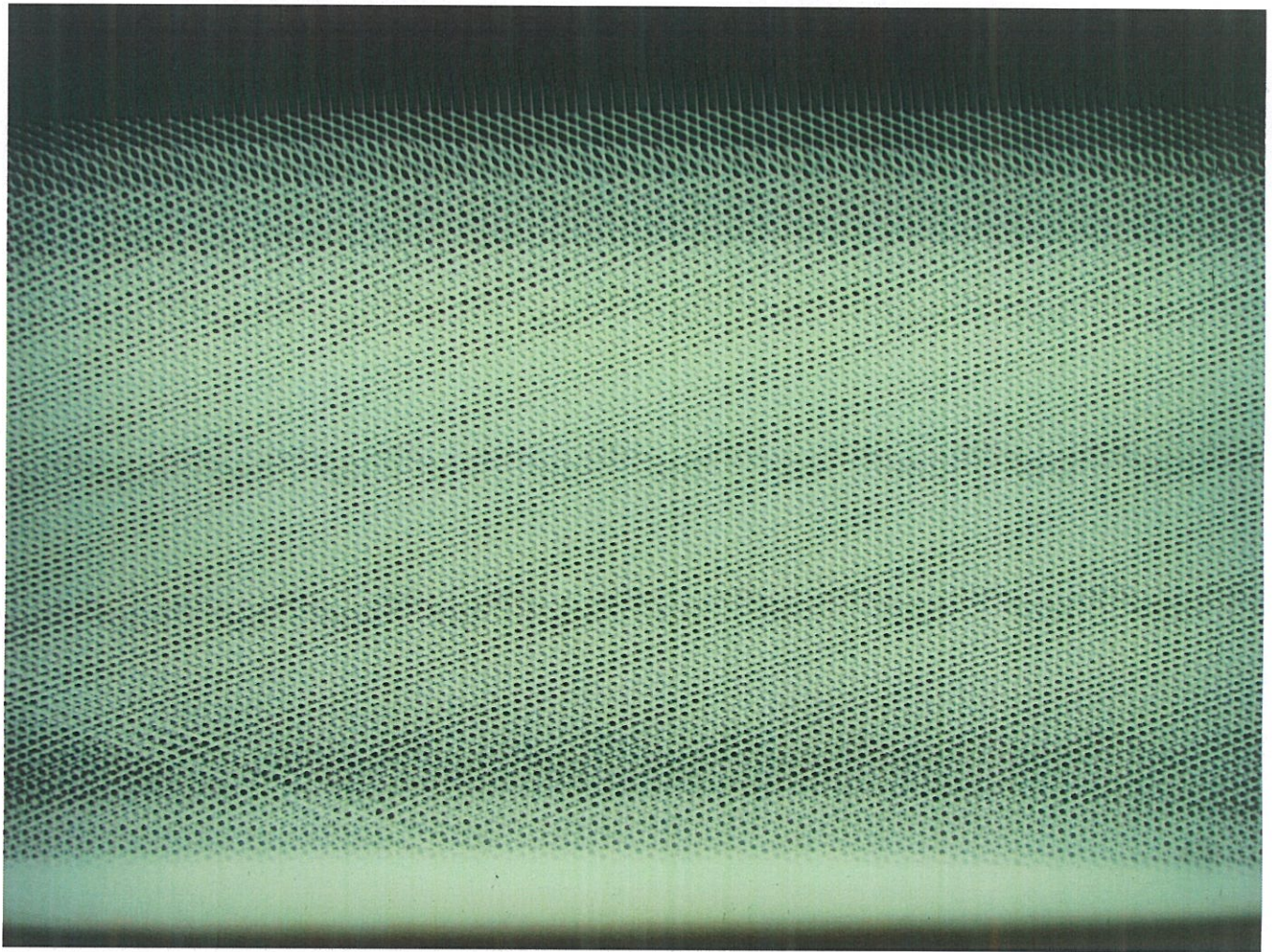


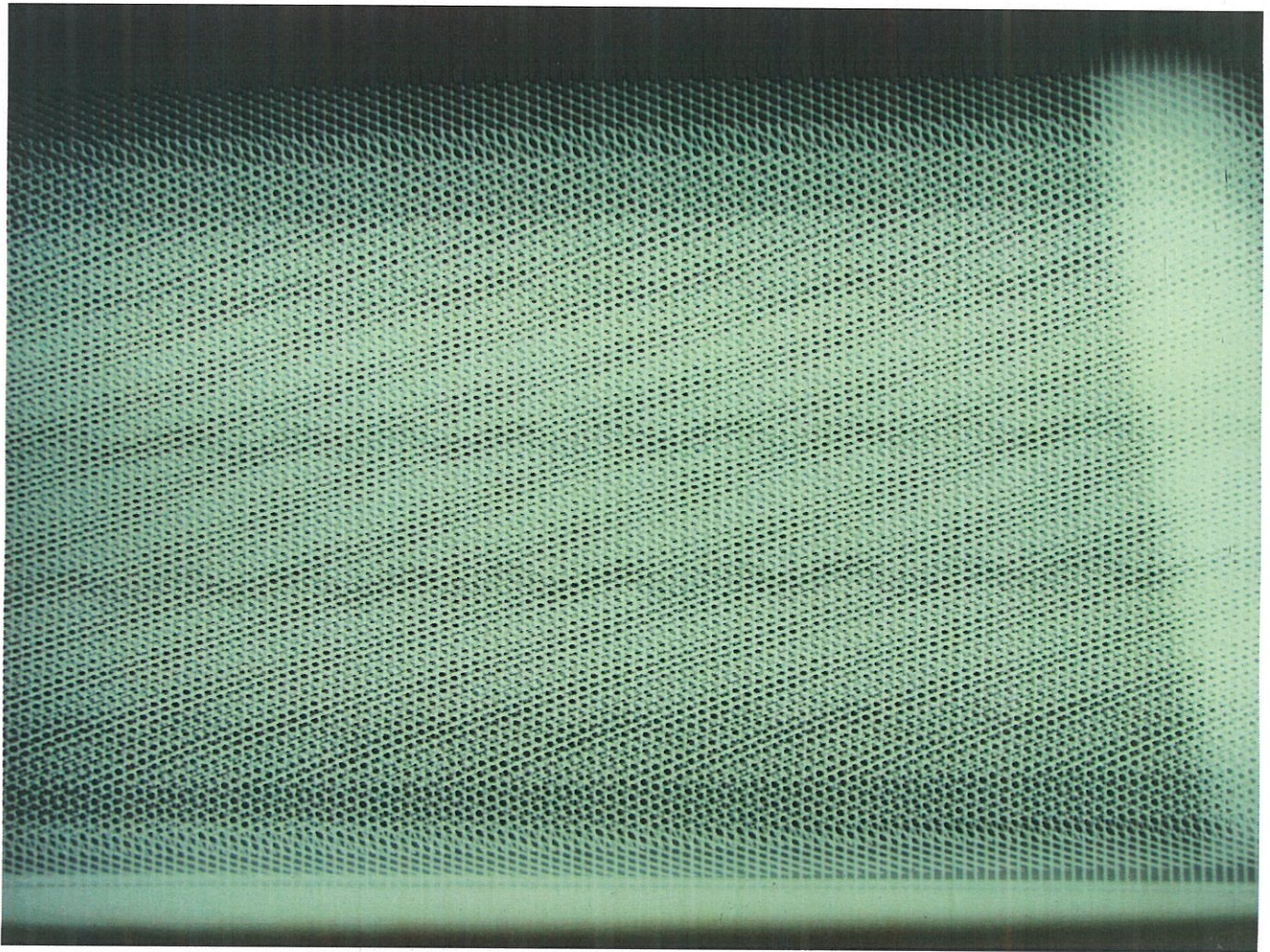


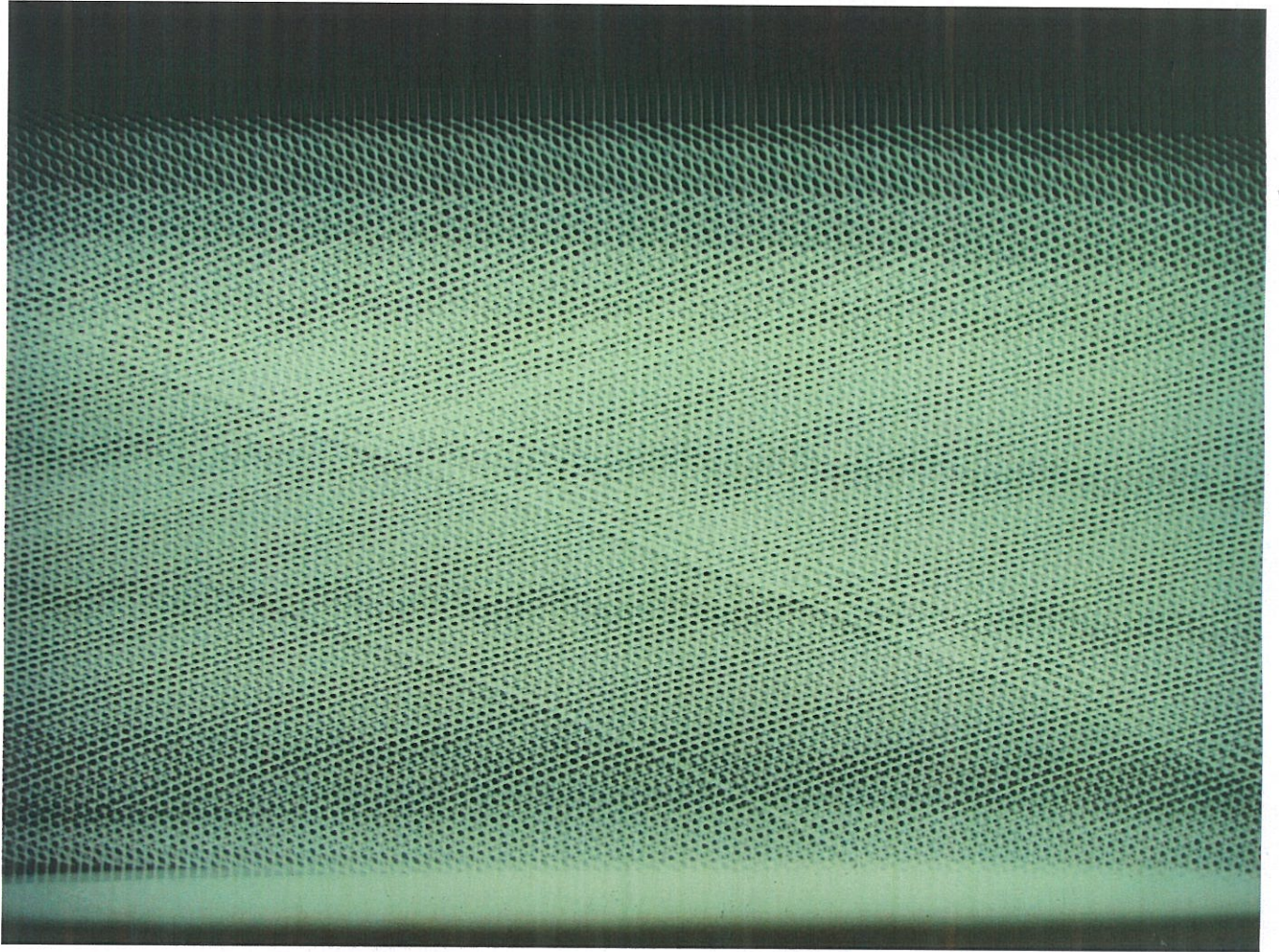


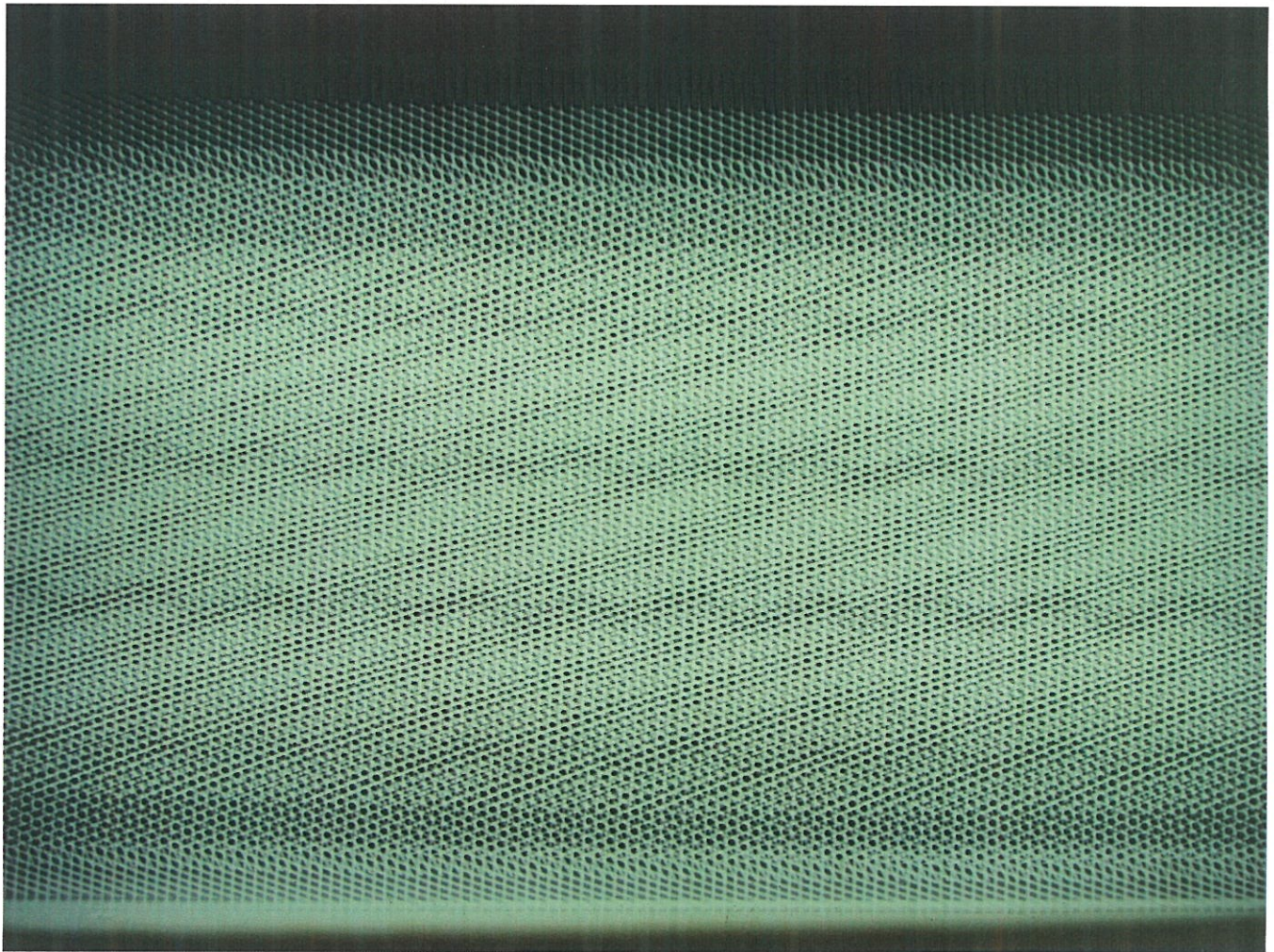
# Tire C - X-ray Images

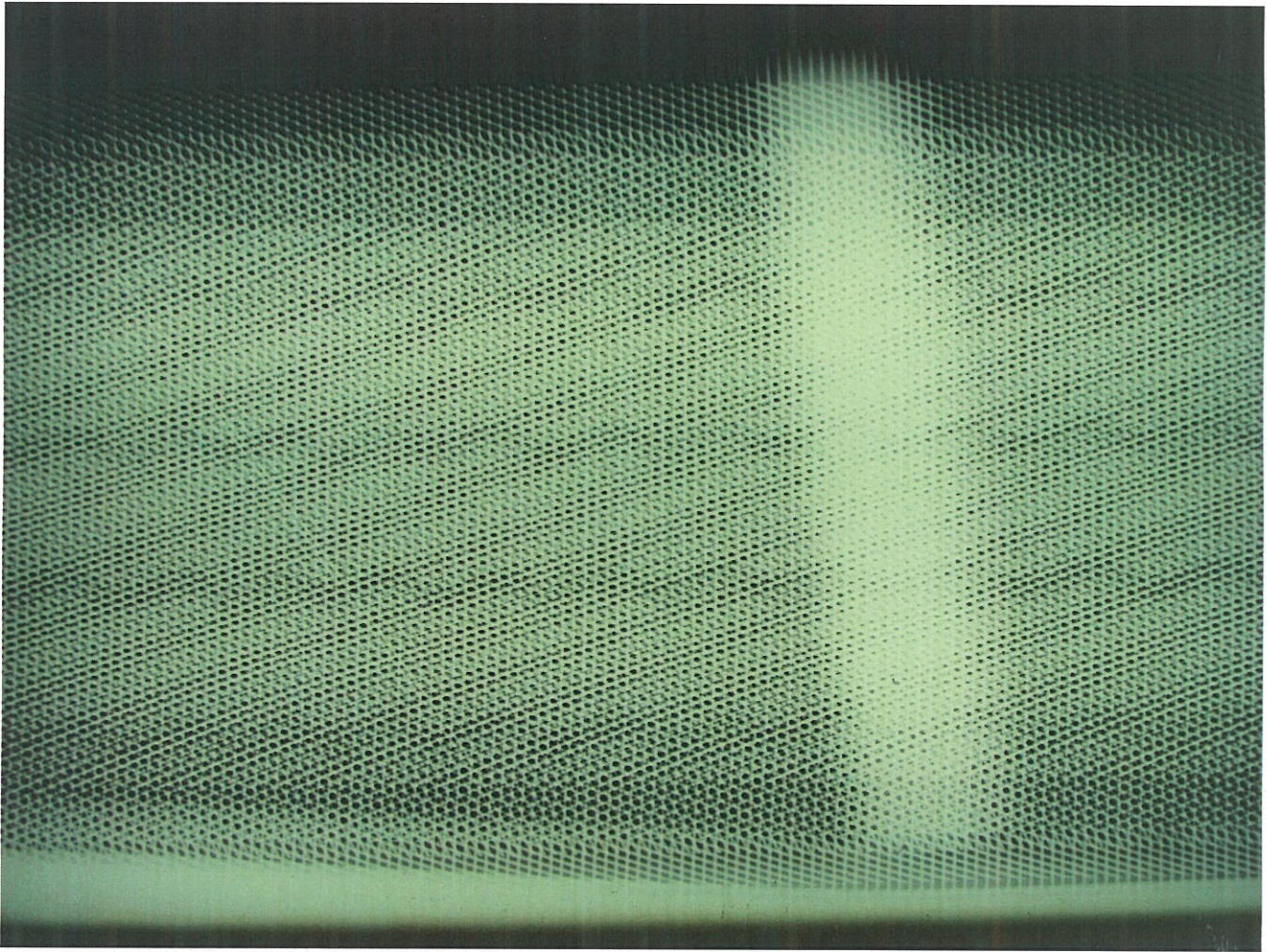


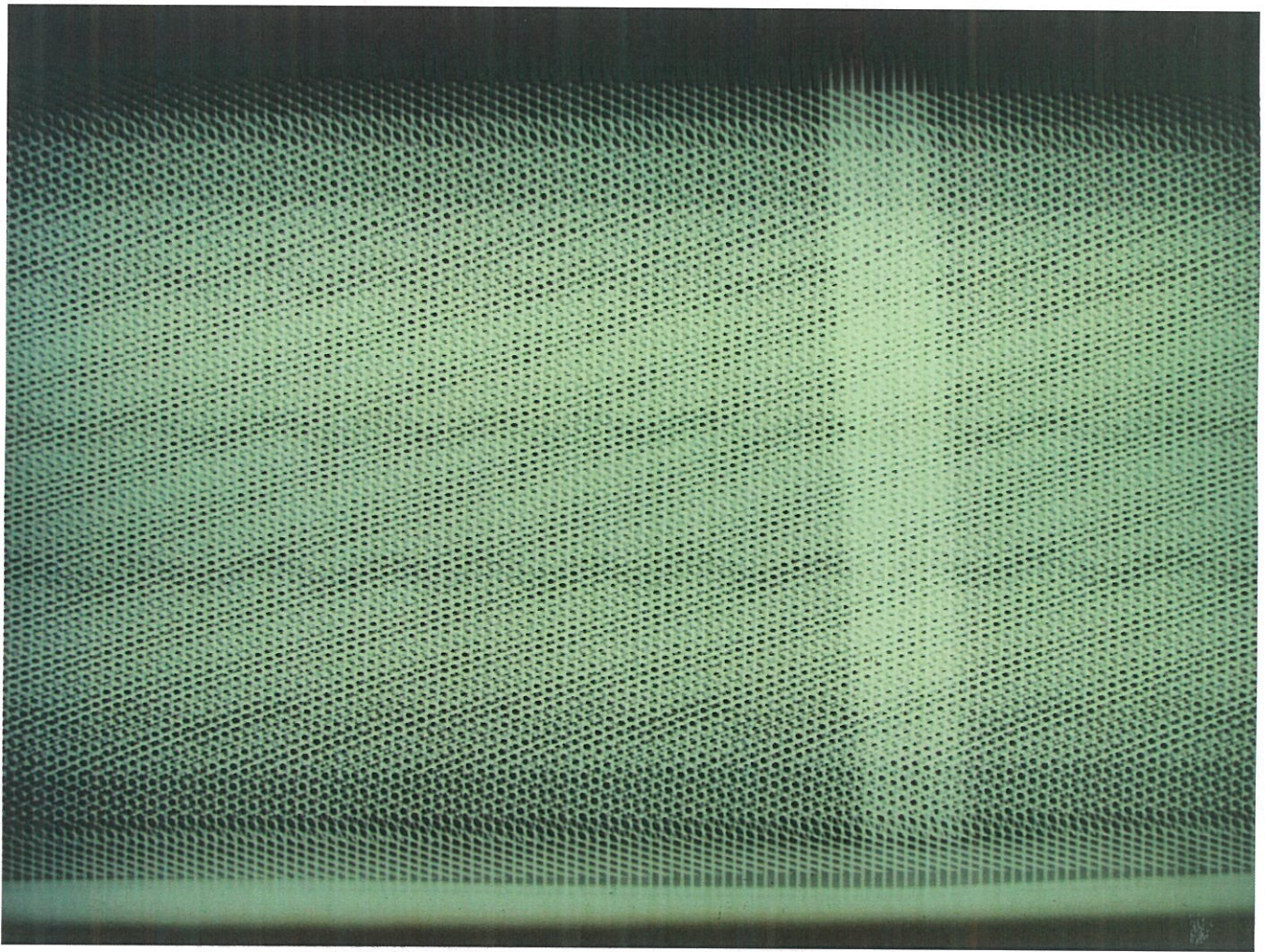


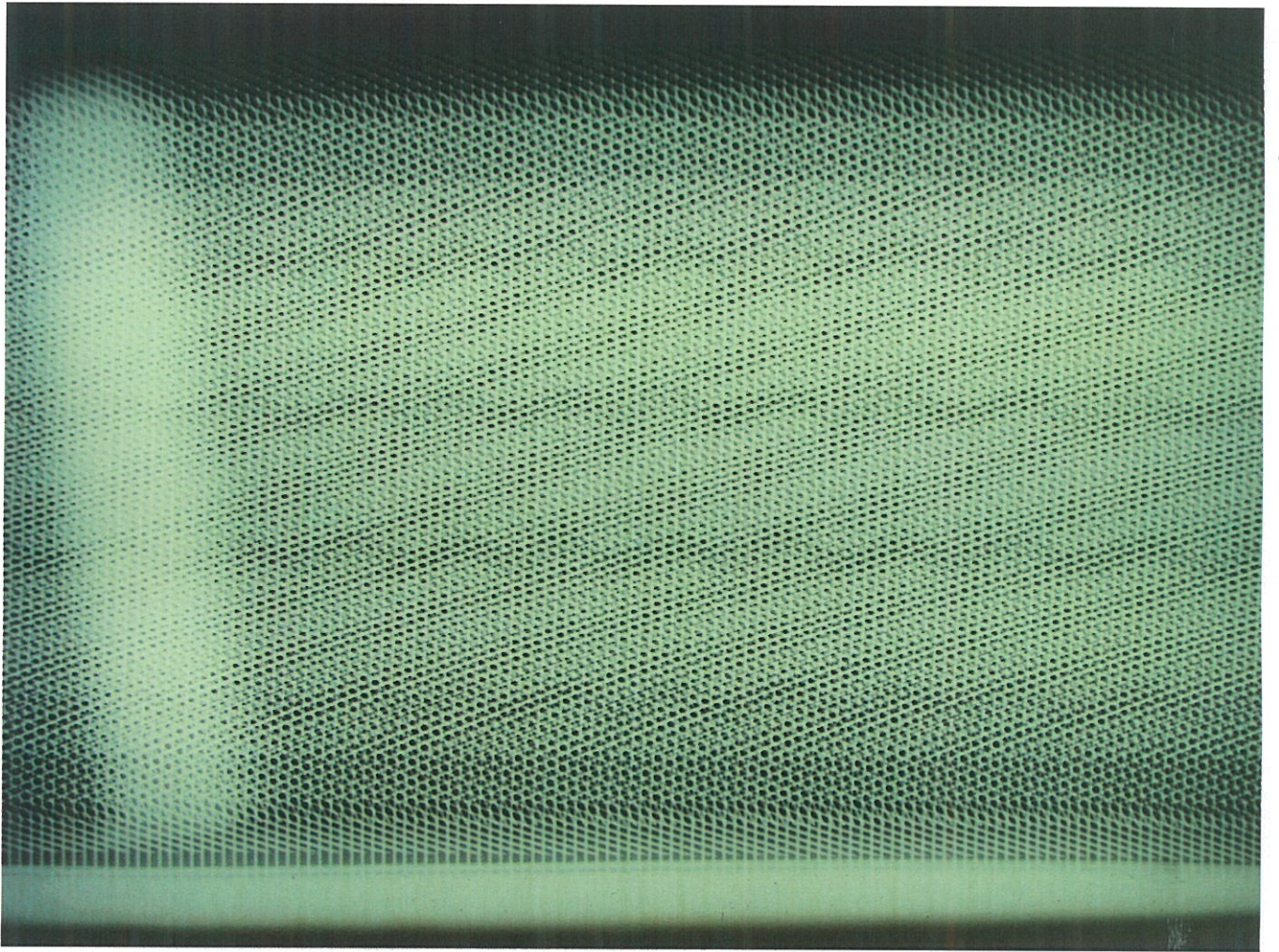


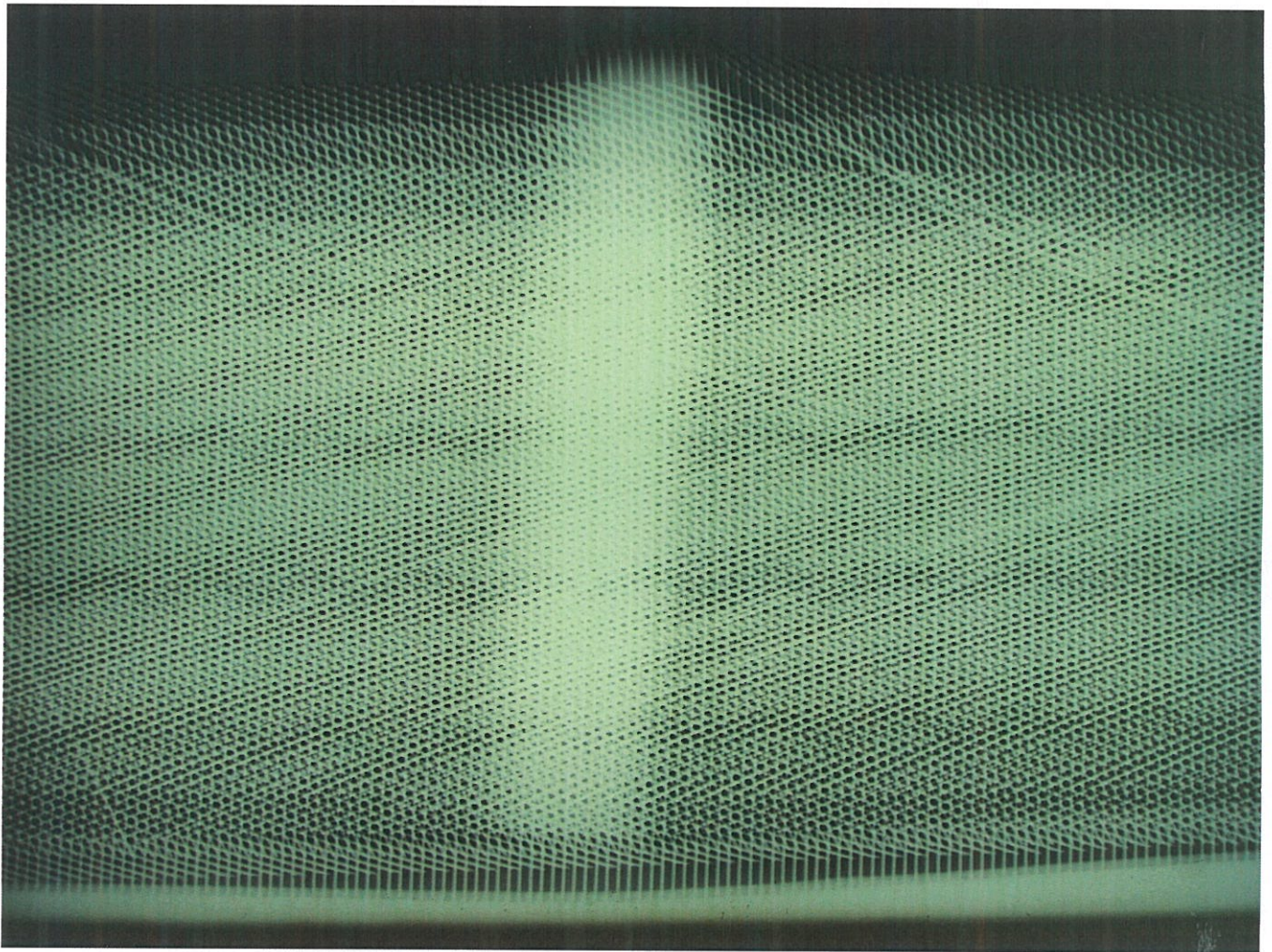


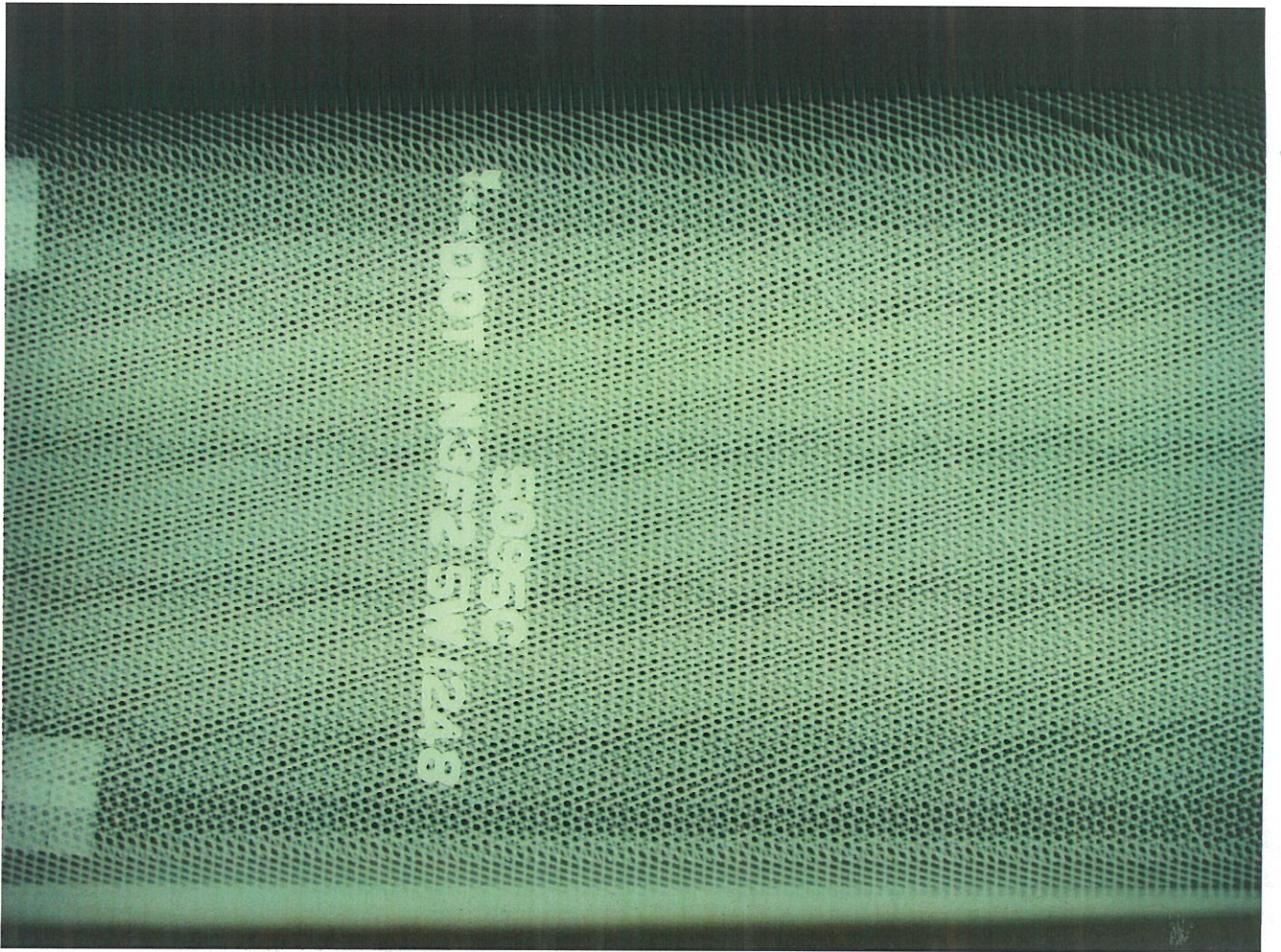






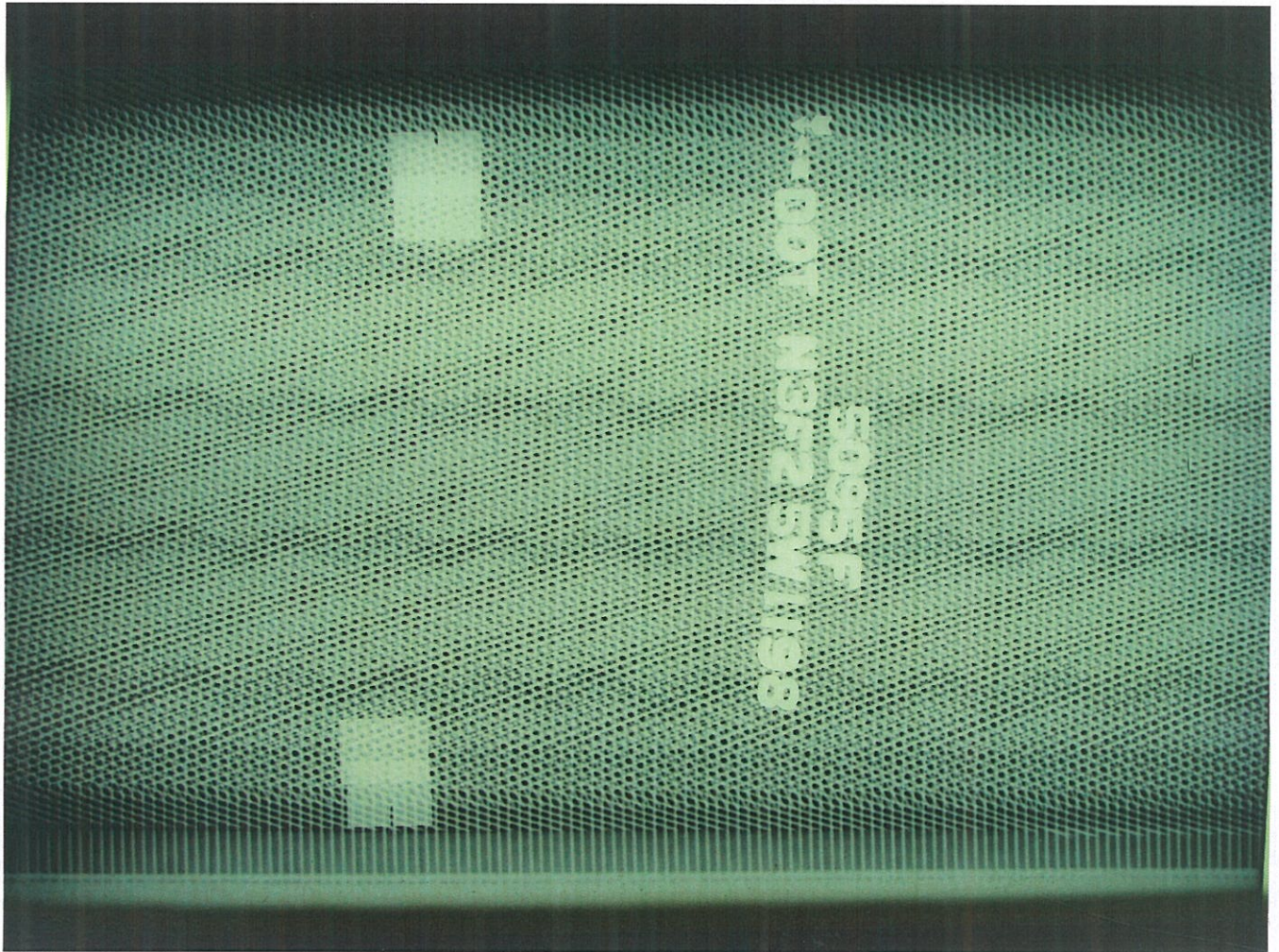




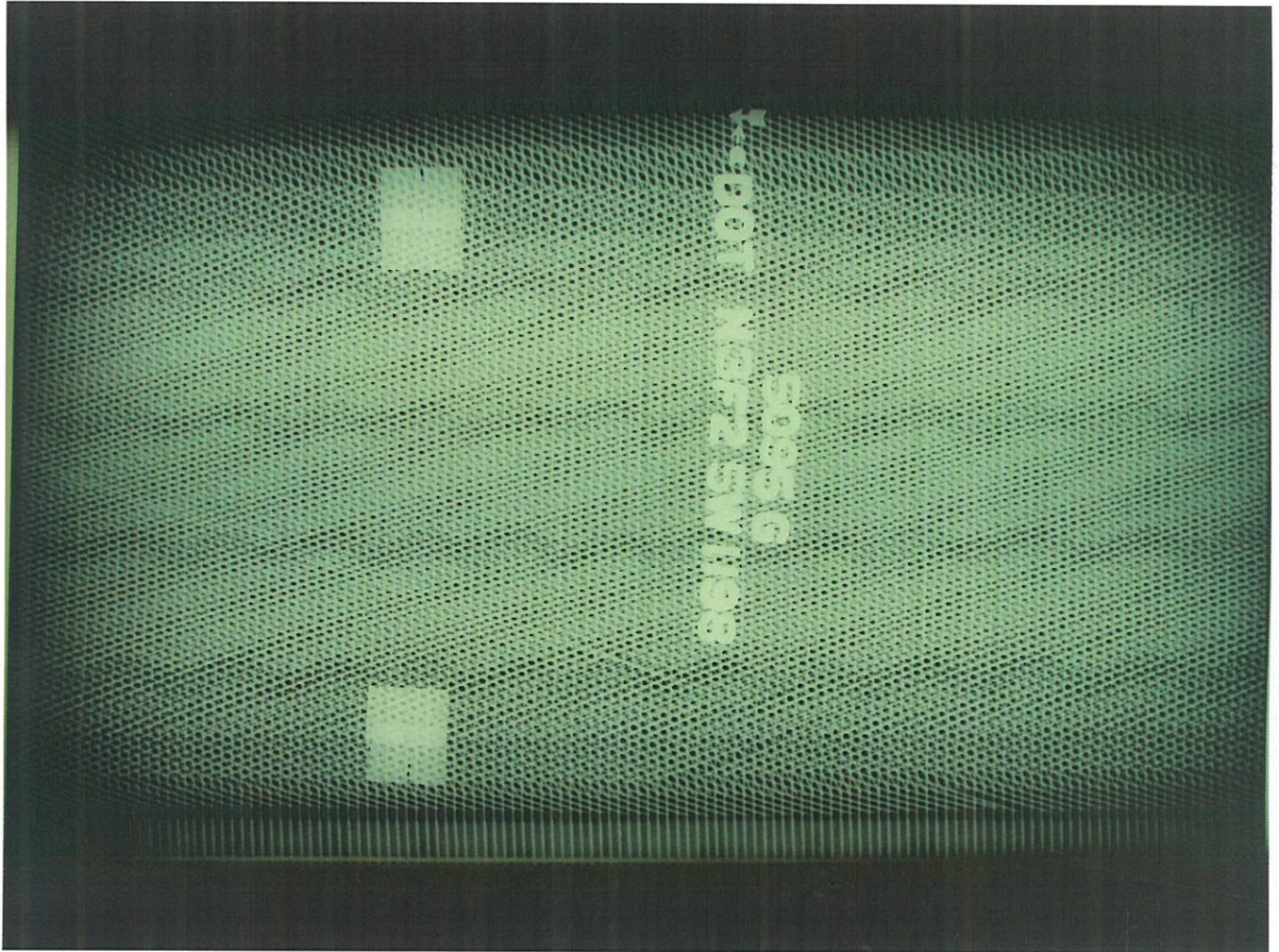




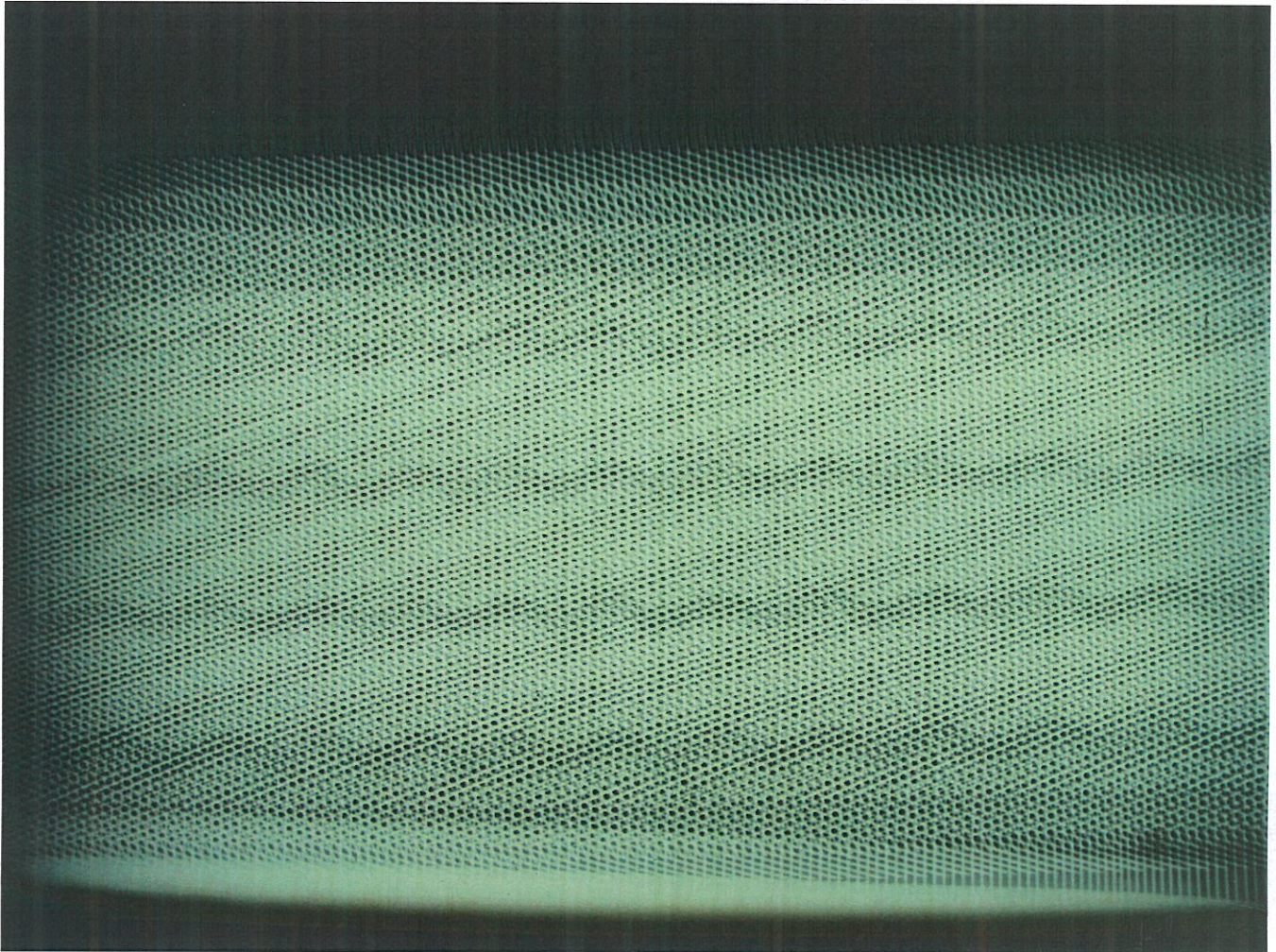
# Tire F - X-ray Image

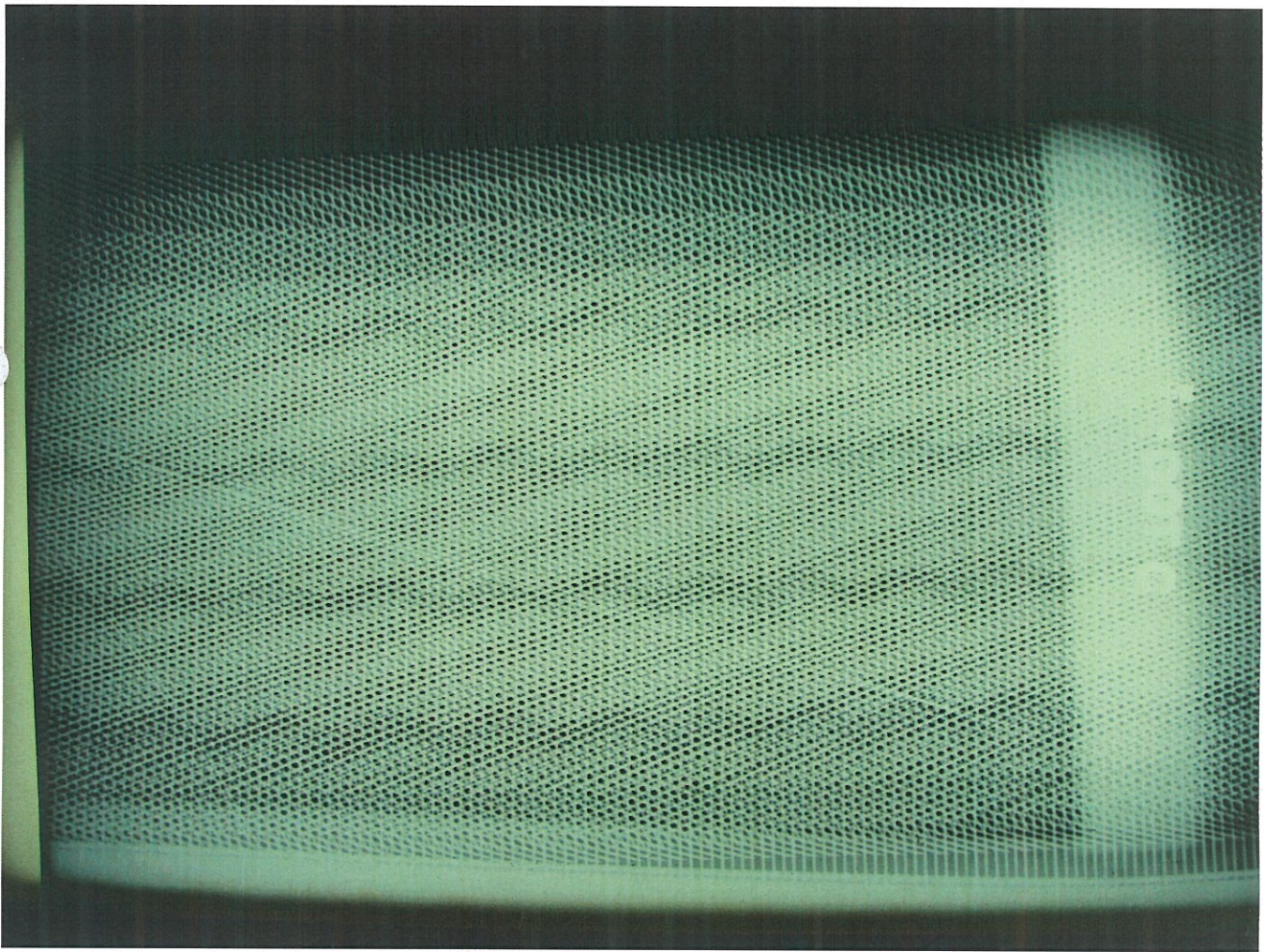


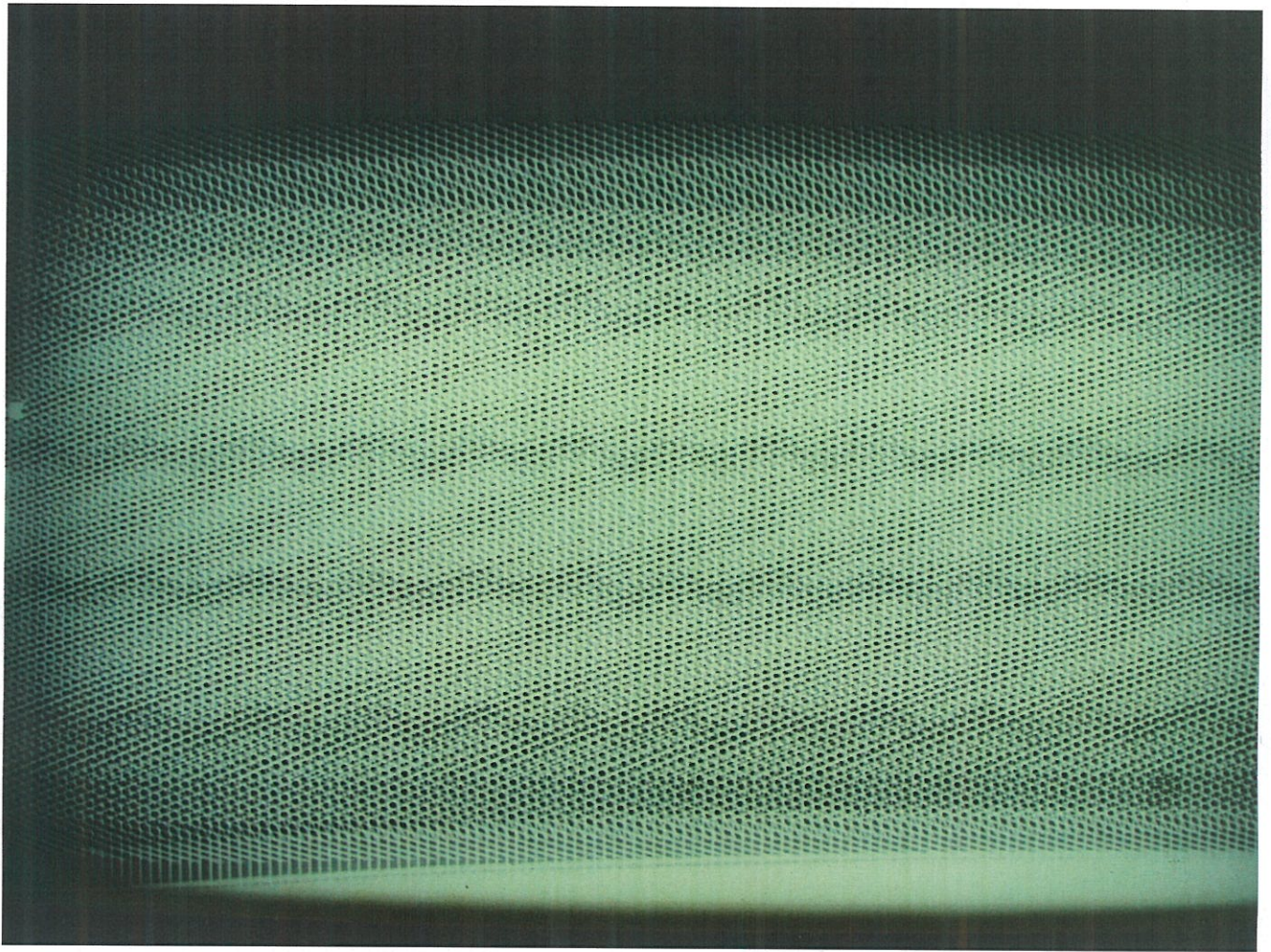
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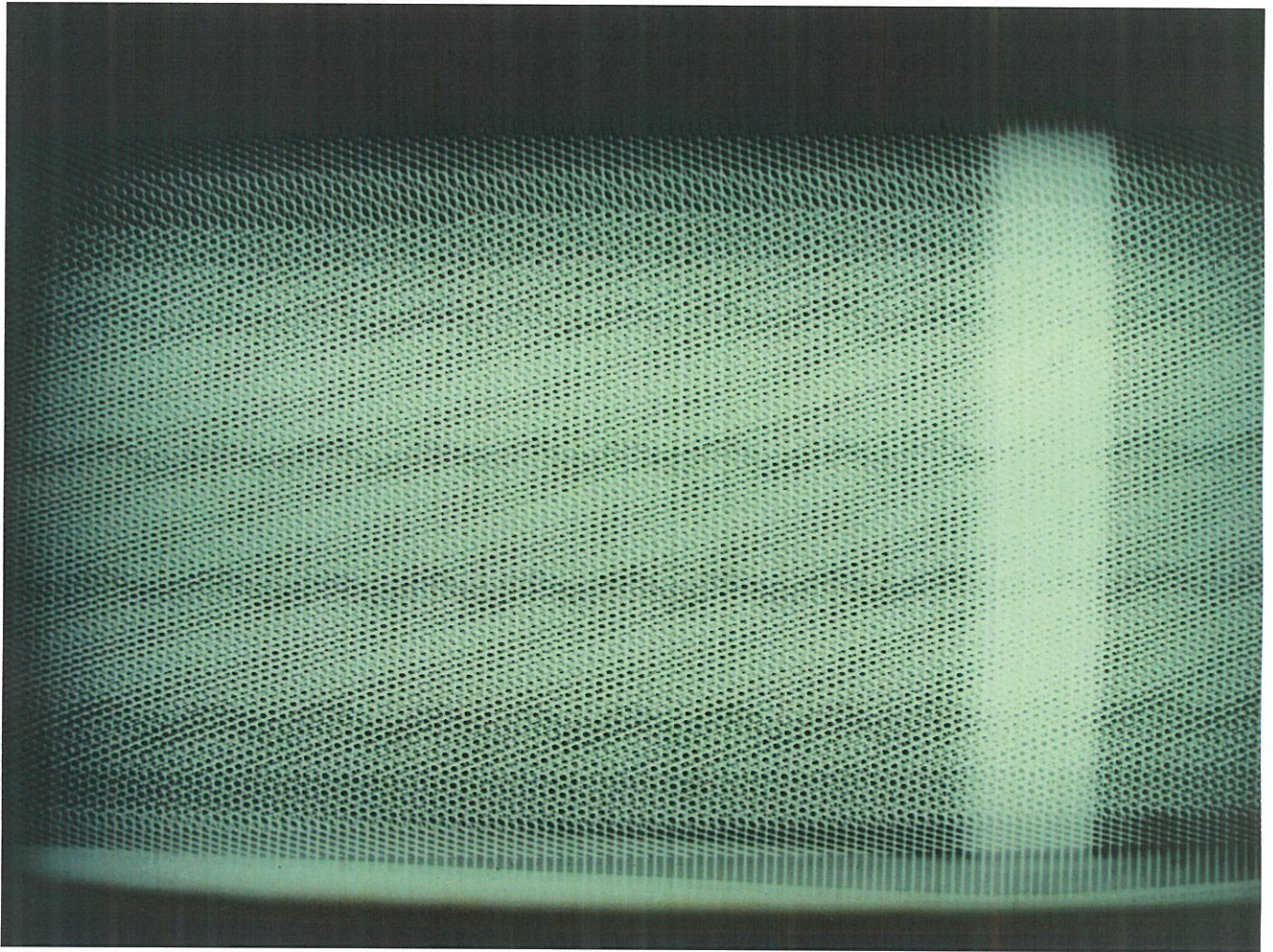


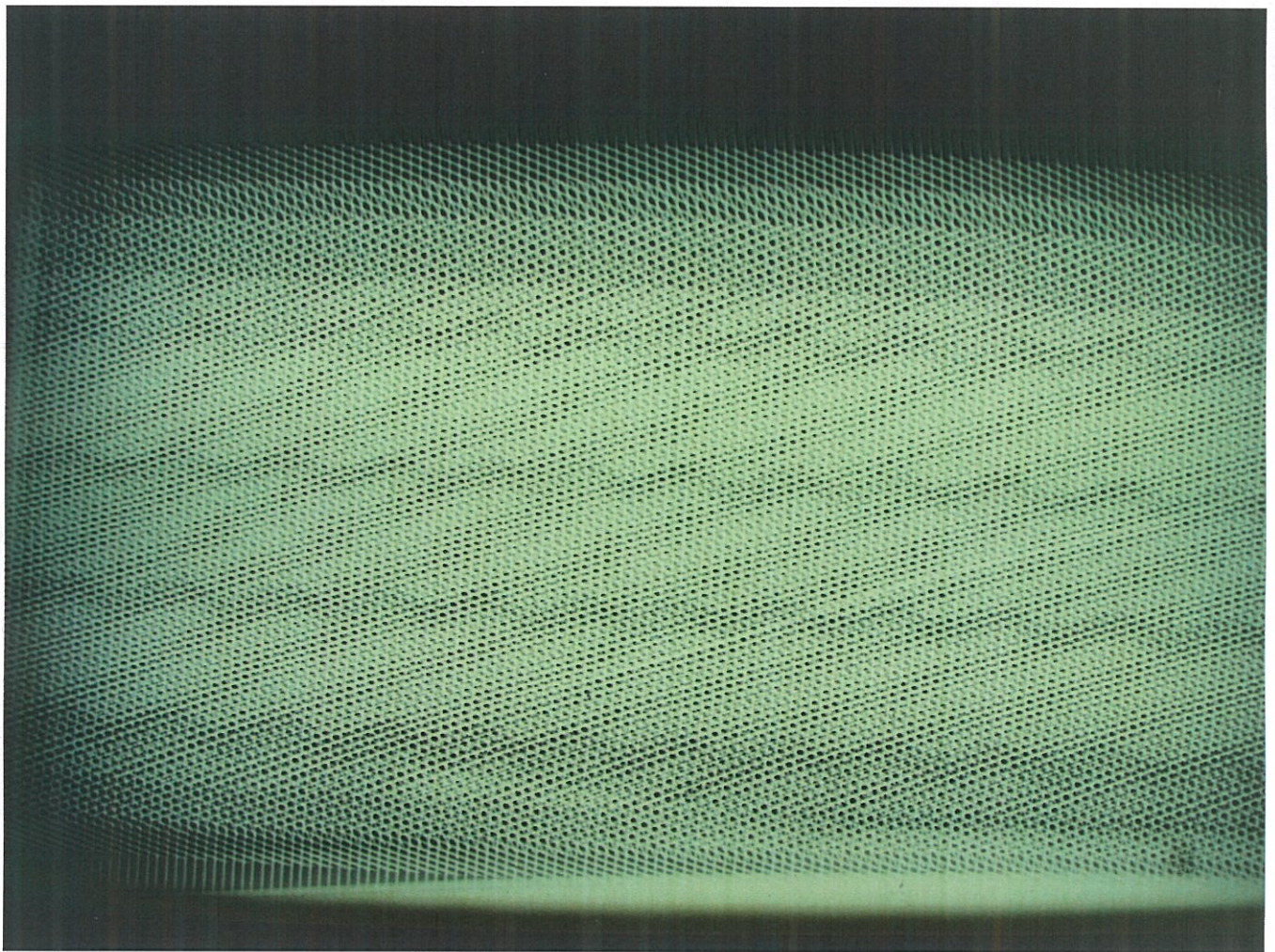
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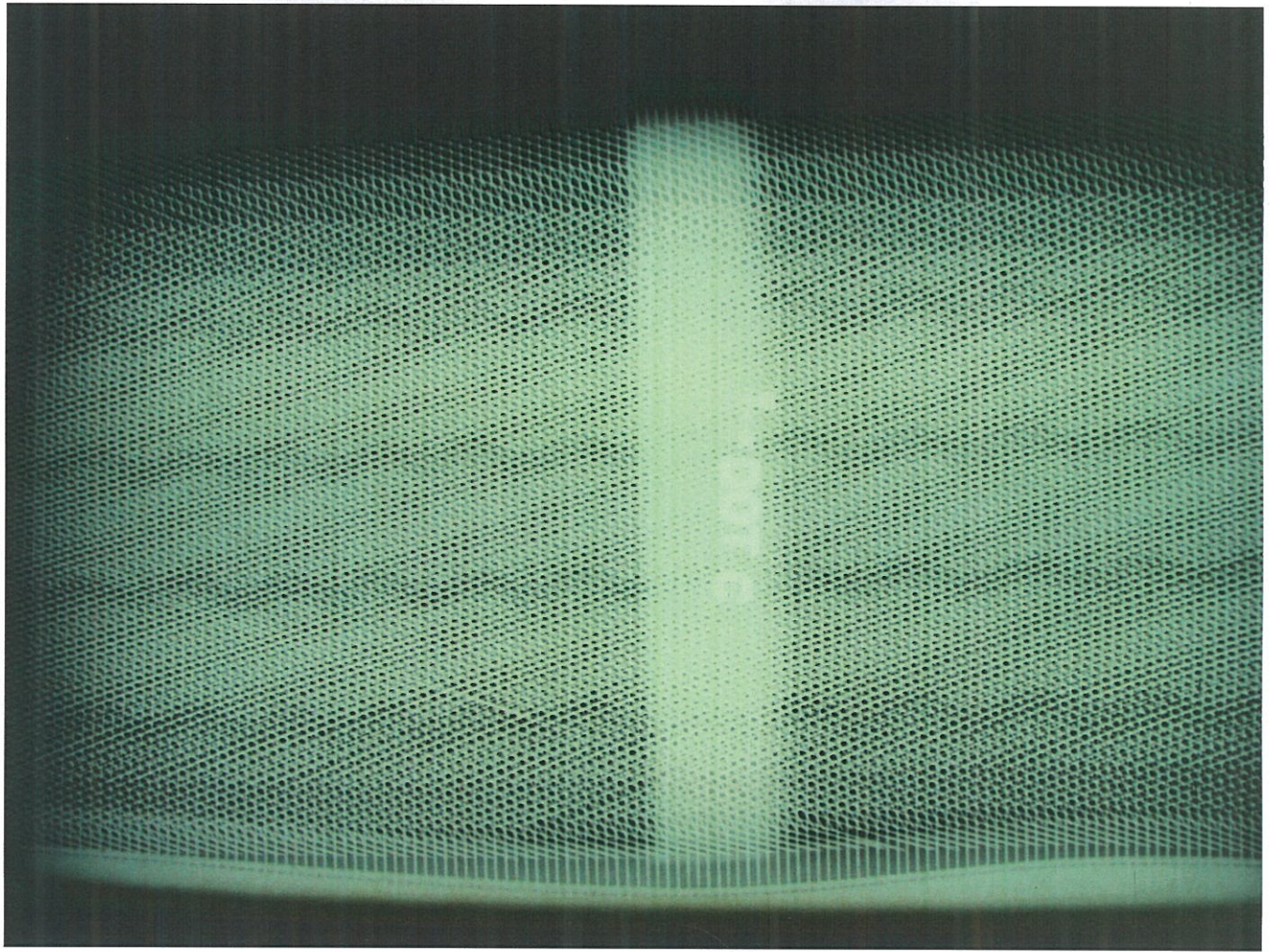


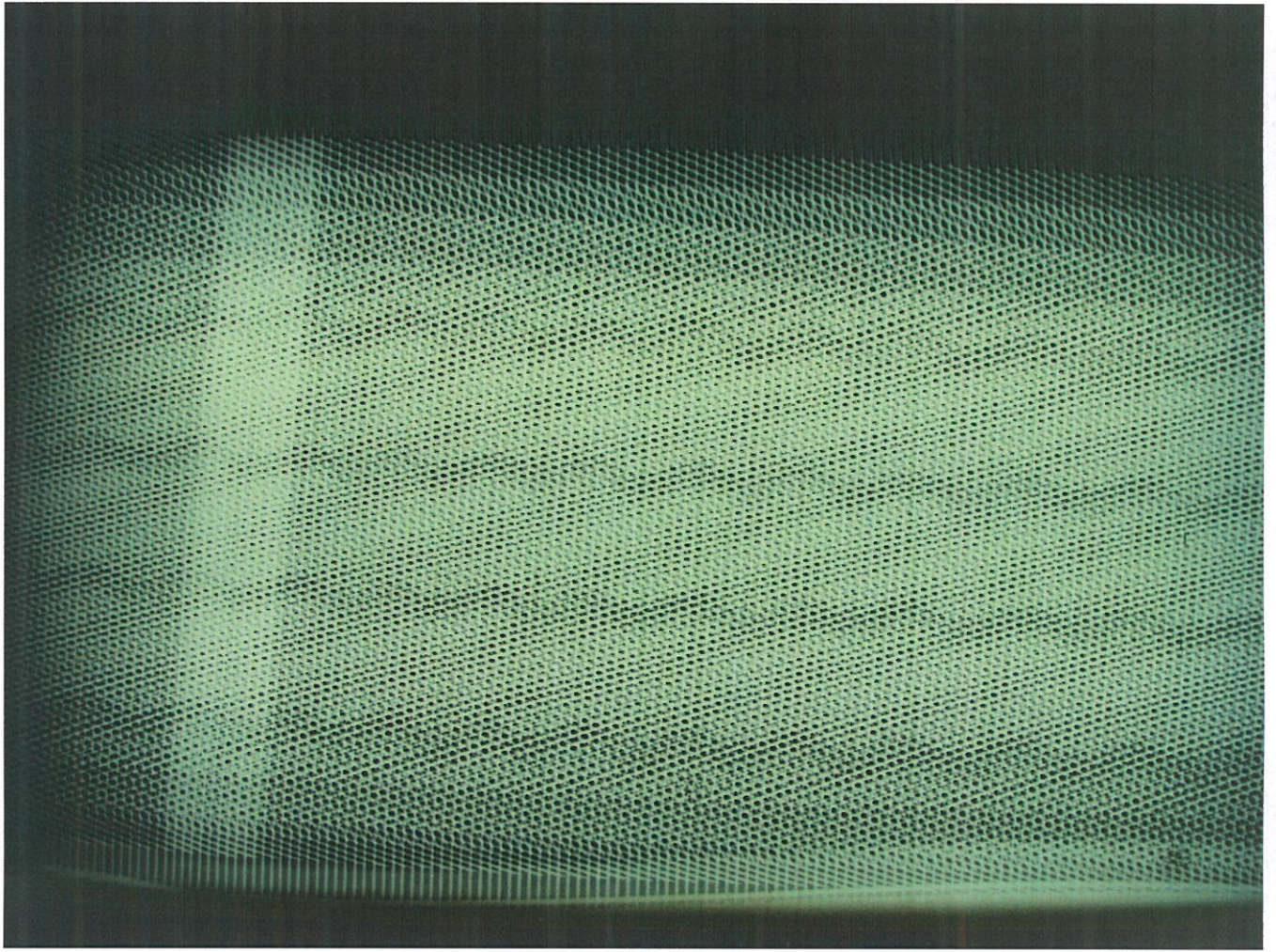


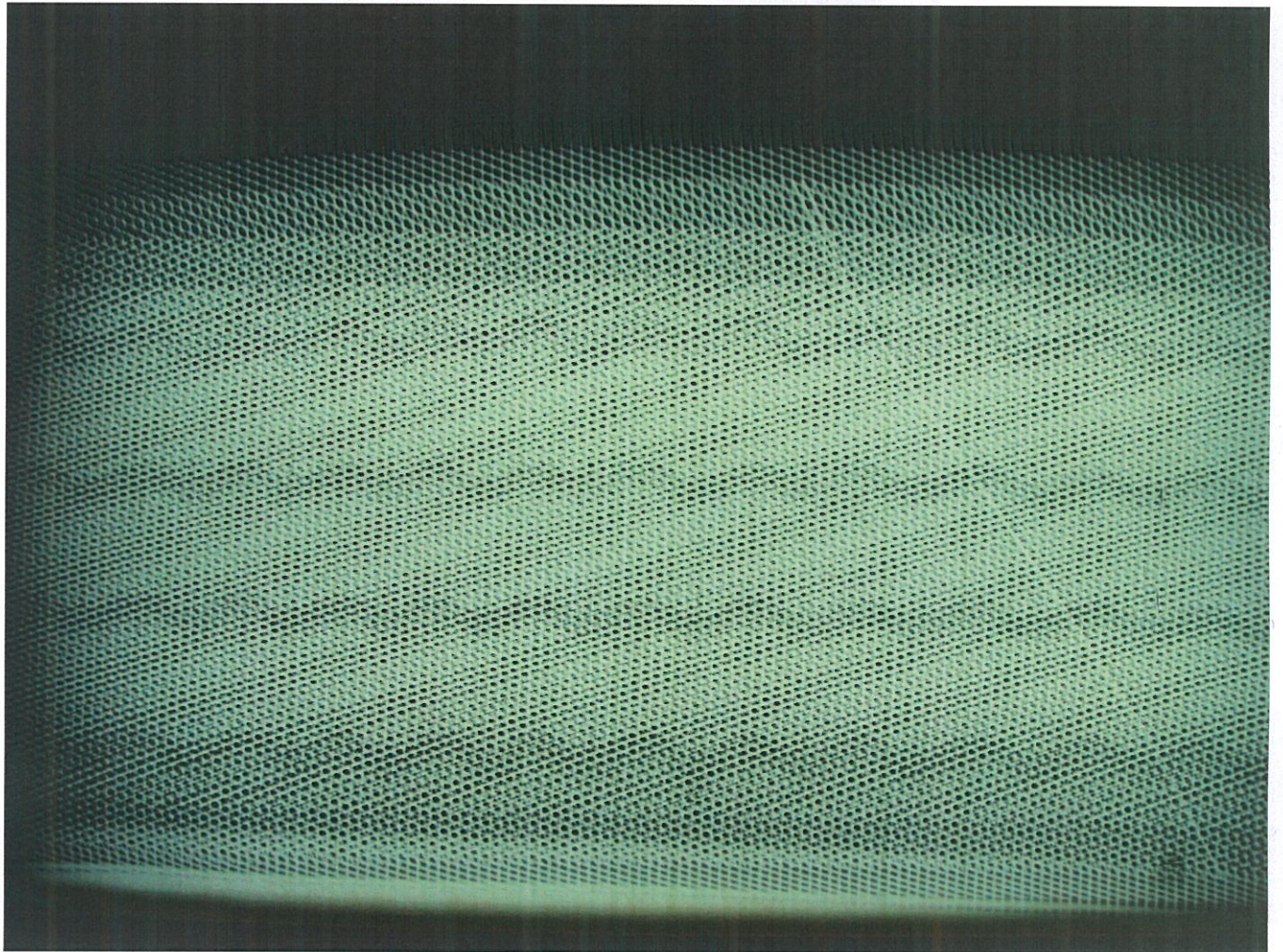


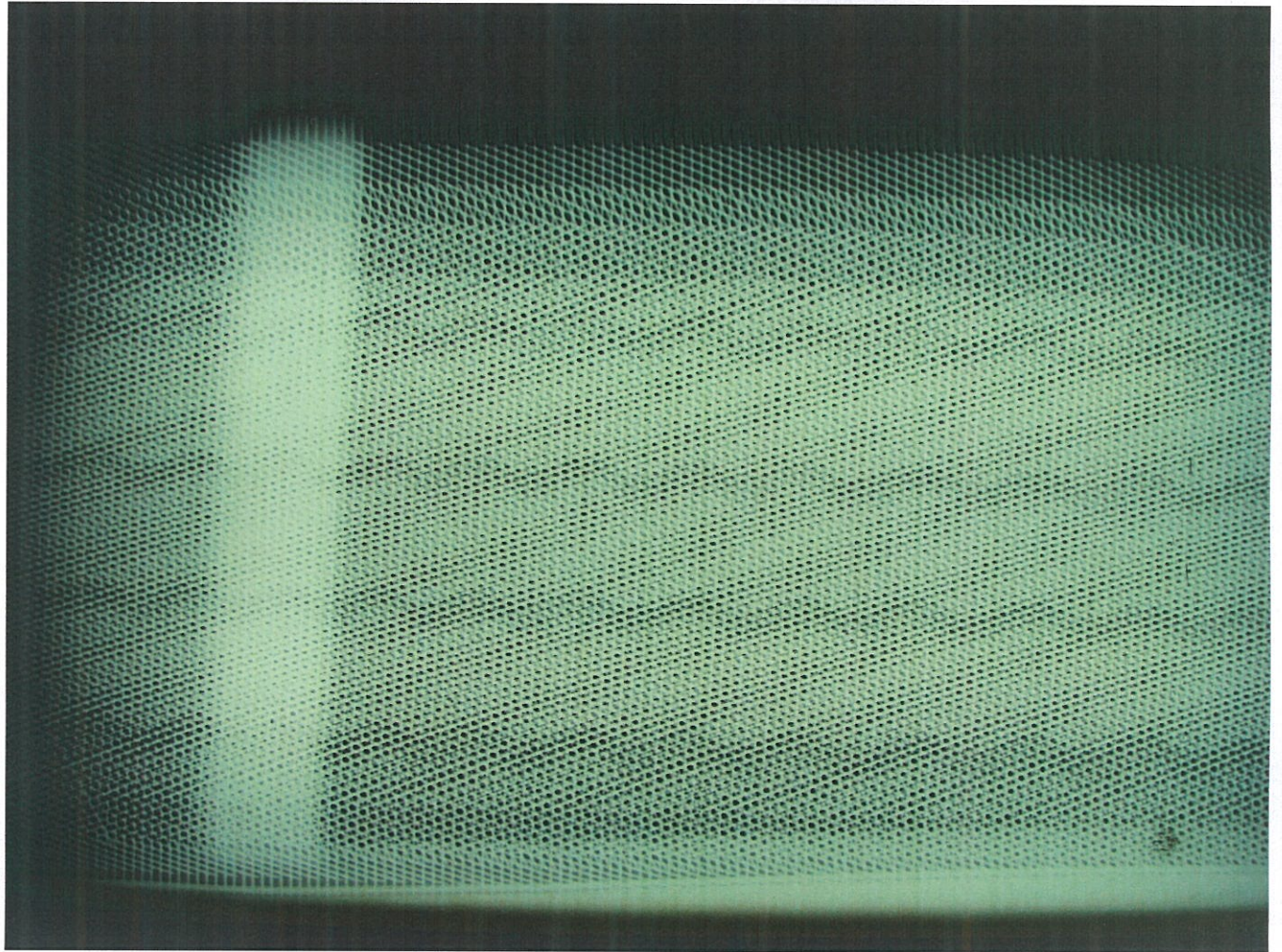


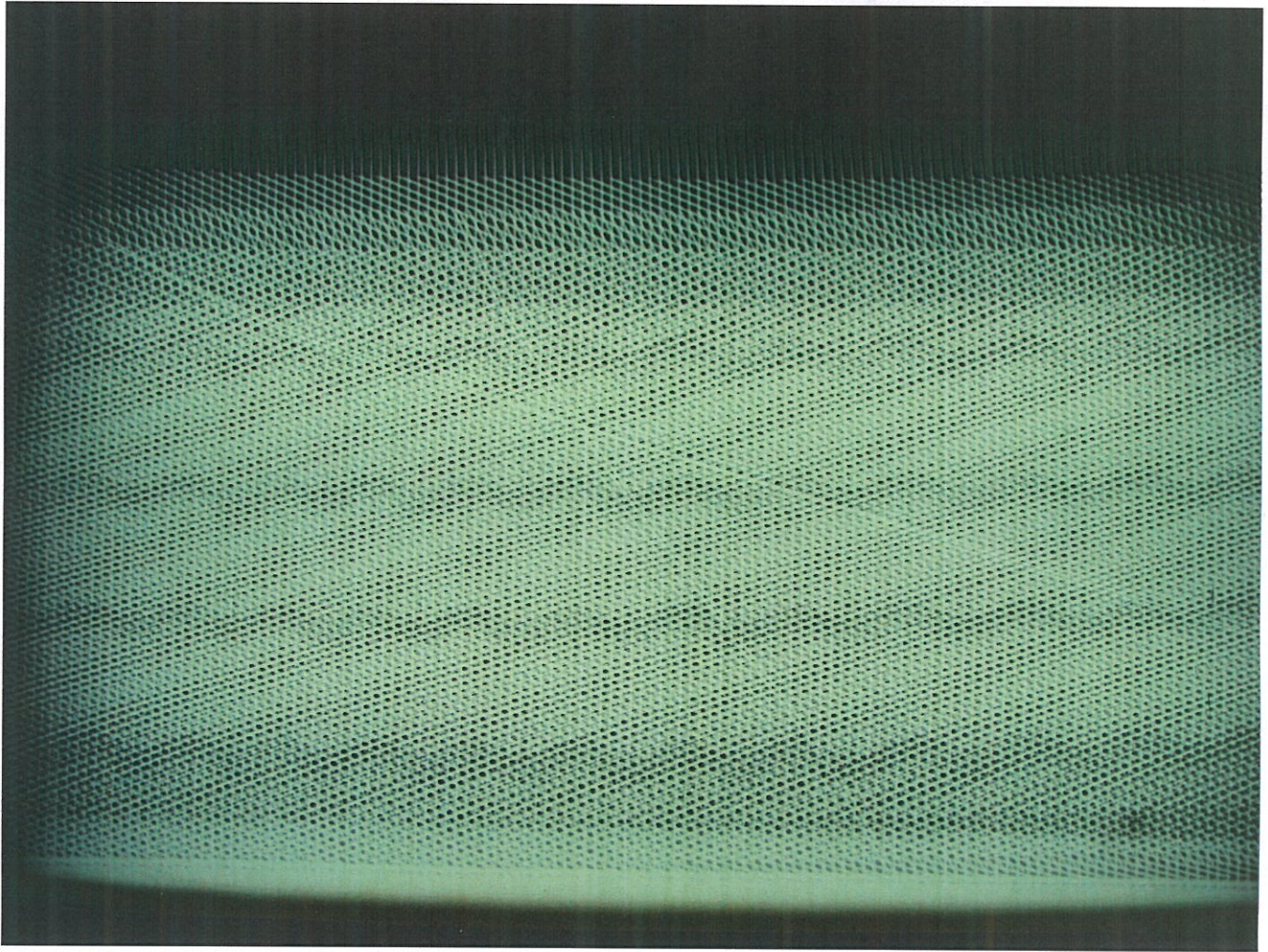




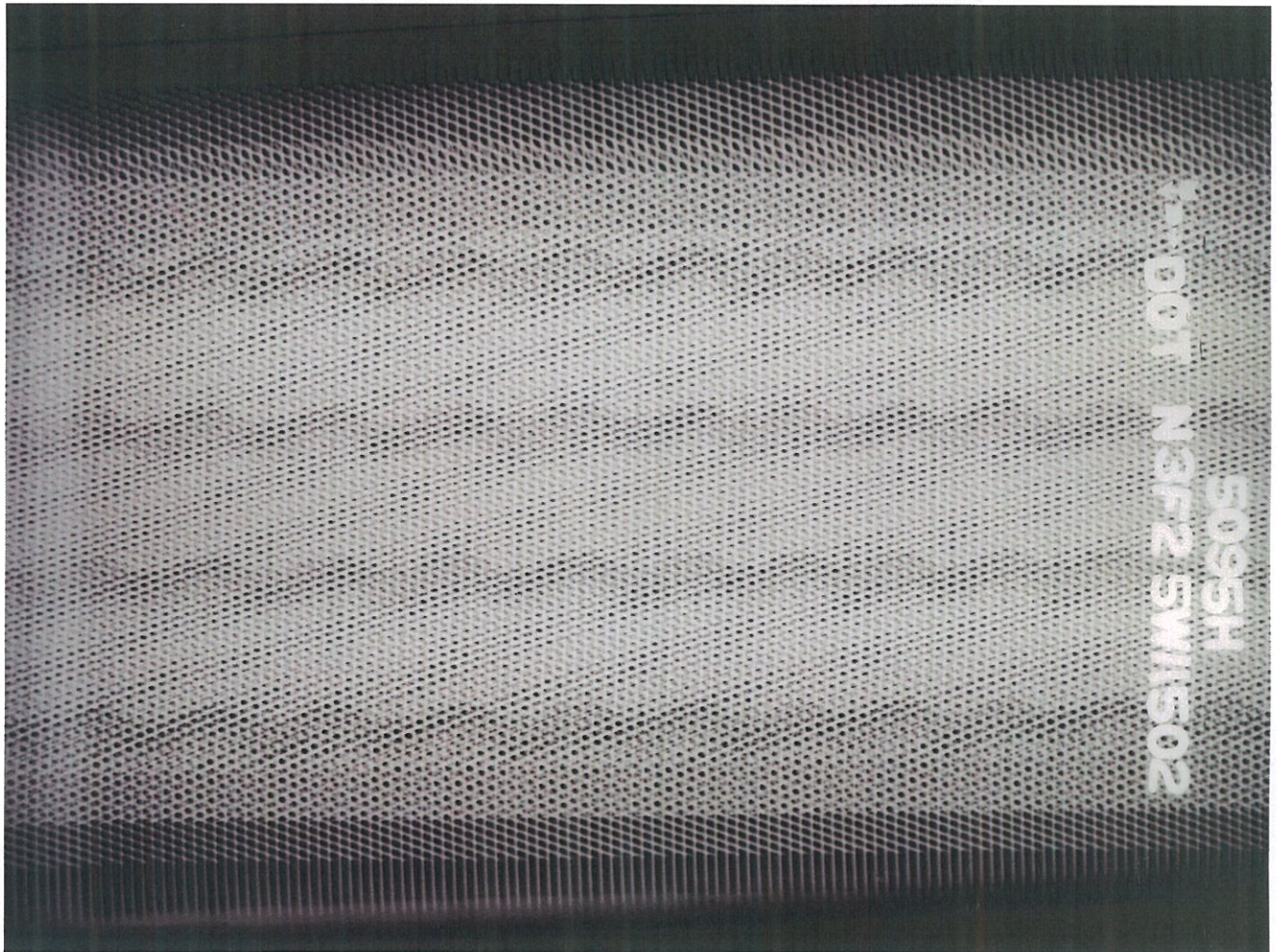


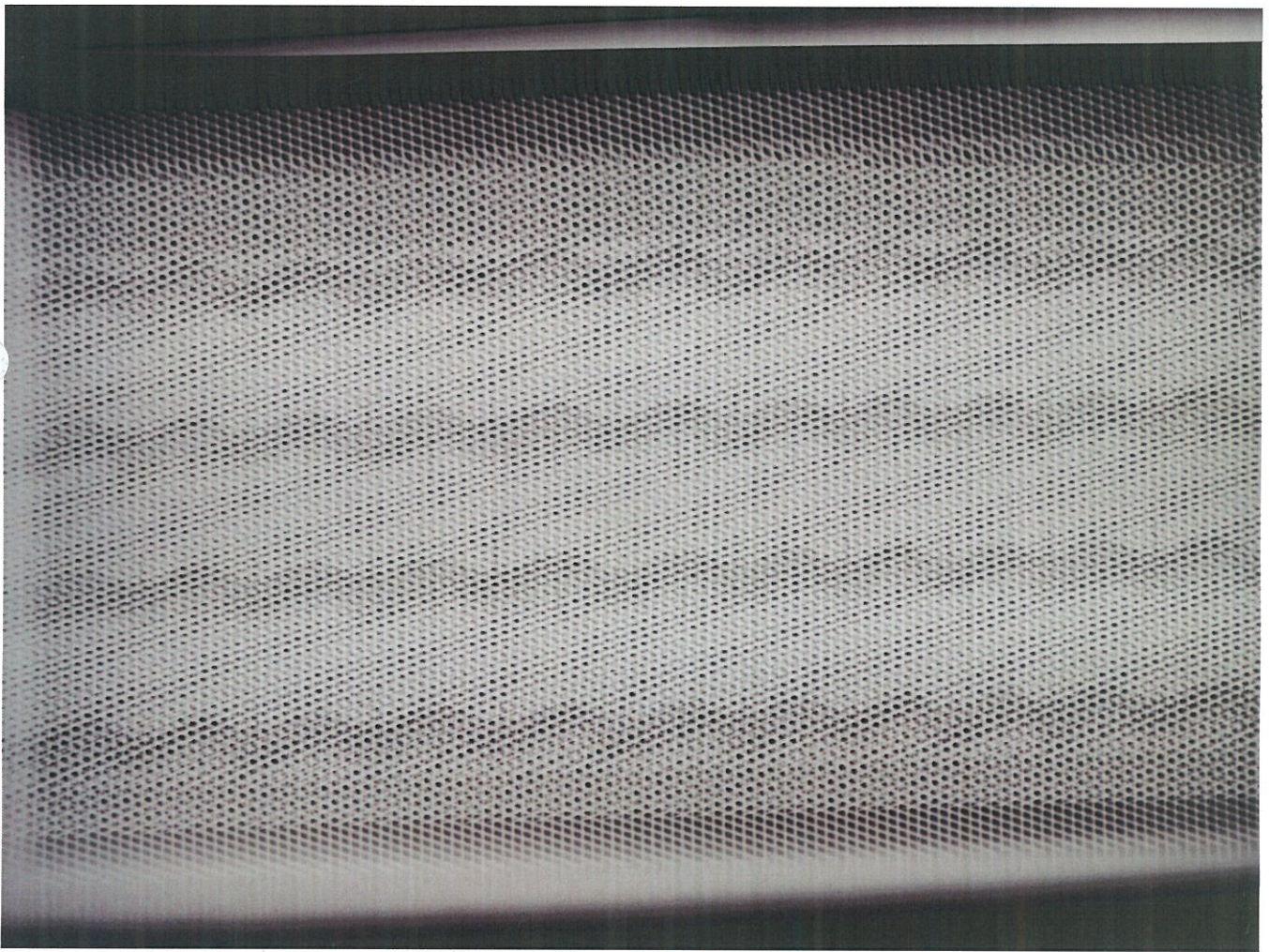


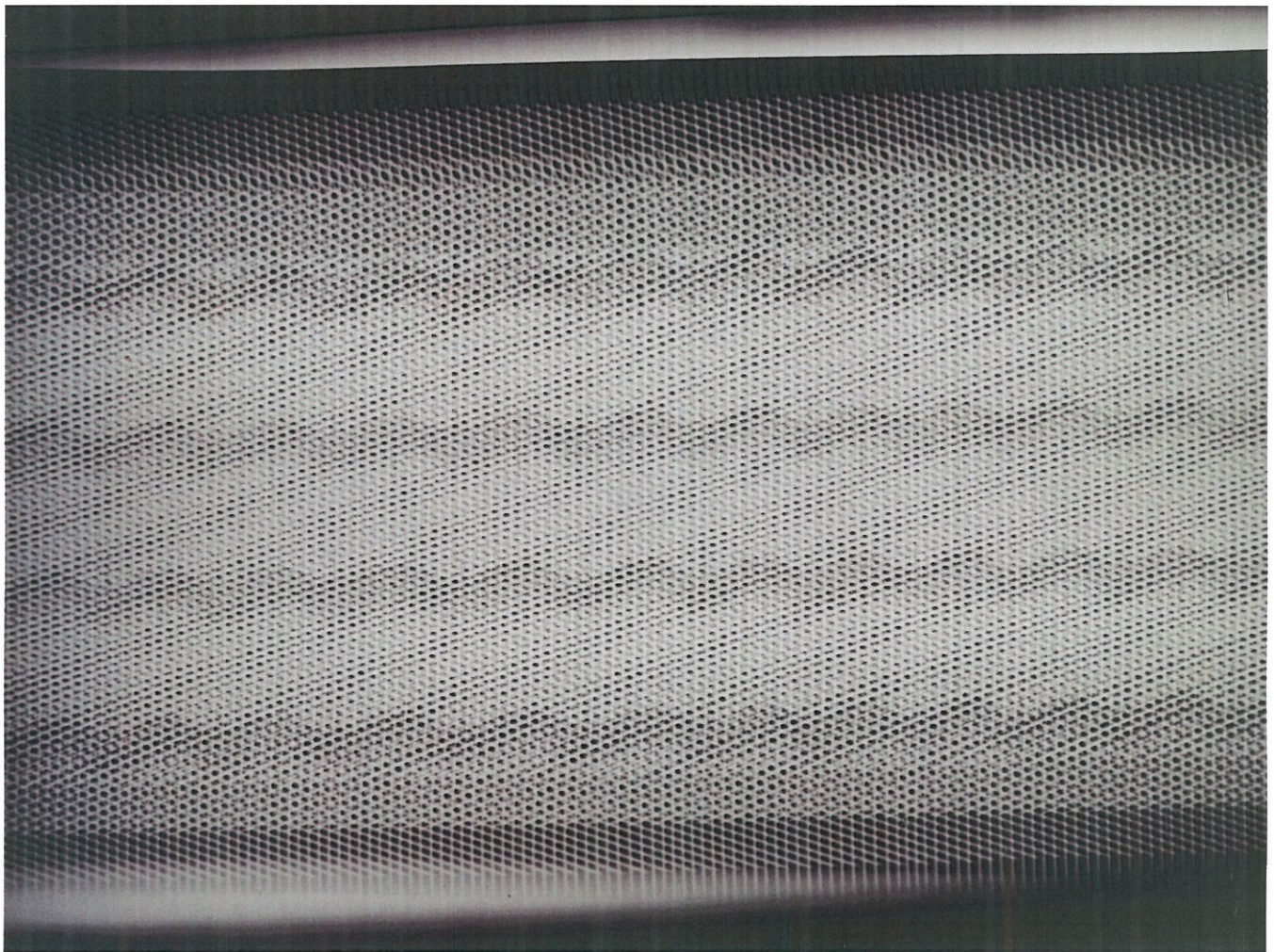


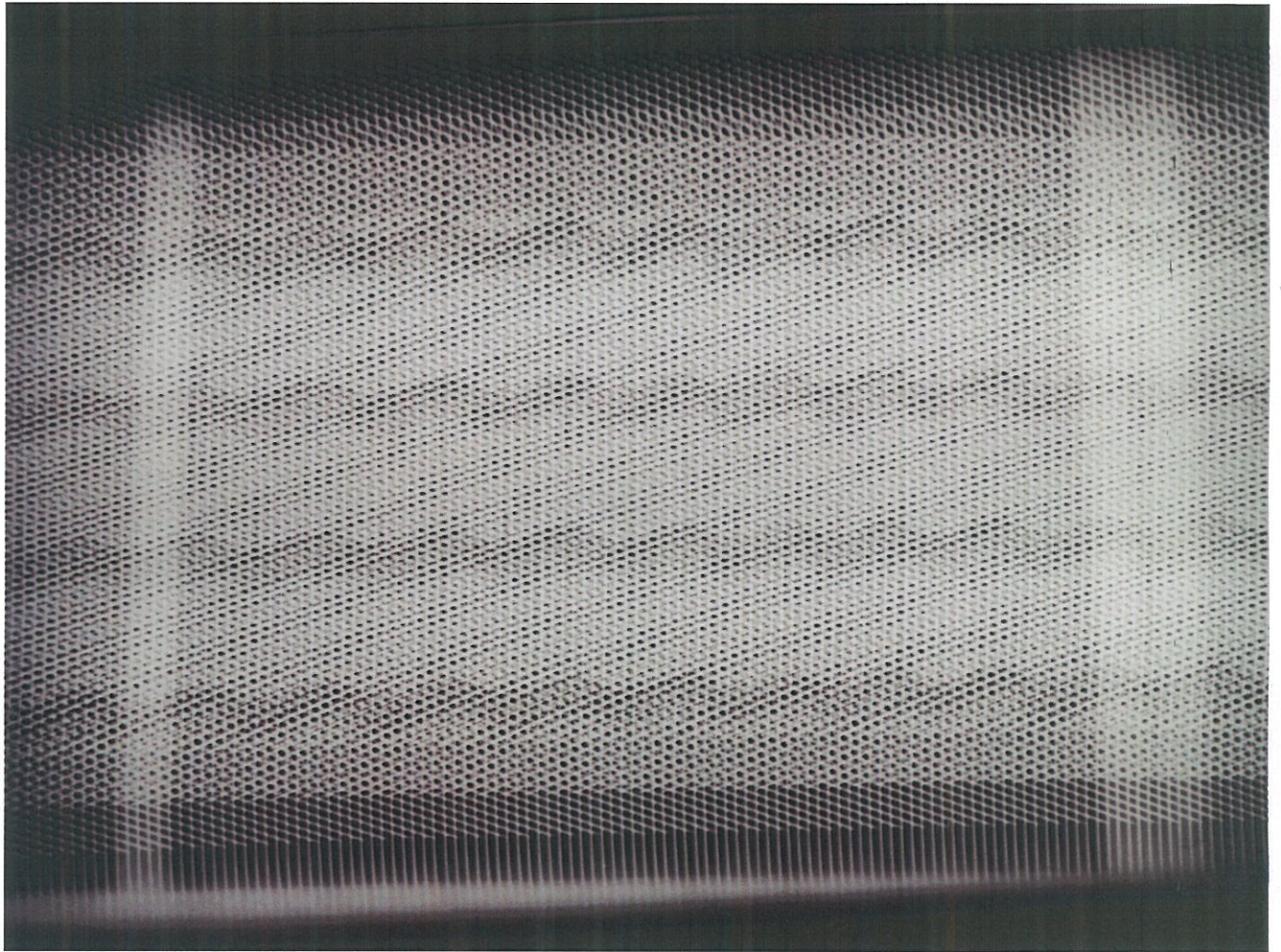


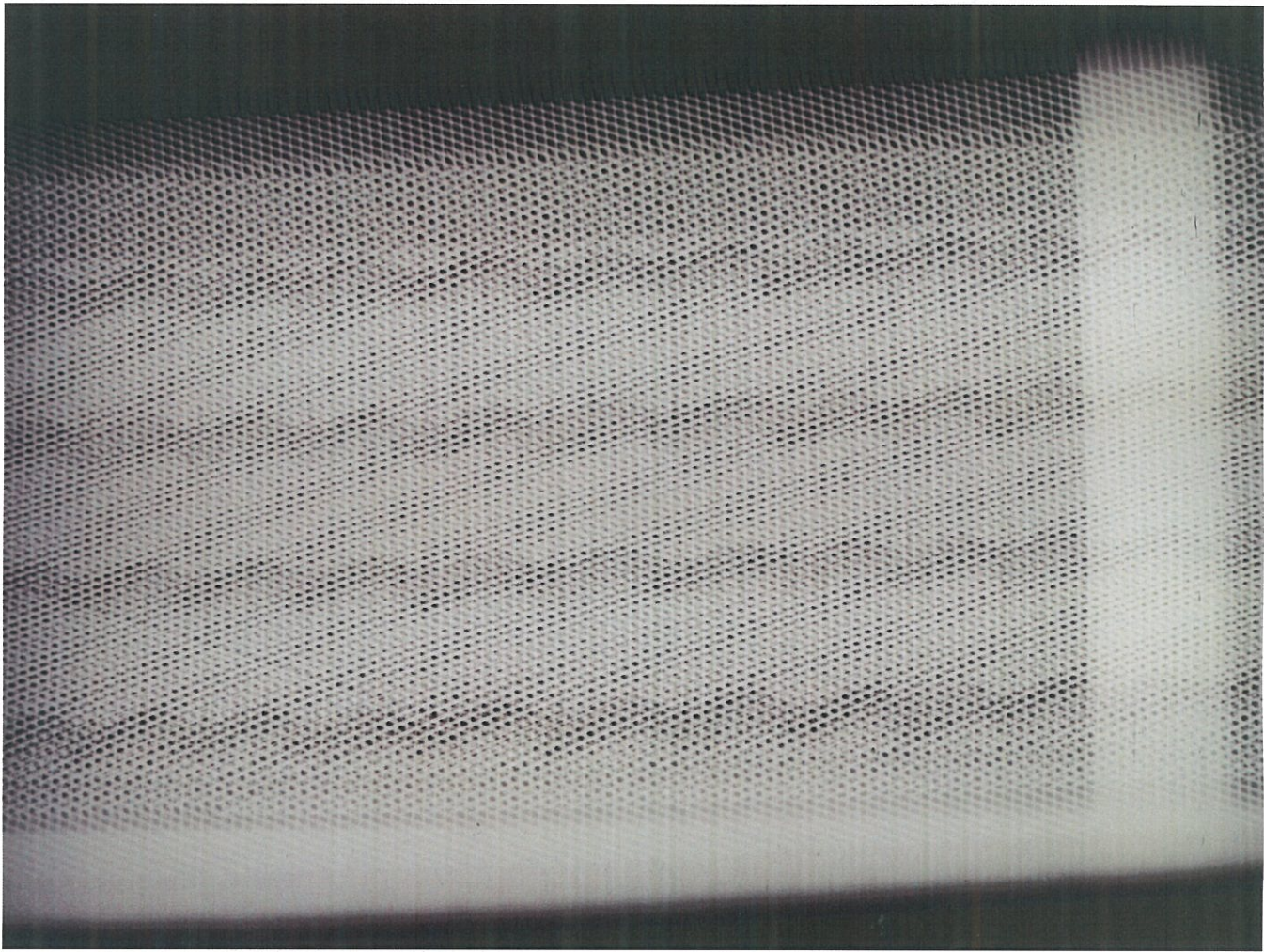
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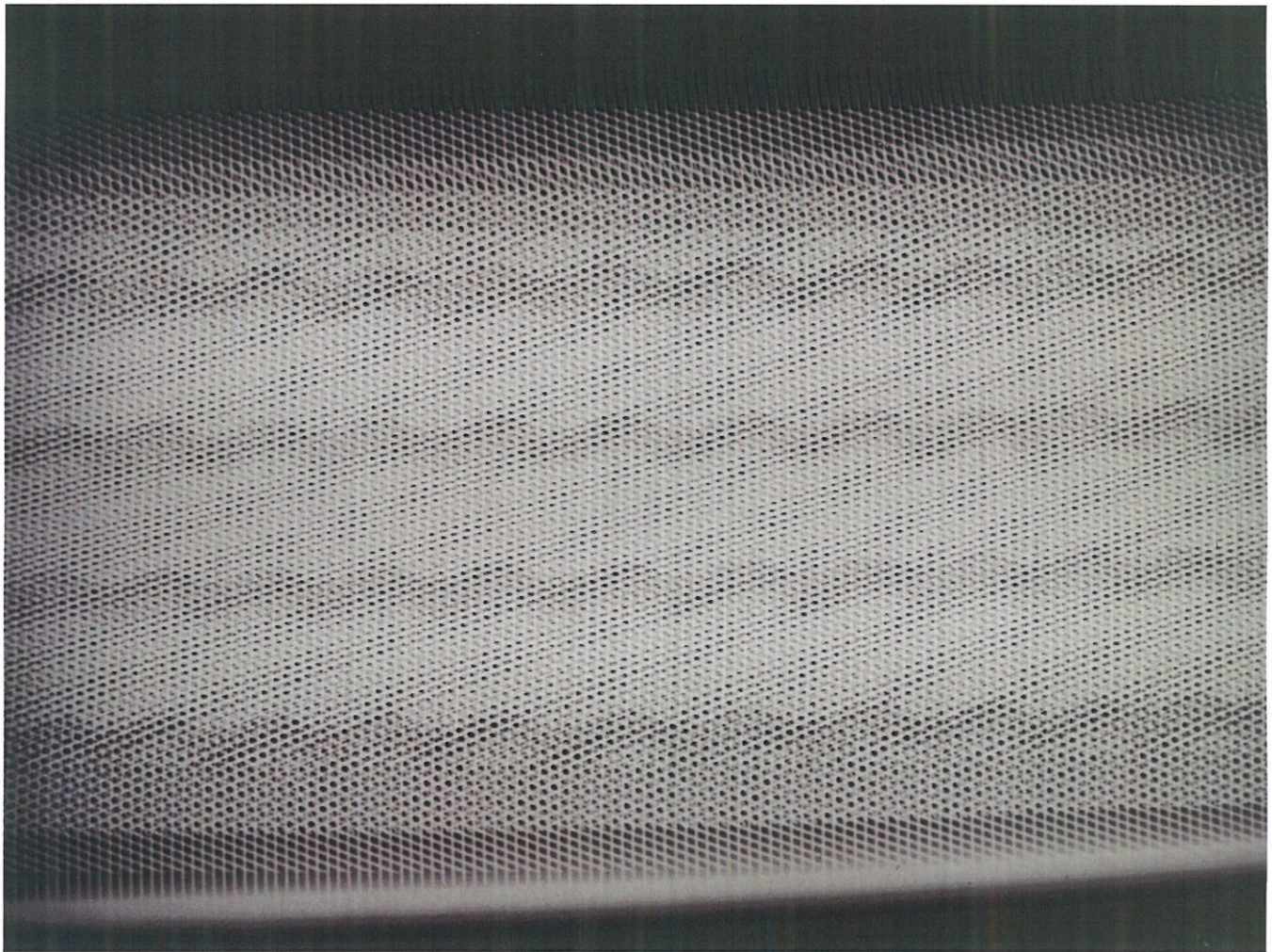


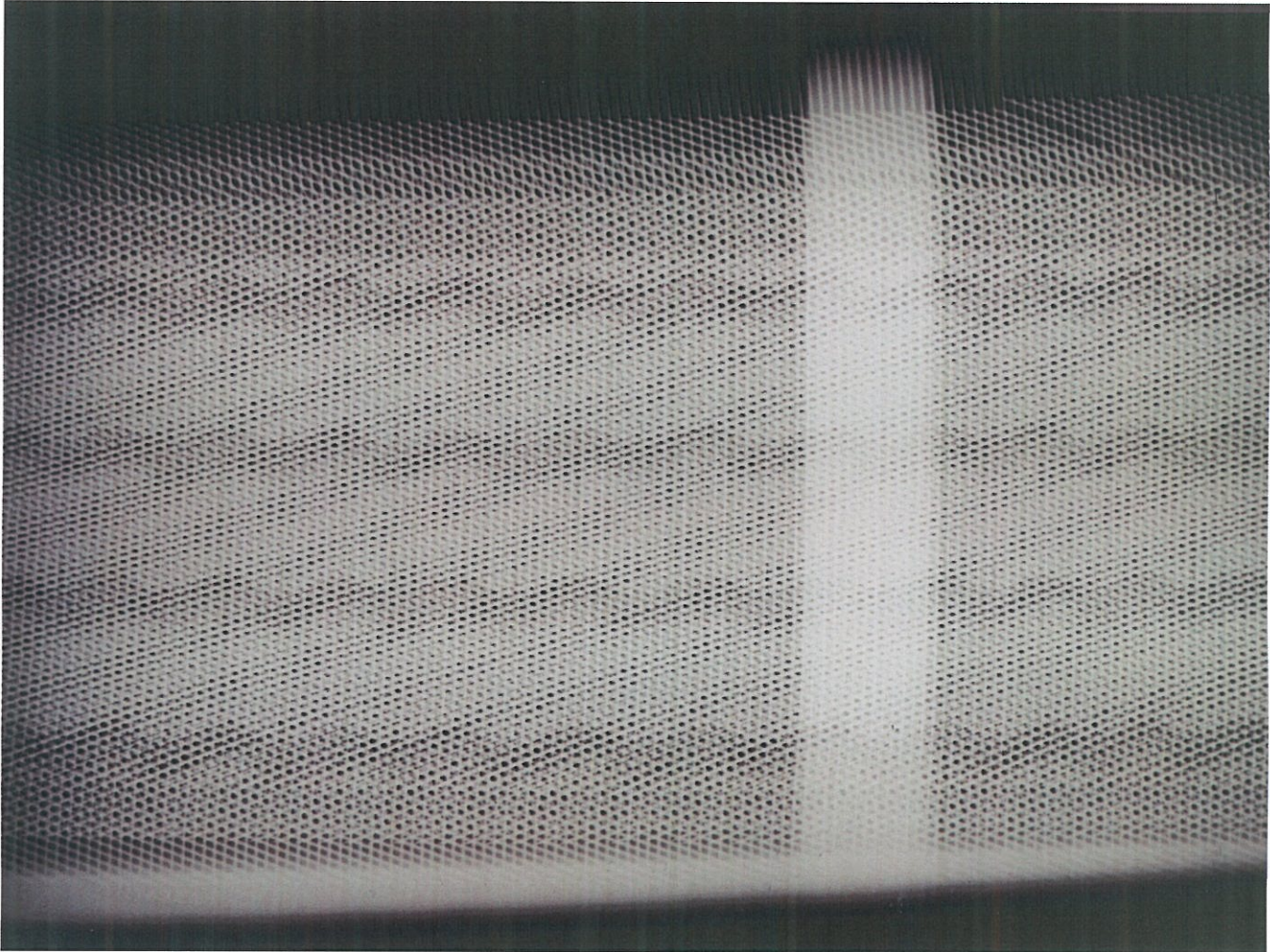


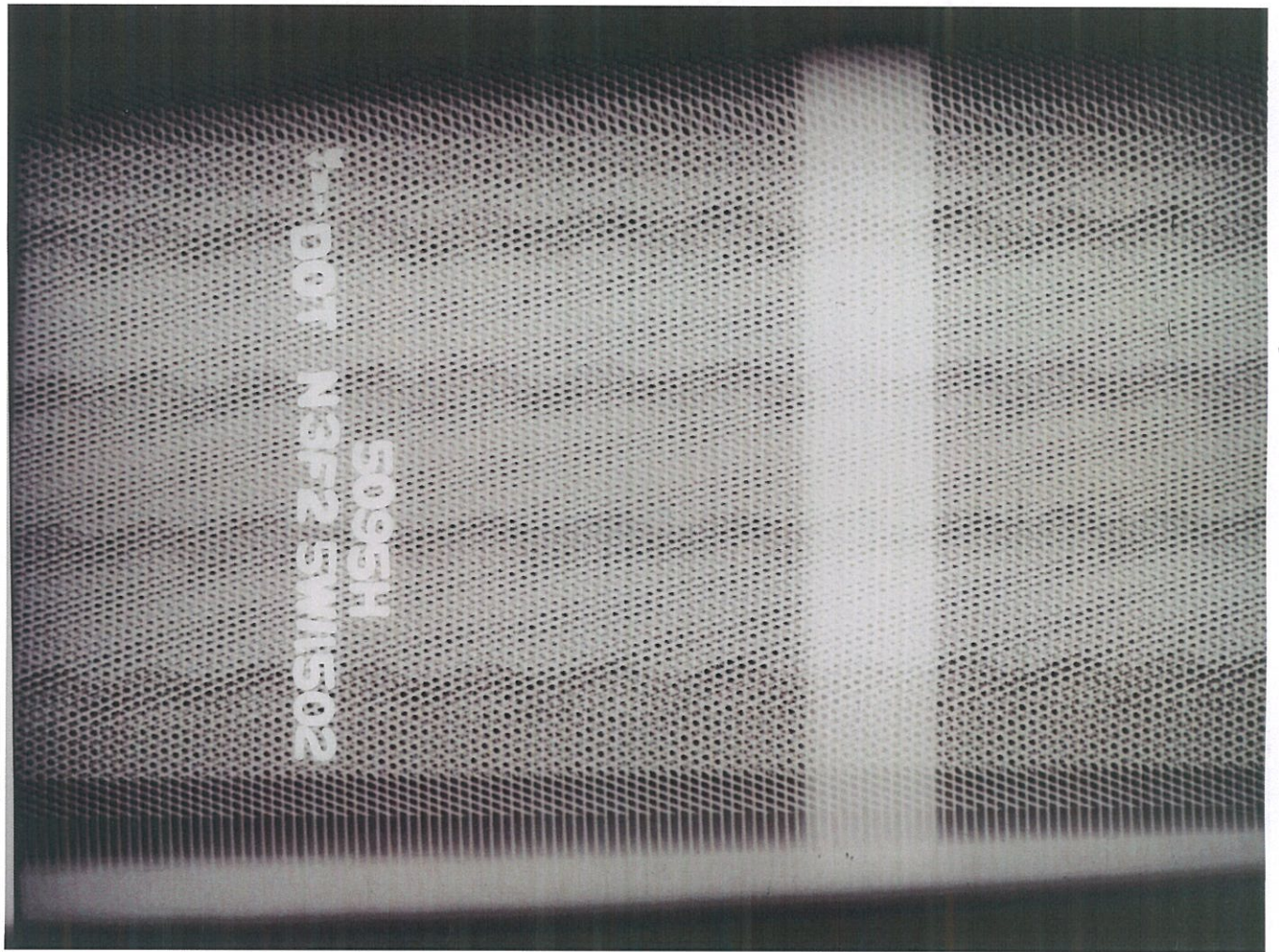


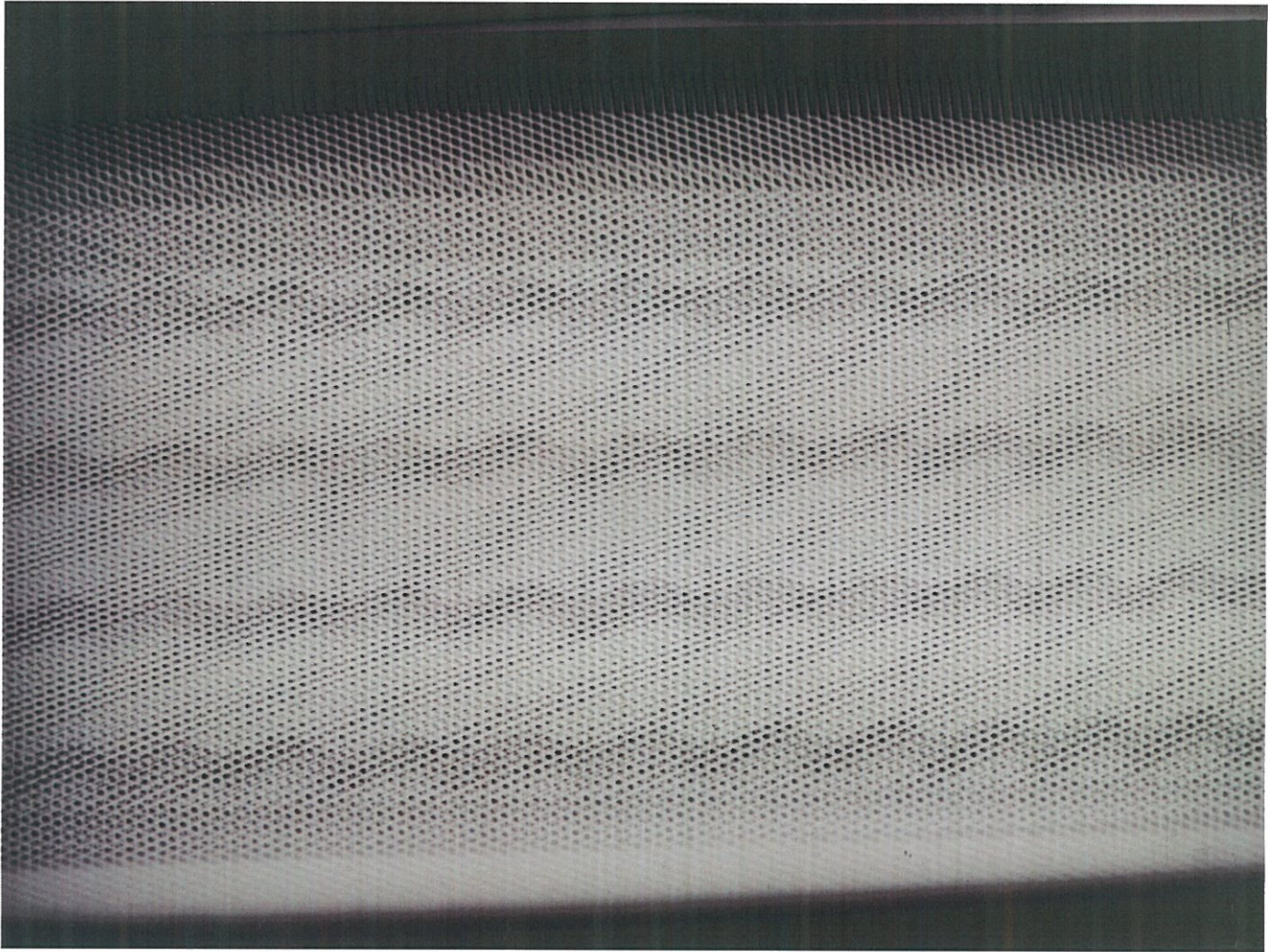




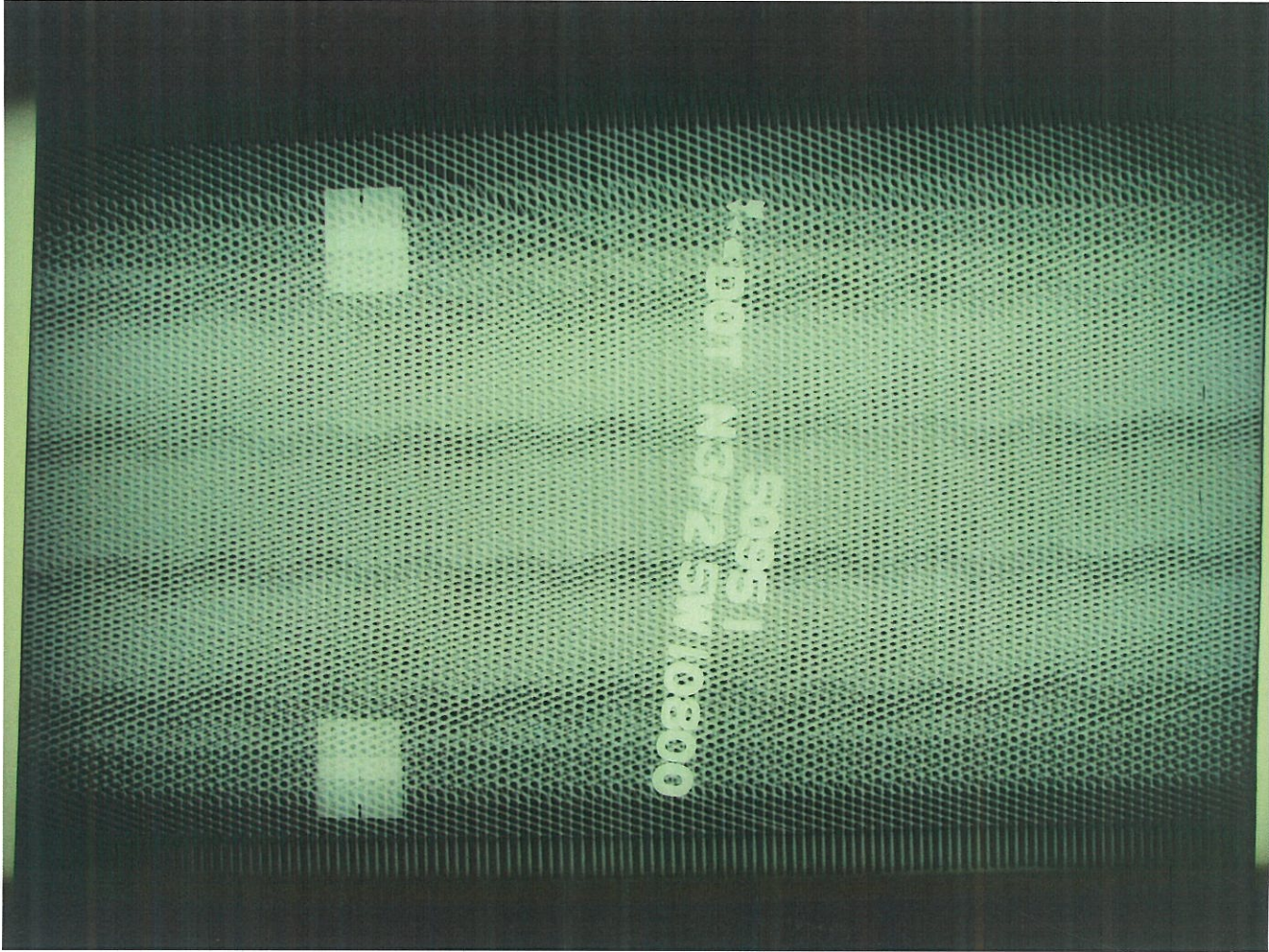




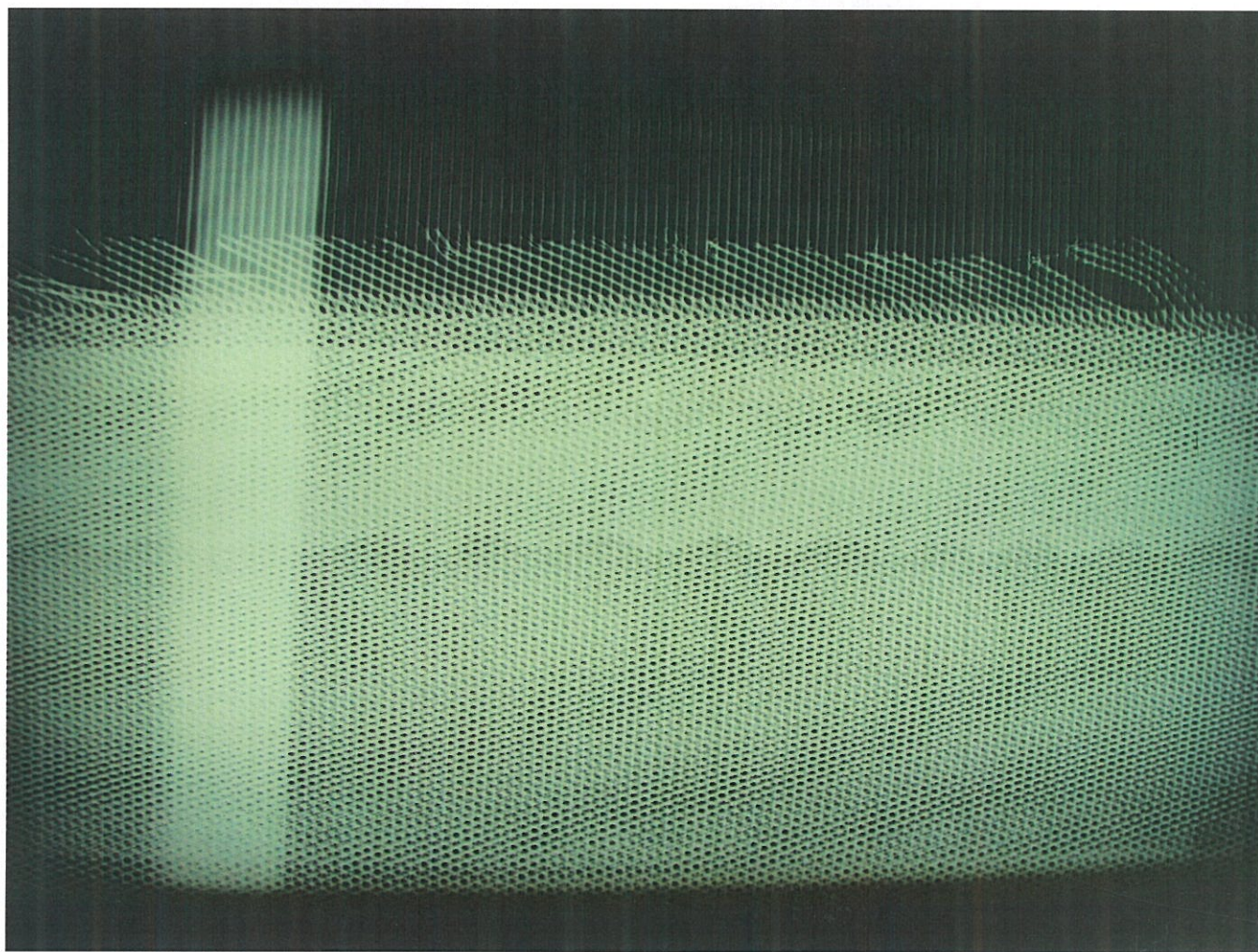


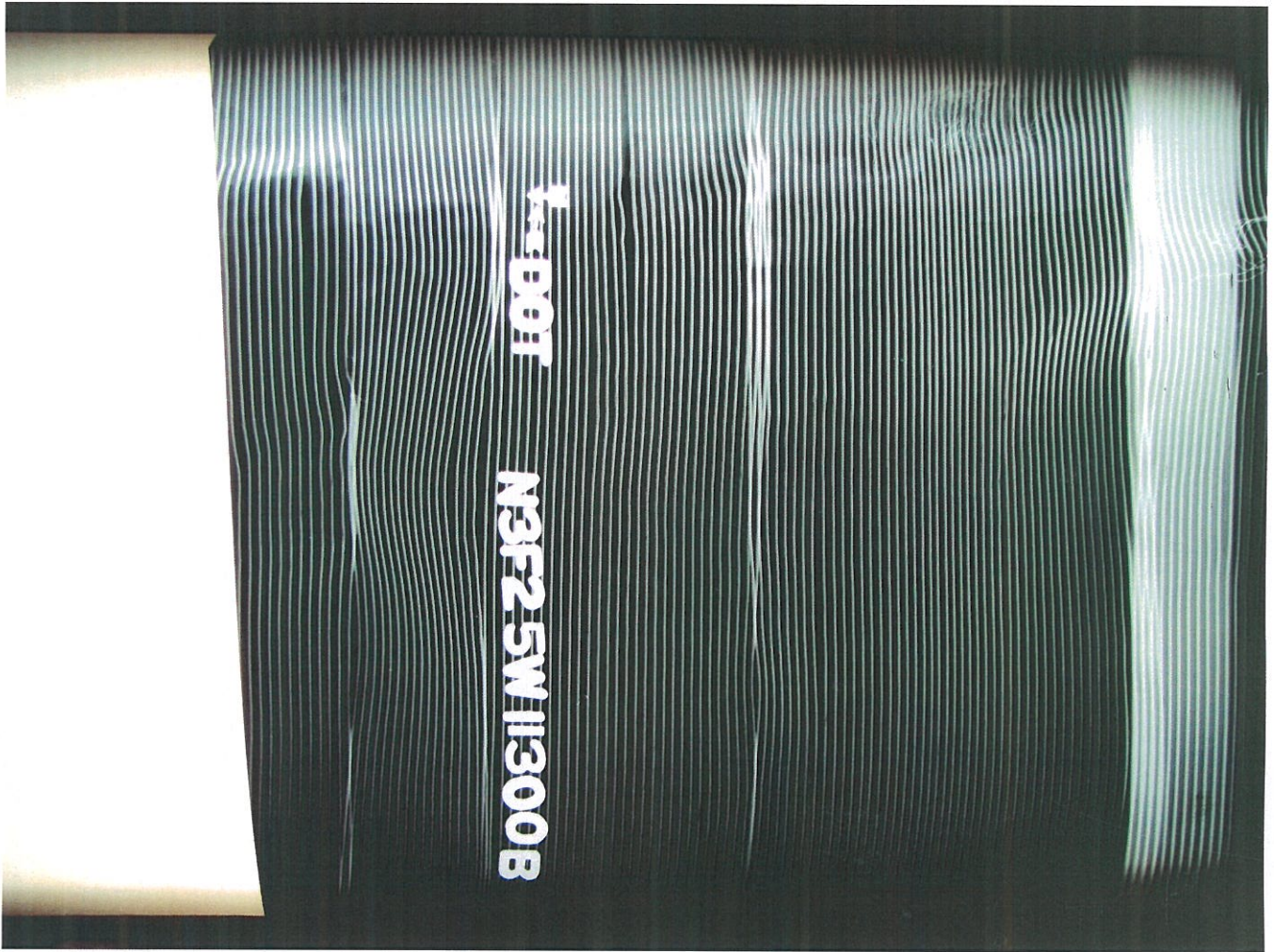


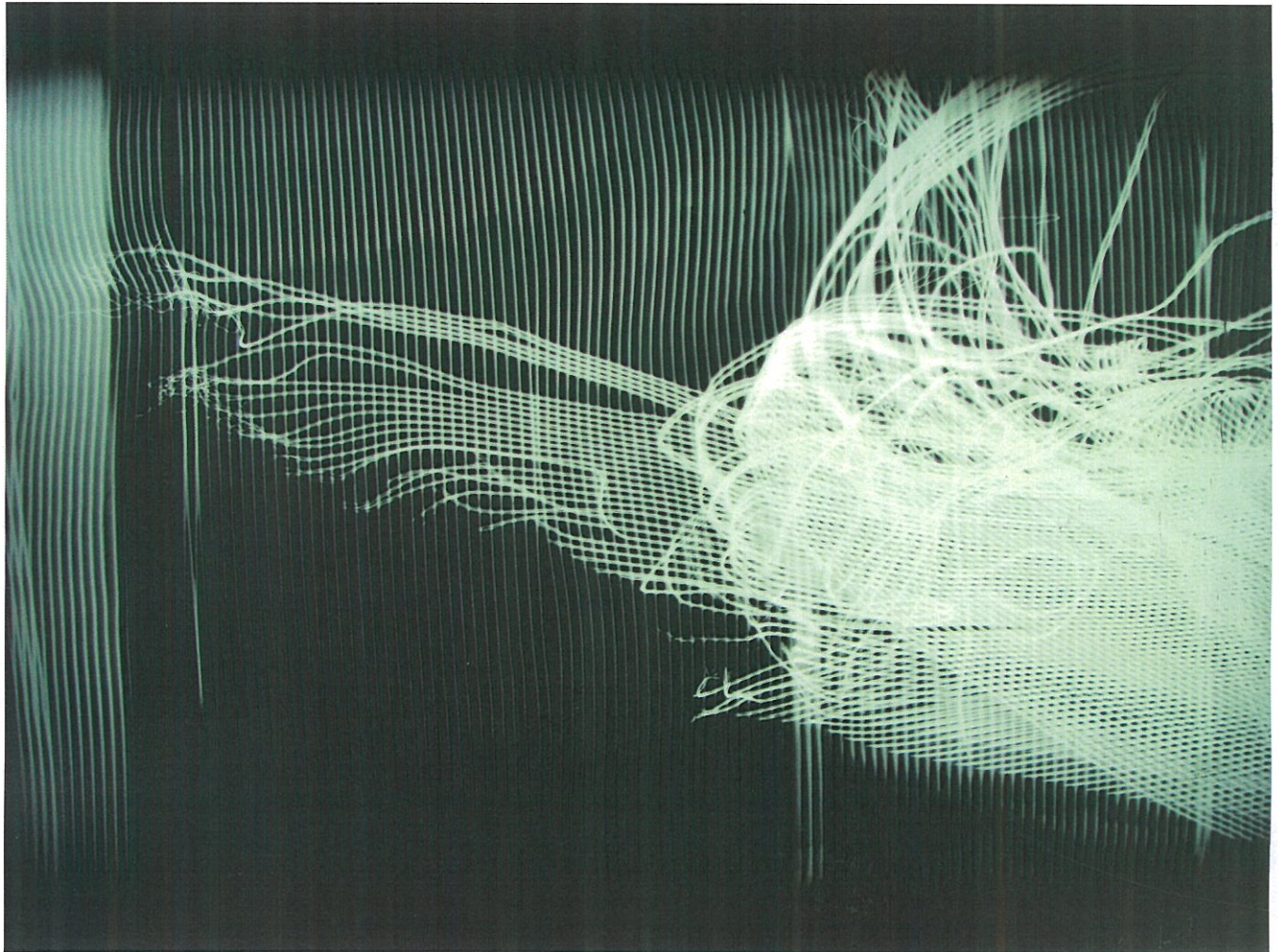
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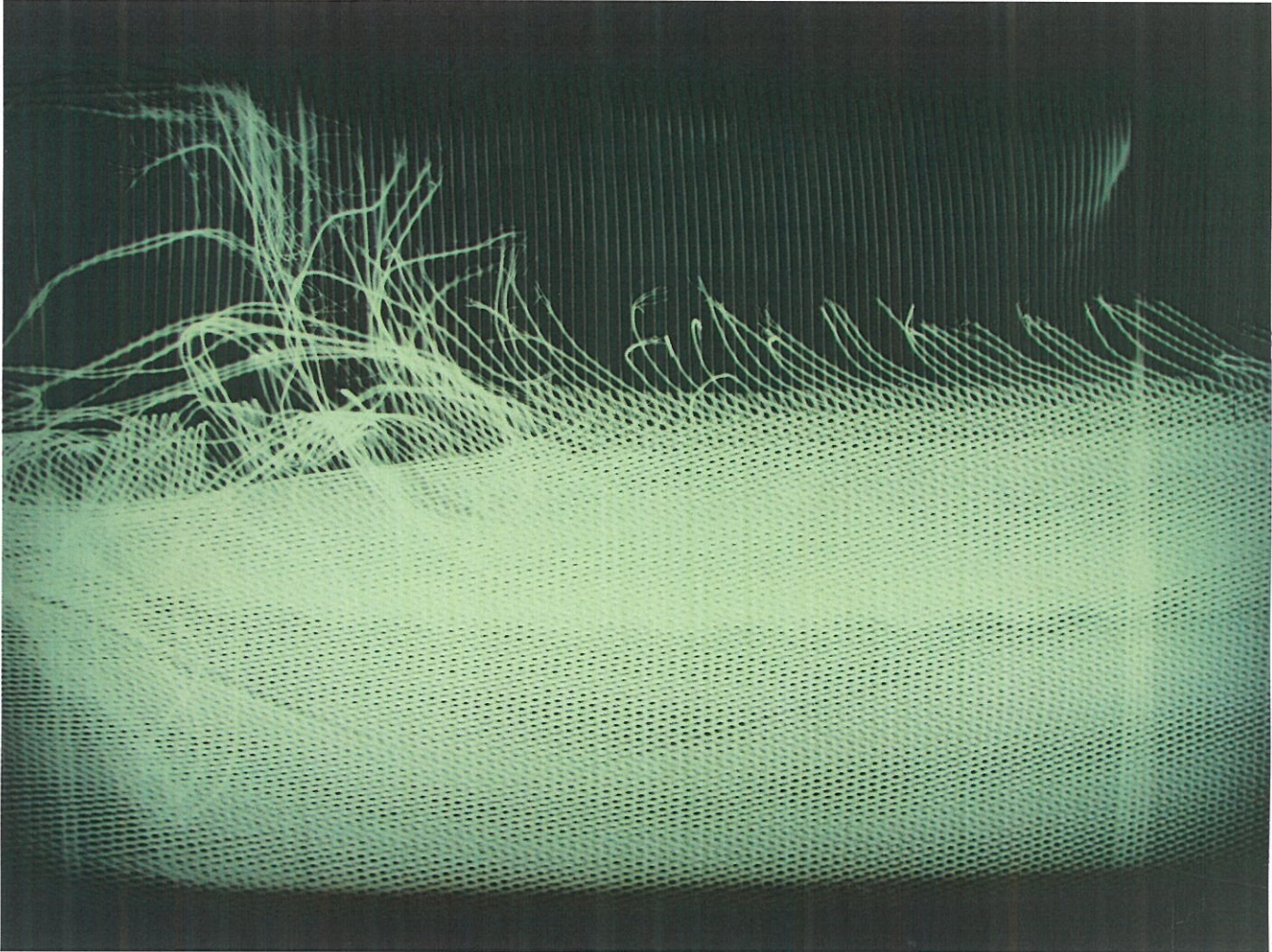


# Tire J - X-ray Images

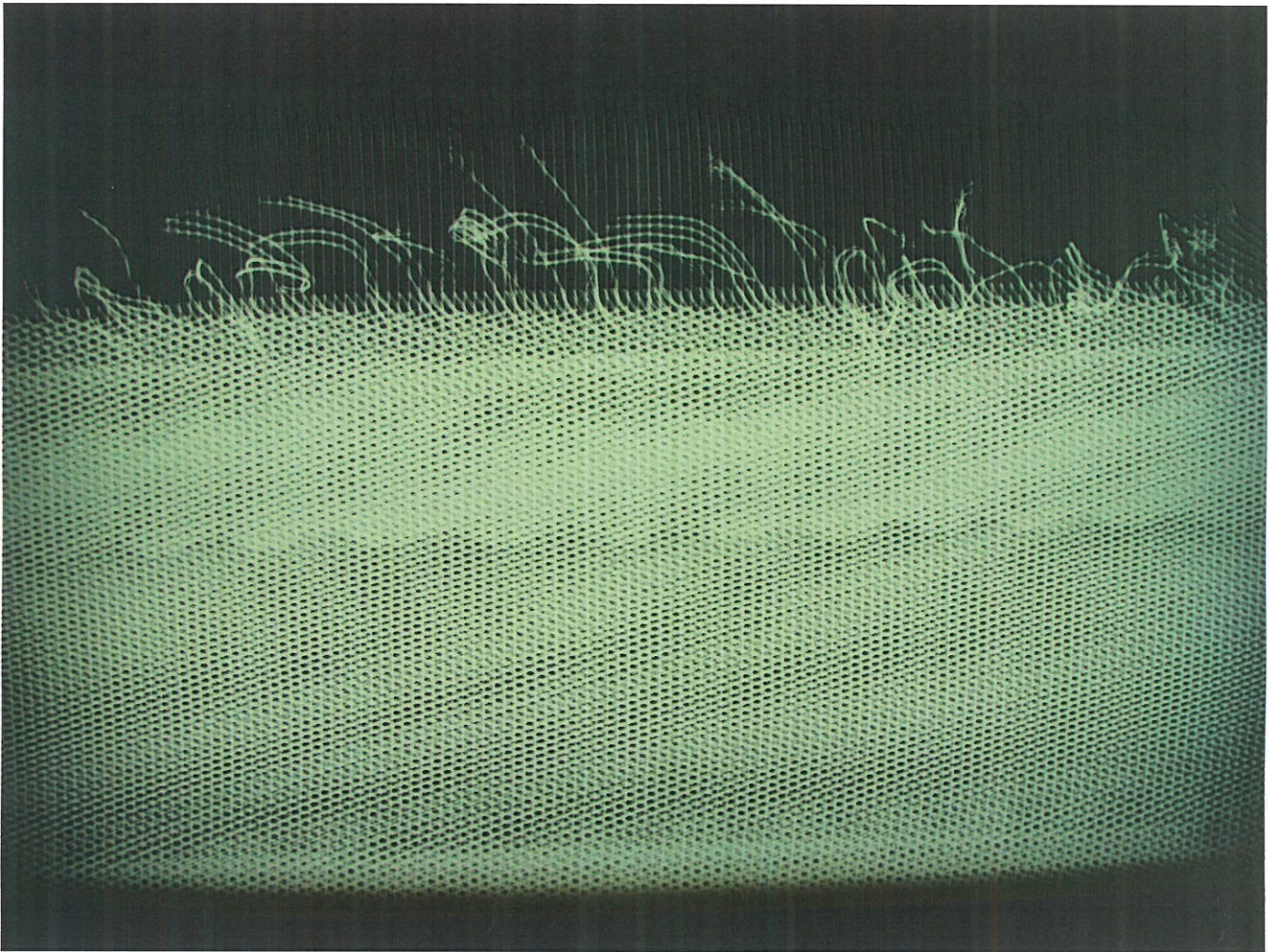


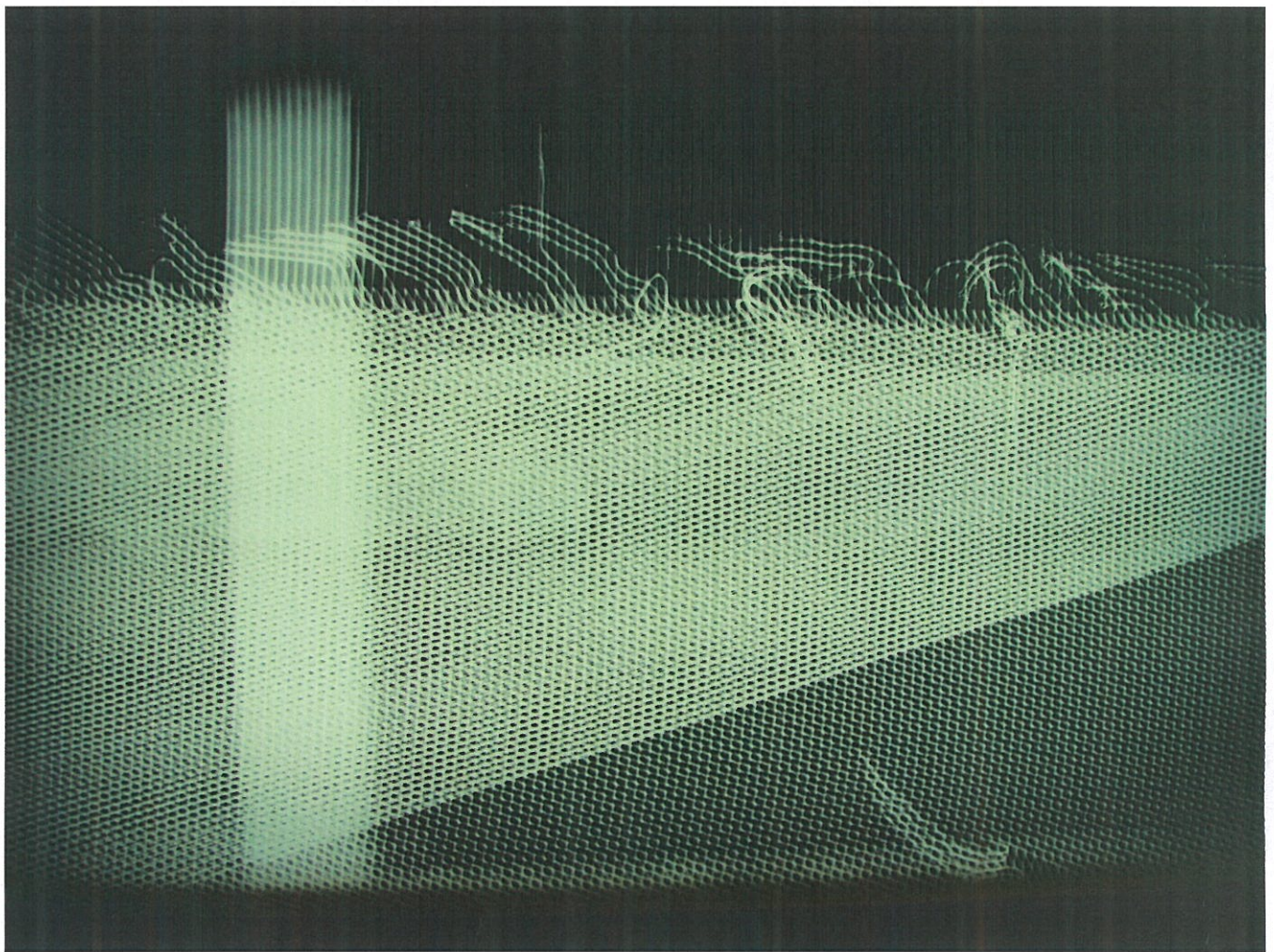


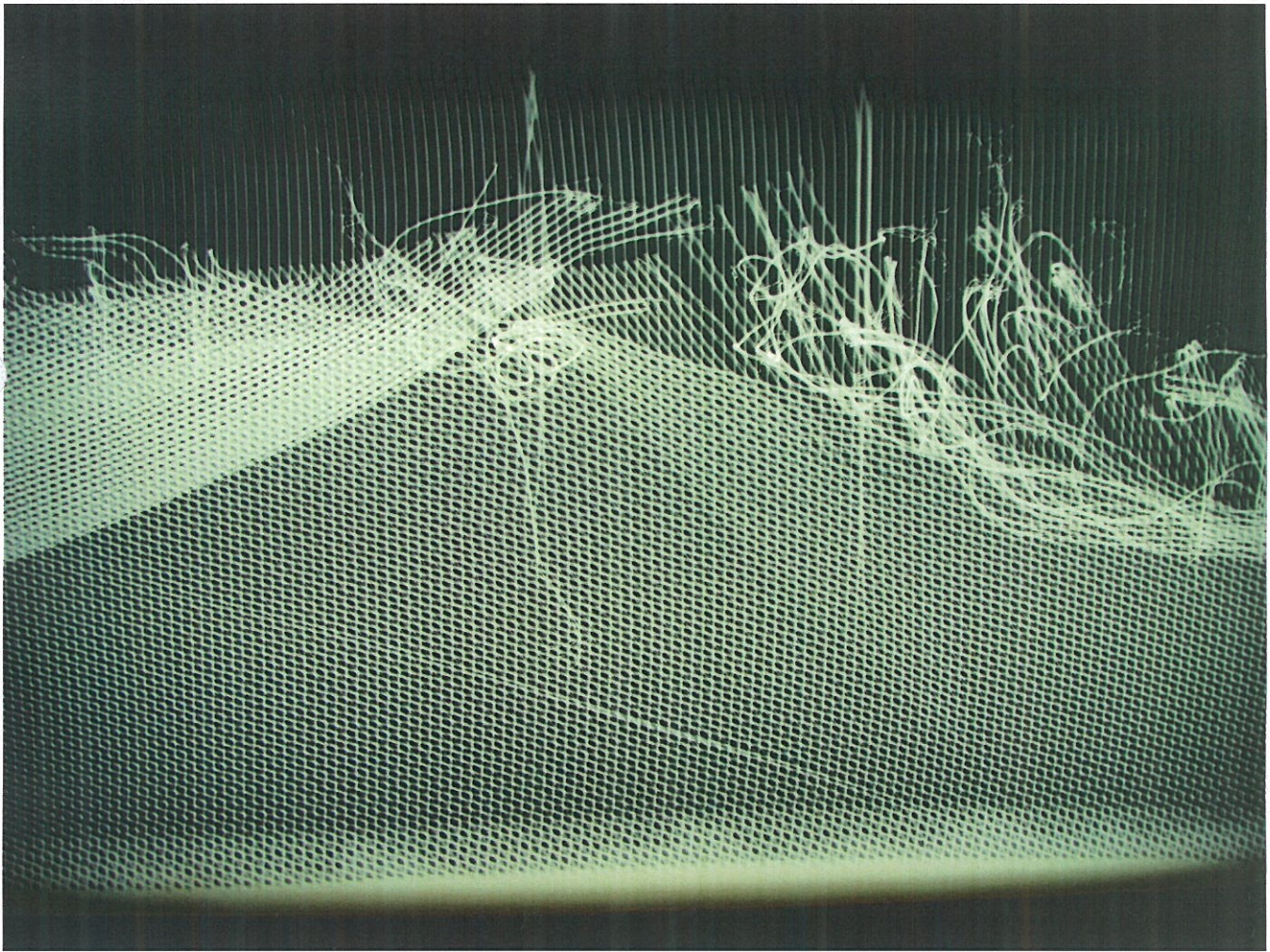


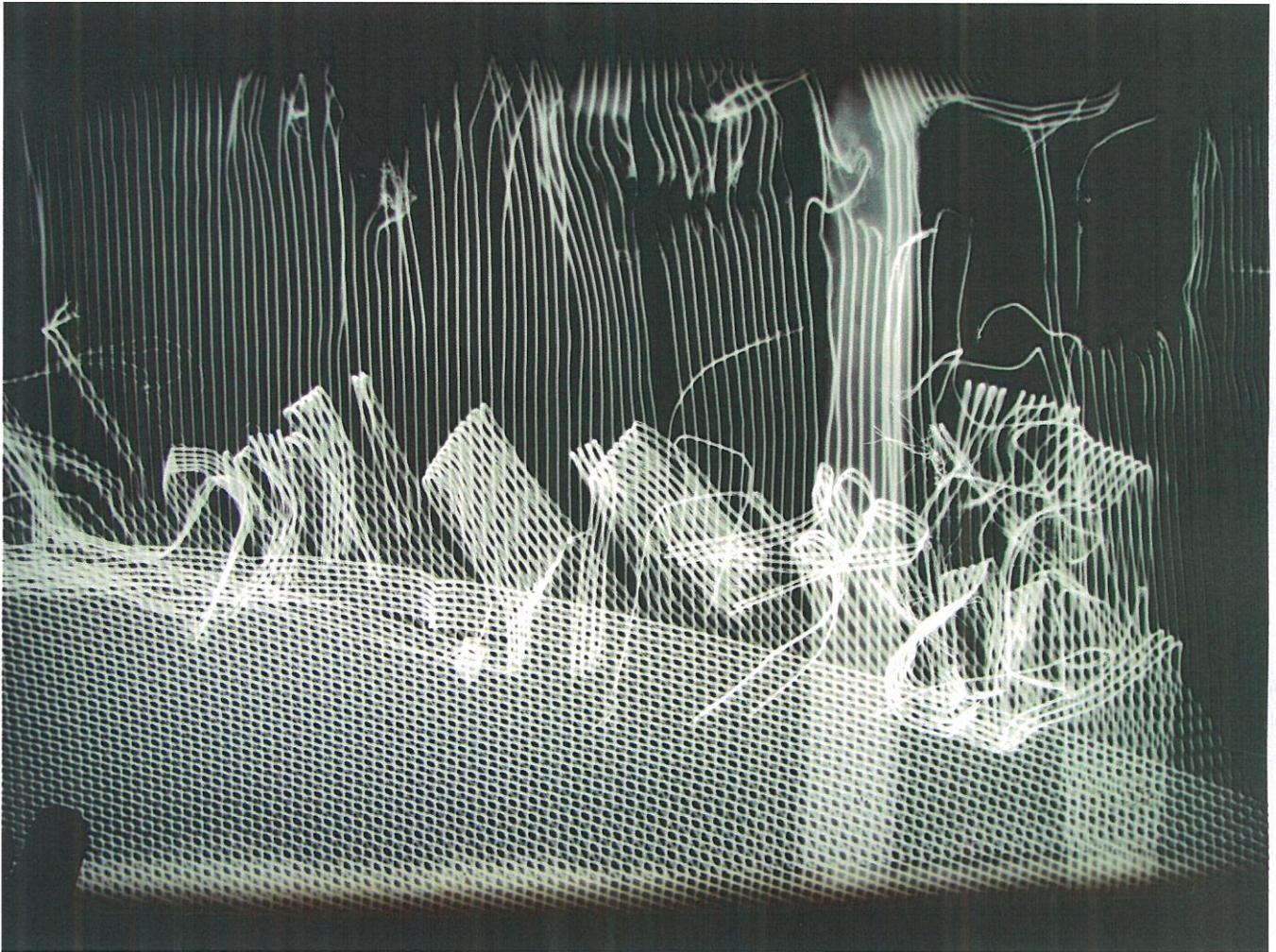




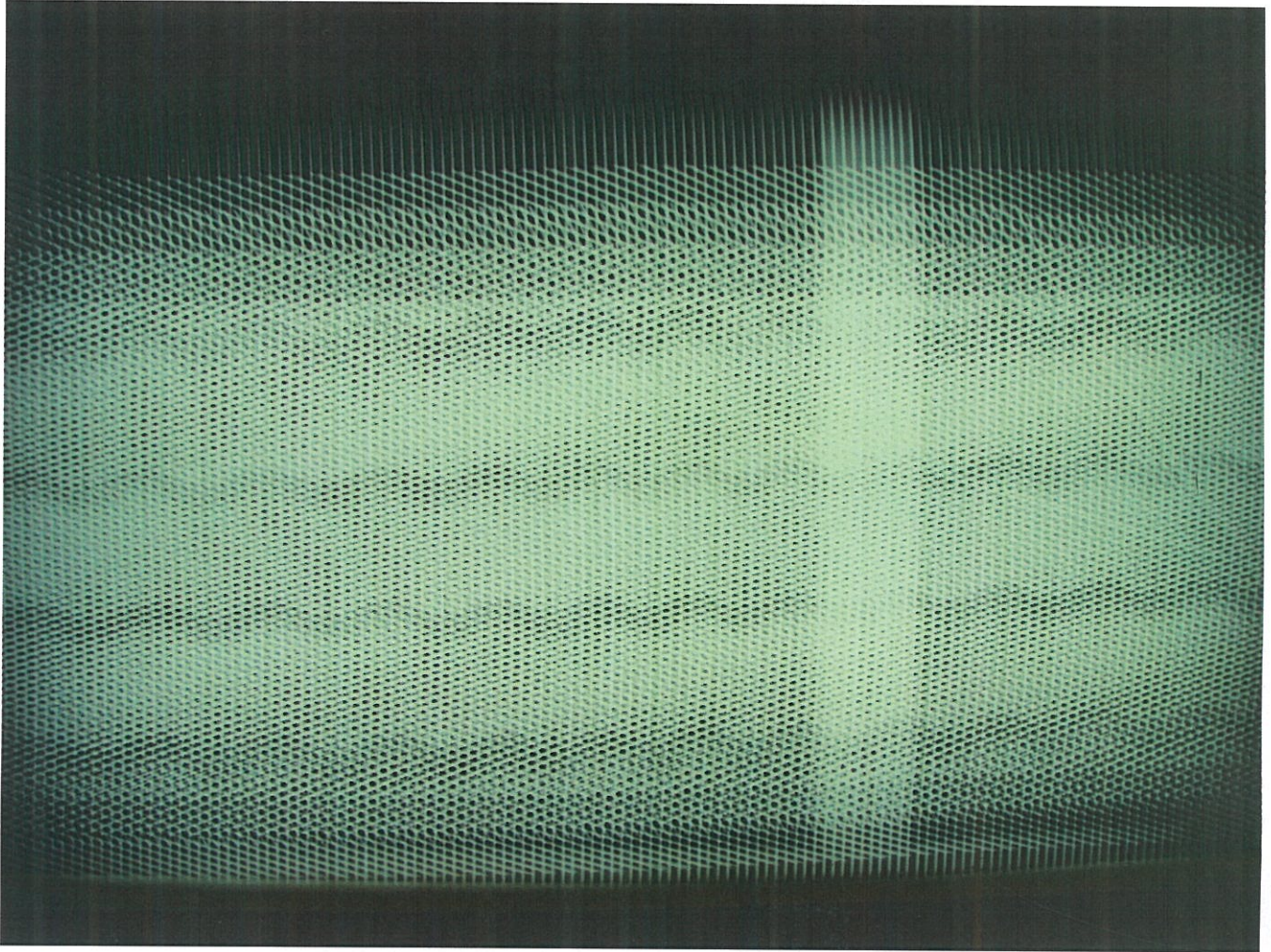


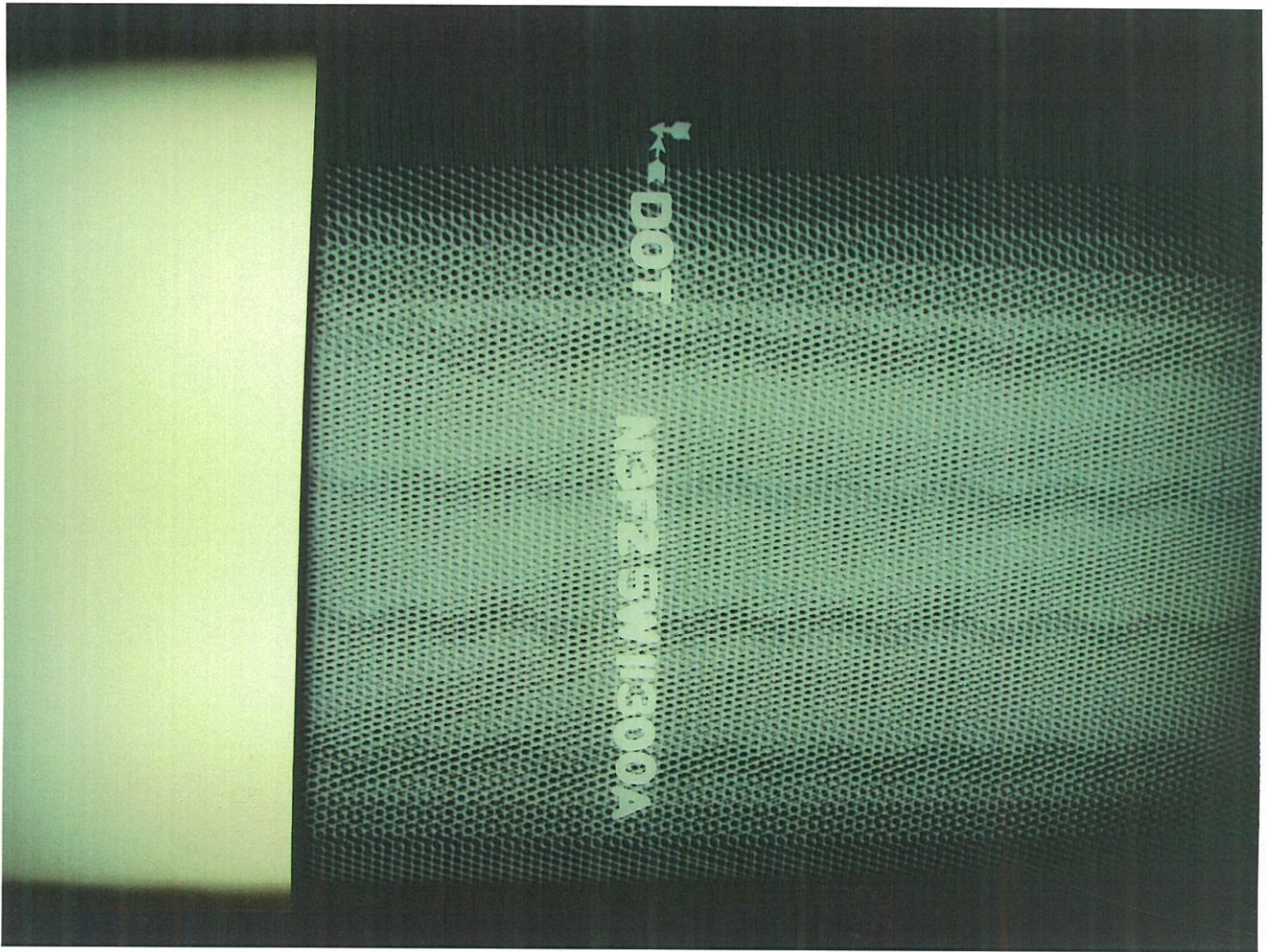


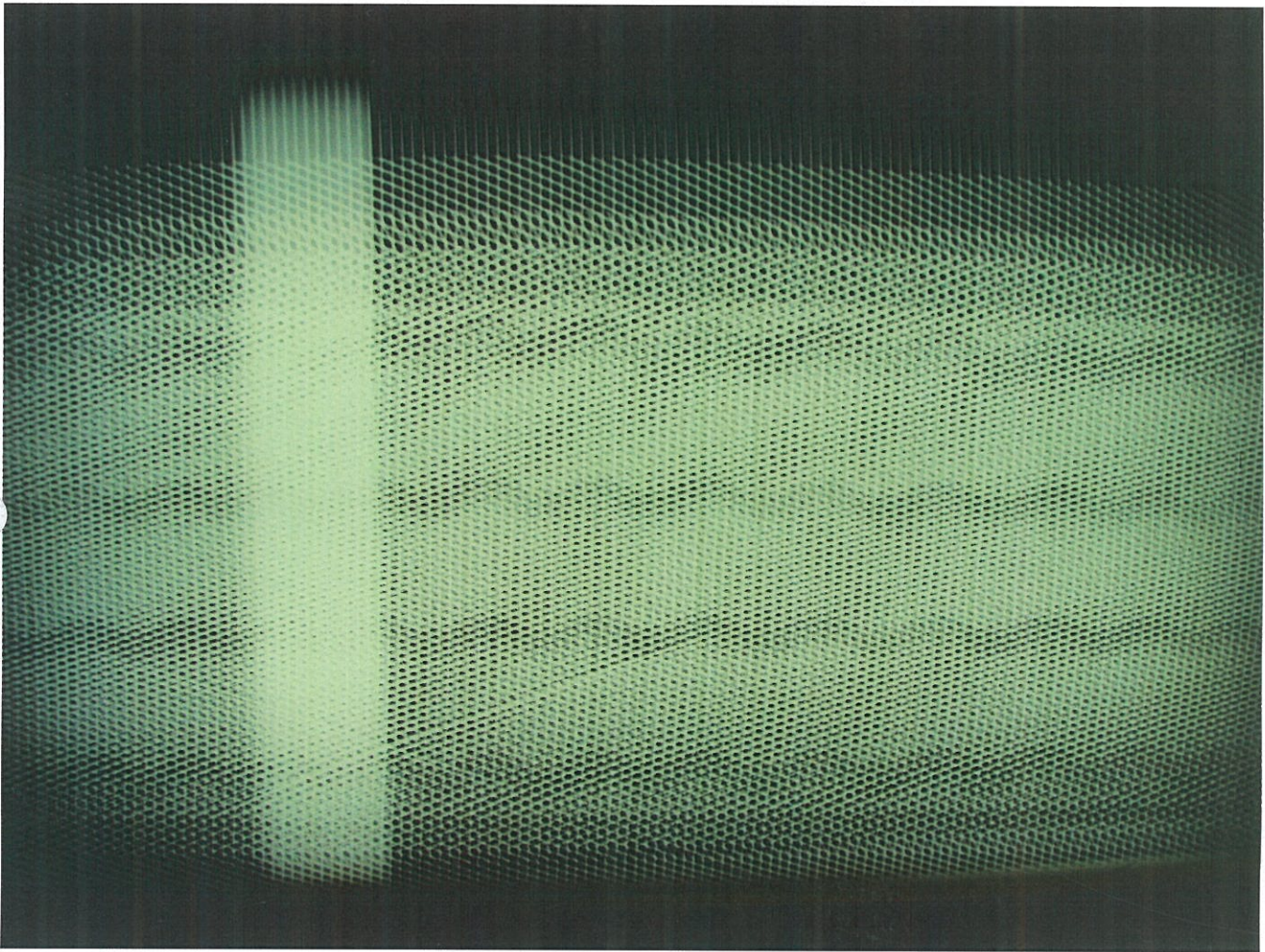


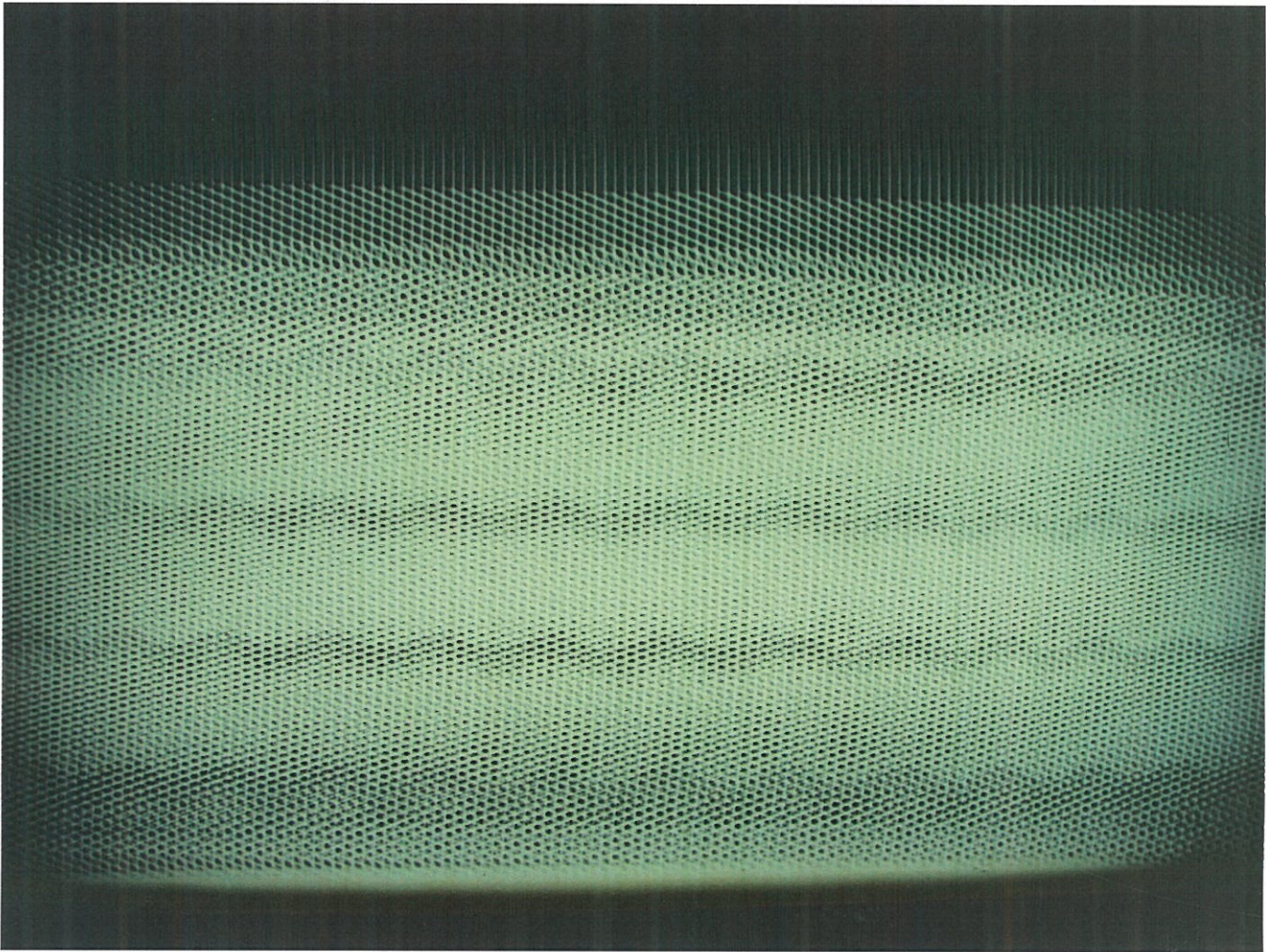


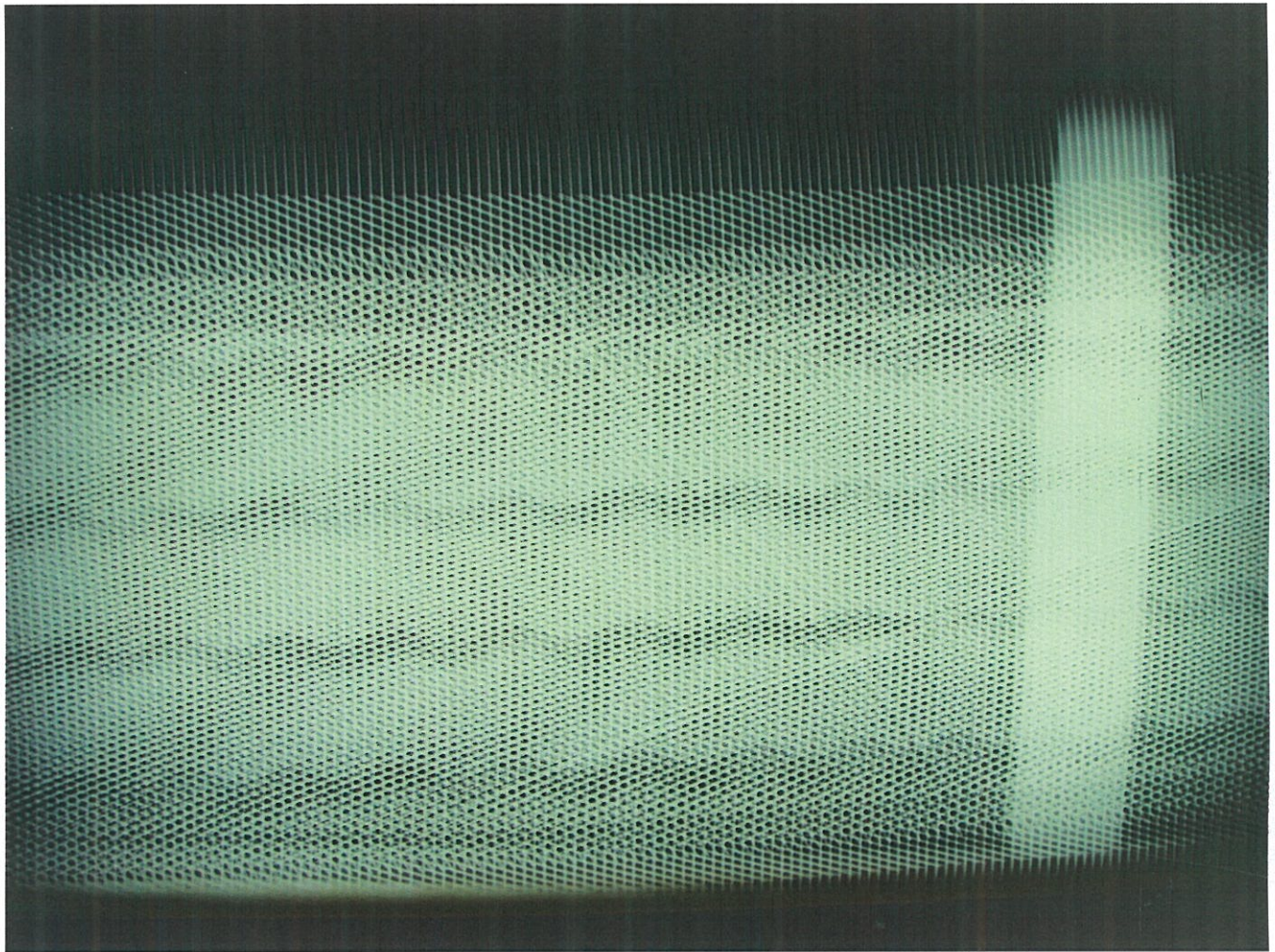
# Tire K - X-ray Images

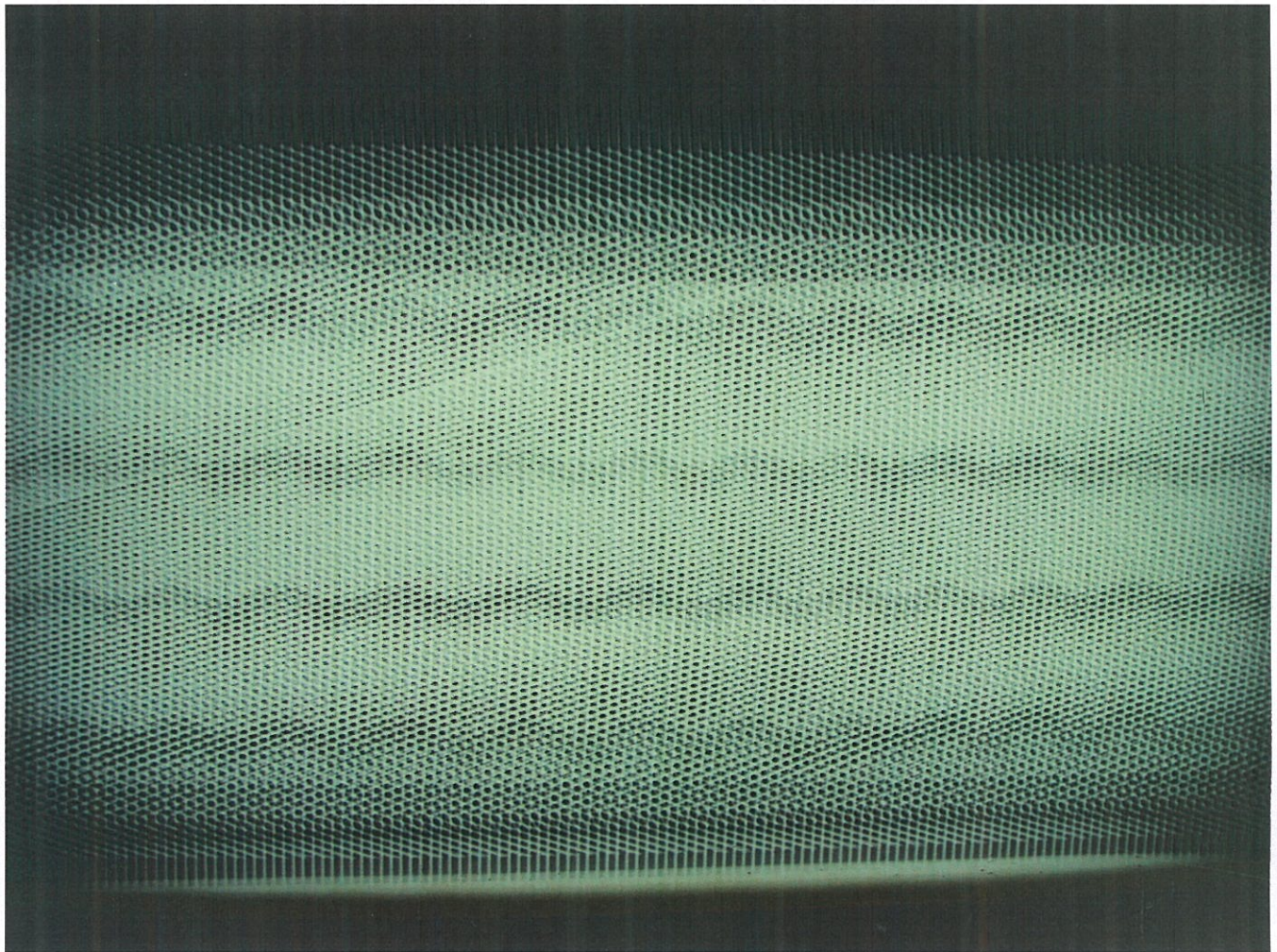


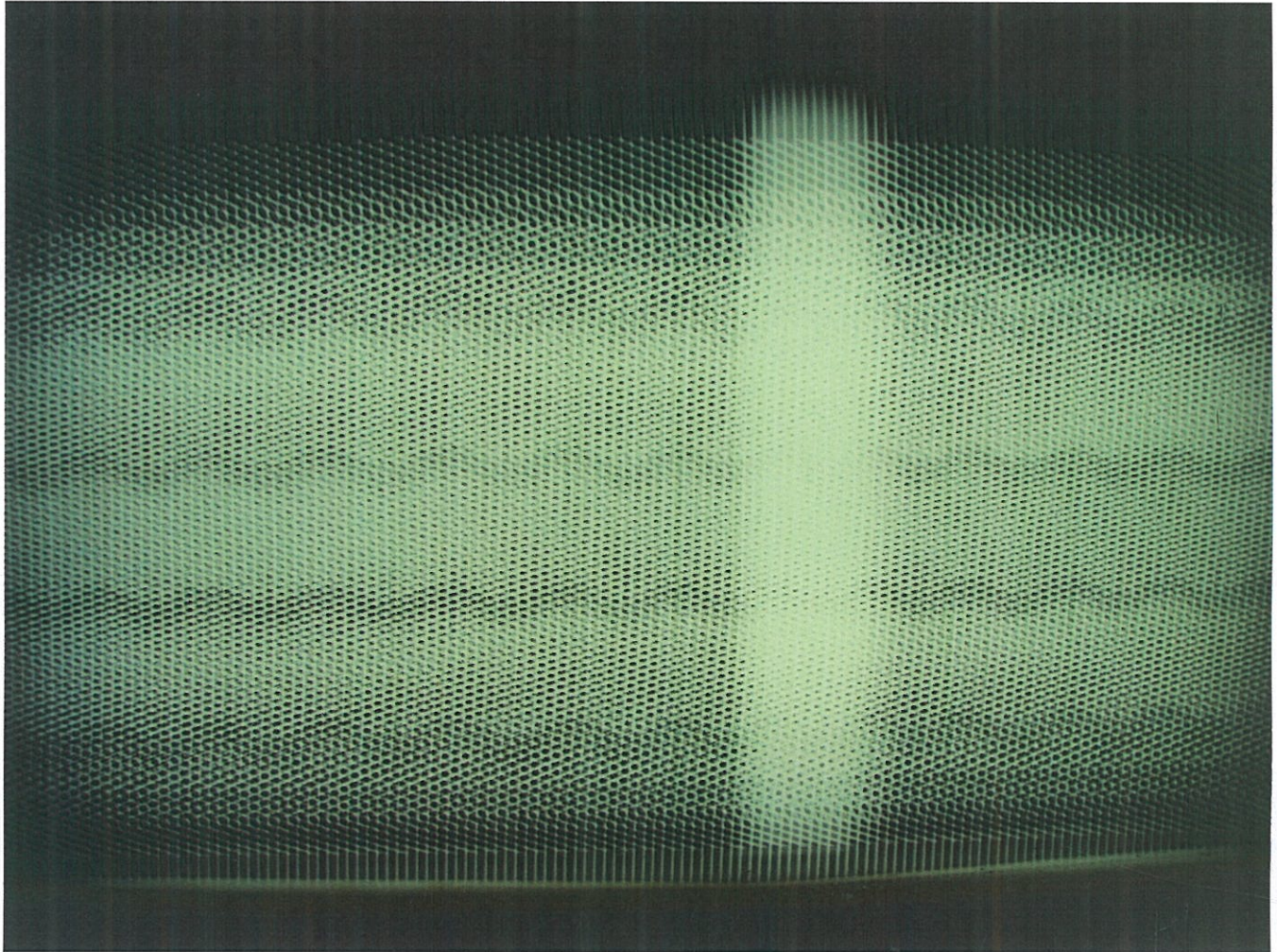


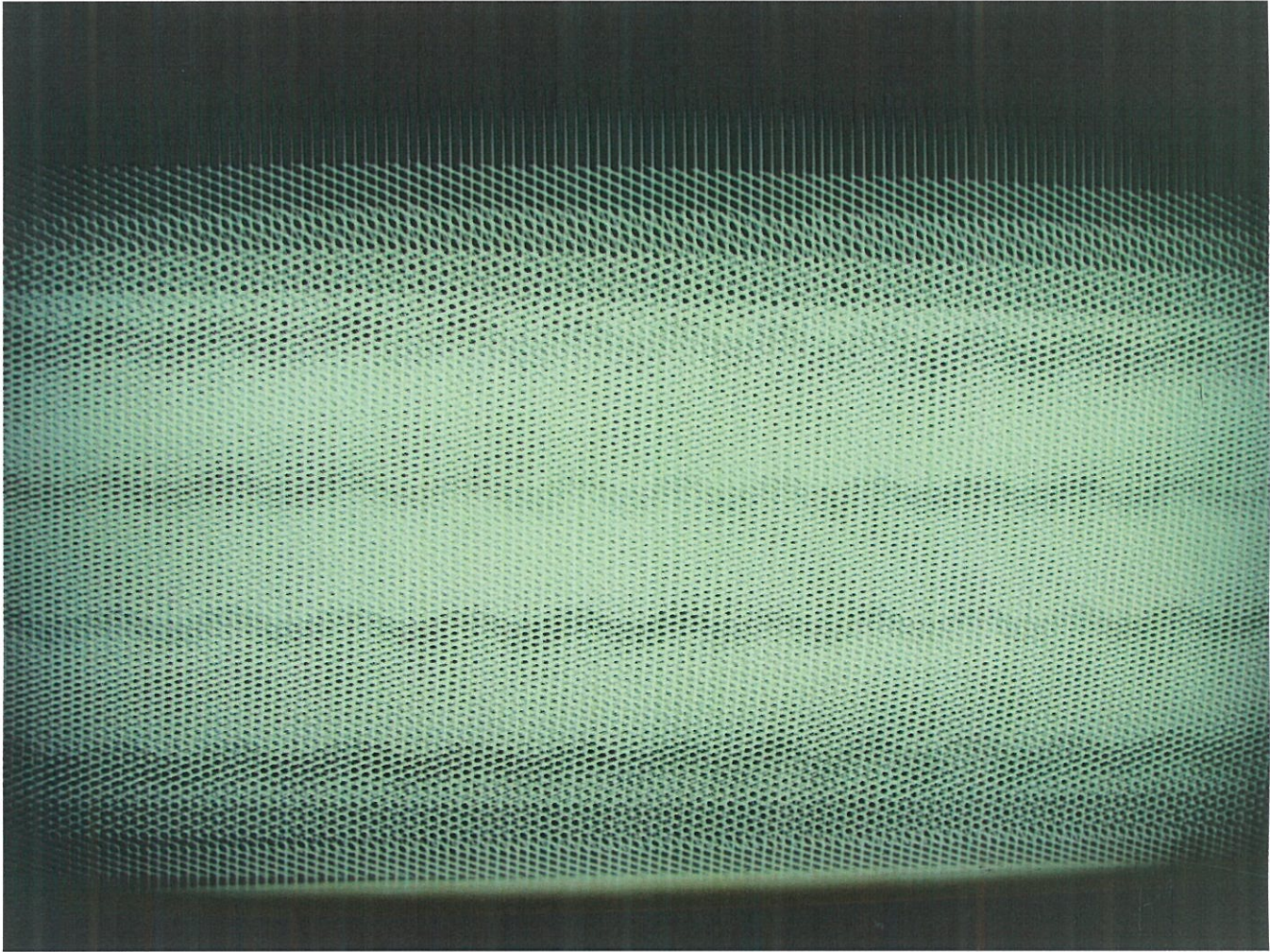


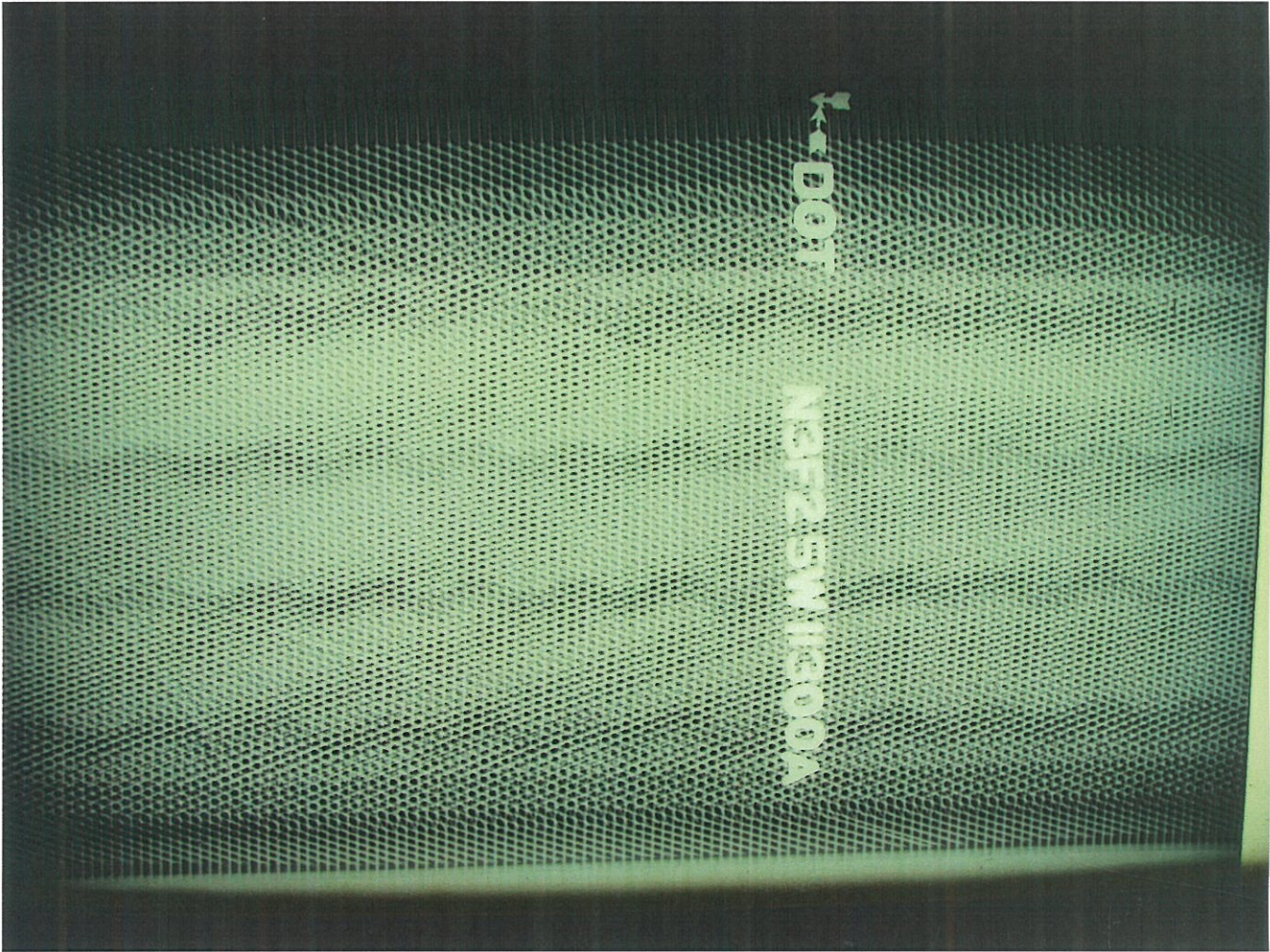












# Appendix E

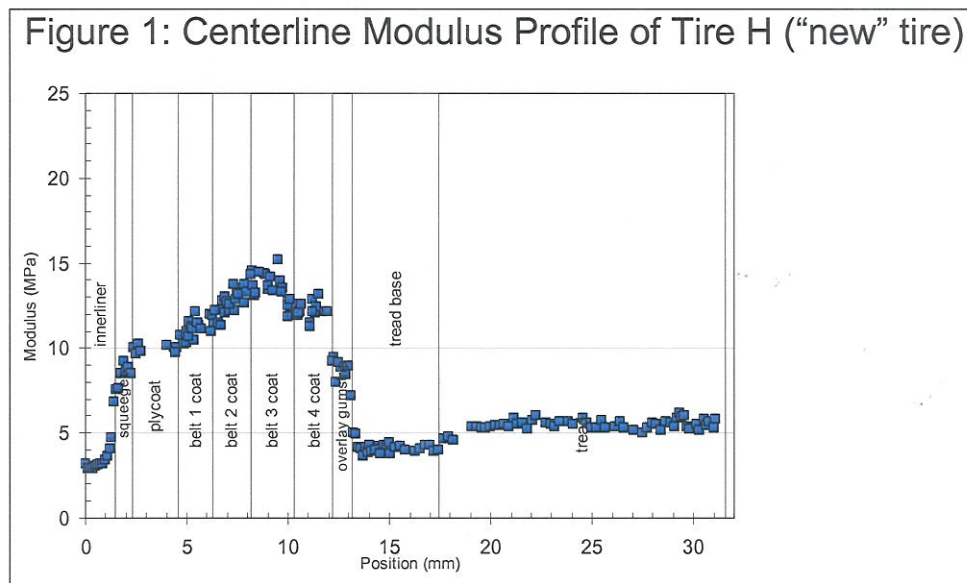
## - MICROSCOPY-

NOTES							
1-TOYO TIRES, A,B,C,F,G,H,I,J,K		Angle made to Belt 0 in degrees	Width of belt in mm	2-GOODYEAR TIRE, Z		Angle made to Belt 0 in degrees	Width of belt in mm
	Belt 0	0	-		Belt 0	0	-
	Belt 1	38	180		Belt 1	32	175
	Belt 2	73	210		Belt 2	70	195
	Belt 3	107	180		Belt 3	110	180
	Belt 4	107	160		Belt 4	70	105
		Belt 0			Belt 0		
		Belt 1			Belt 1		
		Belt 2			Belt 2		
		Belt 3			Belt 3		
		Belt 4			Belt 4		

# Appendix F - Modulus Profile Summary Report

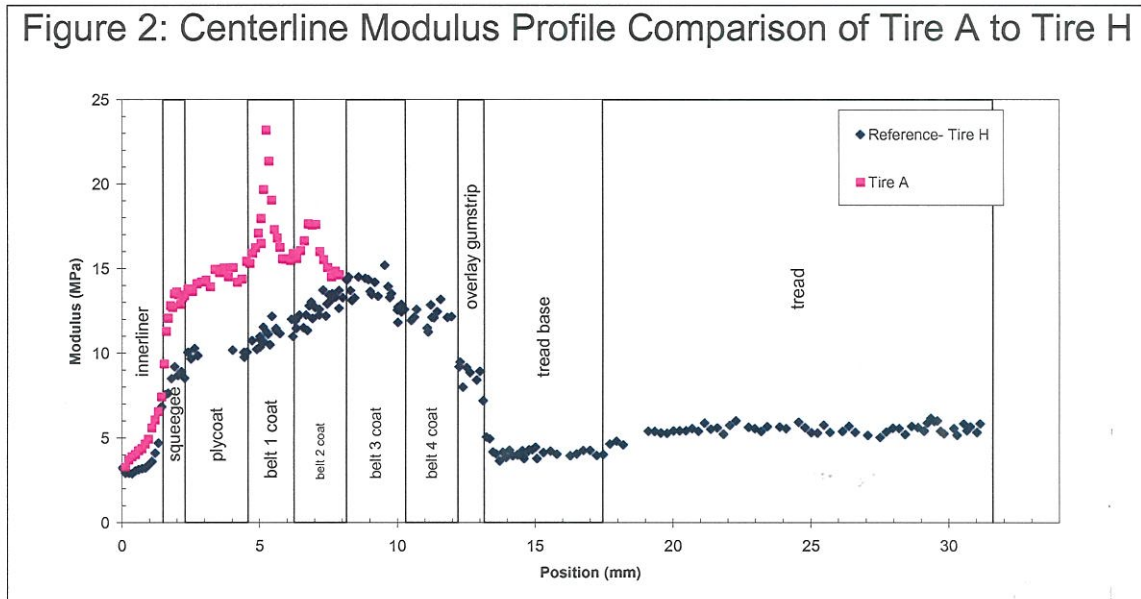
## Indentation Modulus in the Centerline Region

Indentation modulus was measured in the centerline region of tire. The radial scan (modulus profile) was located at the centerline because that region can be a critical (high strain) region in truck tires. Figure 1 shows the centerline modulus profile of Tire H (the “new” tire).

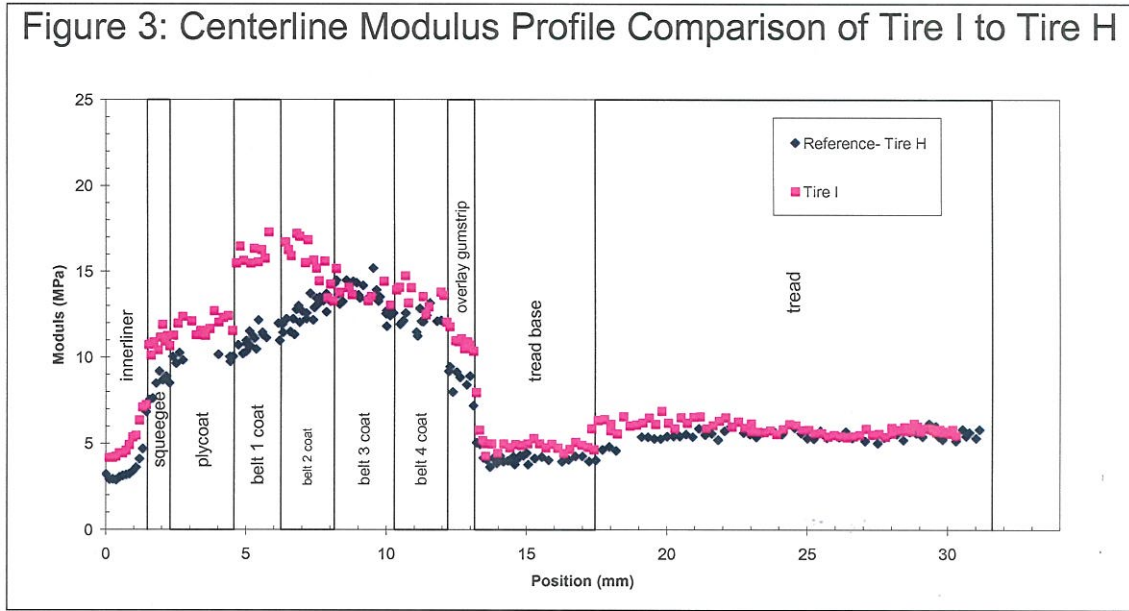


In comparison, the centerline region of tire A was much higher modulus (Figure 2). The overlay plot shows that there was very high modulus increase in the squeegee, plycoat, belt 1 coat, and belt 2 coat. The modulus increase is a result of oxidation. This could be called unusually high level of property deterioration.

Figure 2: Centerline Modulus Profile Comparison of Tire A to Tire H

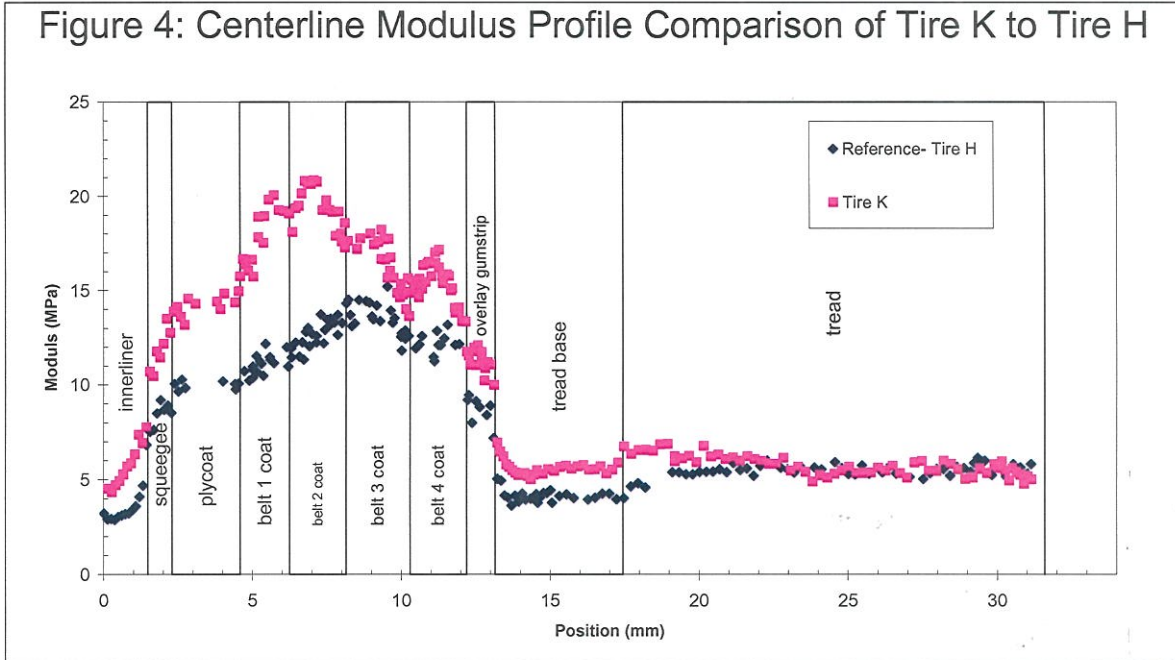


The centerline modulus profile of tire I is shown in Figure 3. The results point to major oxidation in the belt-1-coat and belt-2-coat compounds. This may be associated with high heat and strains in this region of the tire or oxygen somehow reaching this compound (i.e., cord wicking).

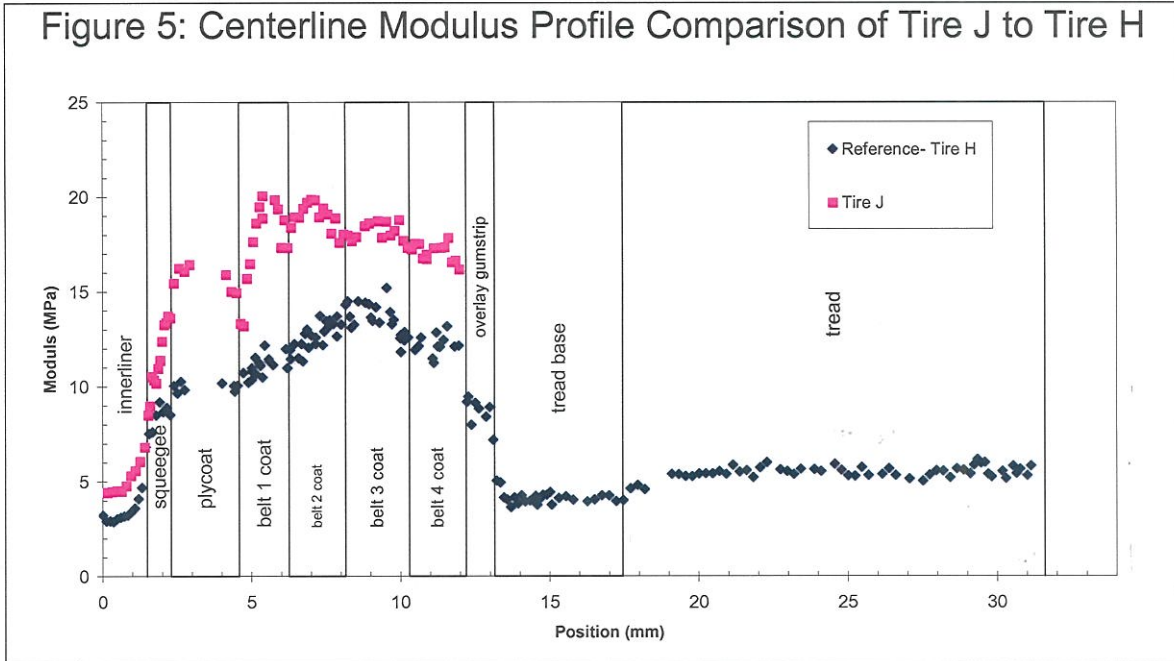


The centerline modulus profile of tire K is shown in Figure 4. The results show large modulus increases in the squeegee, plycoat, belt-1-coat, and belt-2-coat compounds. This is probably caused by oxidation. The modulus values are close to those found in tires A and J, which had experienced separations.

Figure 4: Centerline Modulus Profile Comparison of Tire K to Tire H

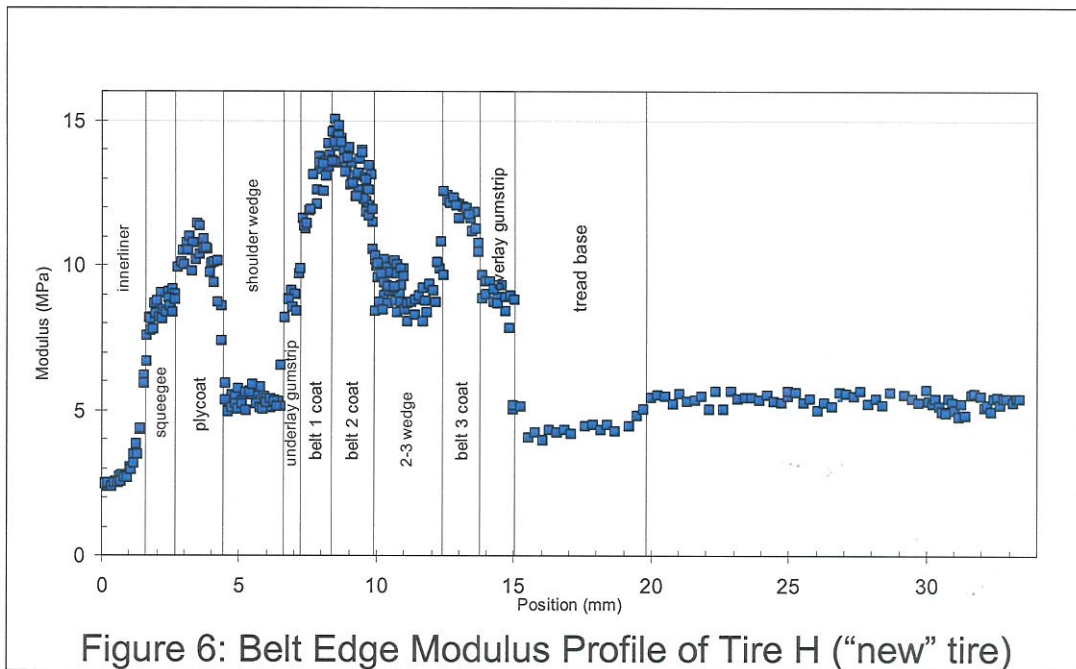


The centerline region of tire J was high in modulus (Figure 5). The overlay plot shows that there were large modulus increases in the squeegee, plycoat, belt 1 coat, and belt 2 coat. The oxidative hardening appears to be close to the cords, suggesting oxygen wicking along the cords. This could be called unusually high level of property deterioration.

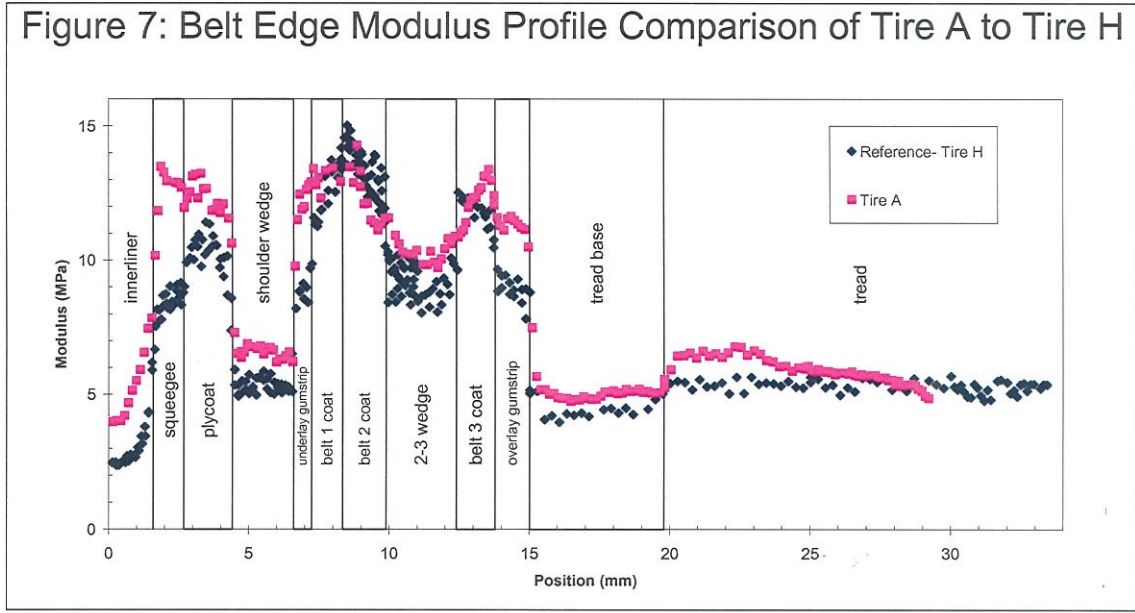


## Indentation Modulus in the Shoulder (Belt Edge) Region

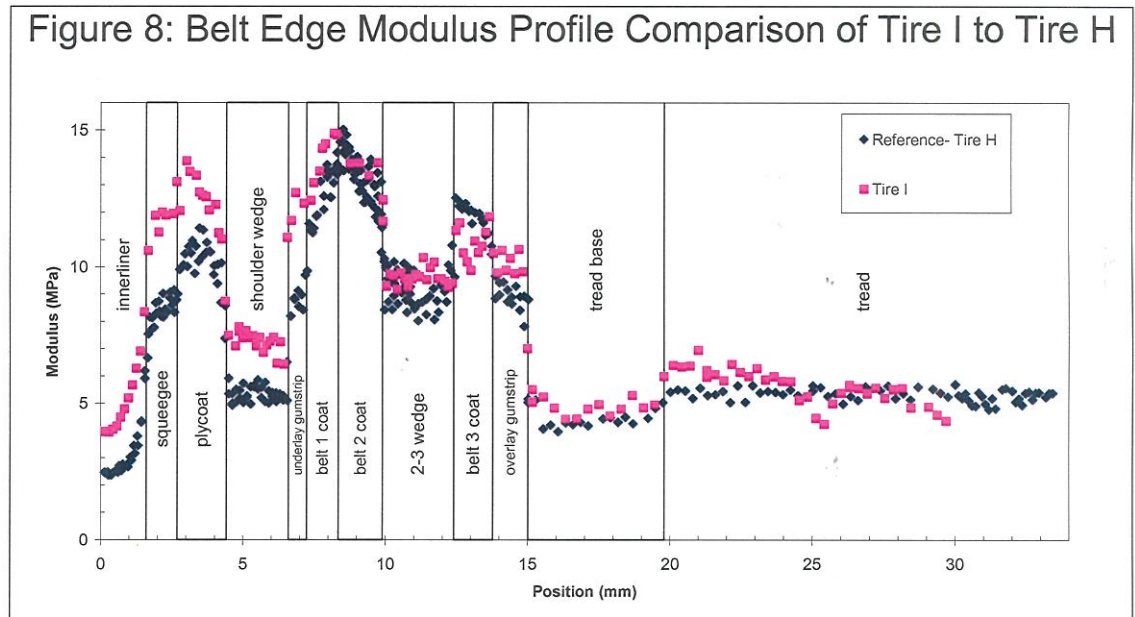
Indentation modulus was measured in the shoulder region of tire. The radial scan (modulus profile) was located at the edge of belt 3 because that is the critical (high strain) region of the working belts. Figure 6 shows the centerline modulus profile of Tire H (the “new” tire in the belt edge region.



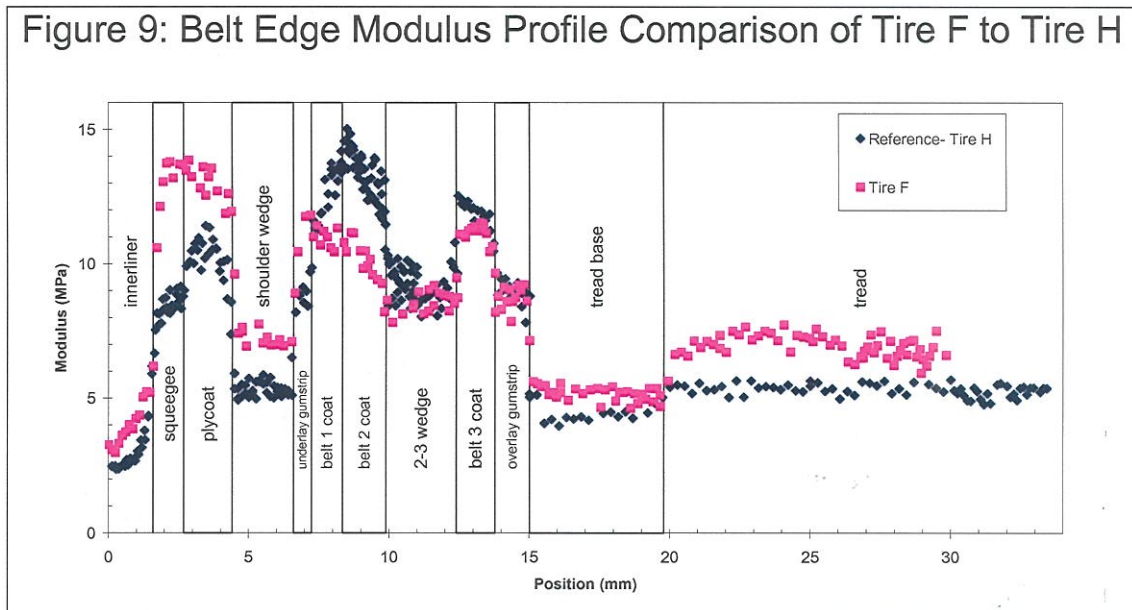
In a comparison plot of Tire A to Tire H, the belt region results indicate oxidative hardening in all components except belt 2 coat (Figure 7). The modulus change in belt-2-coat was probably dominated by mechanical softening.



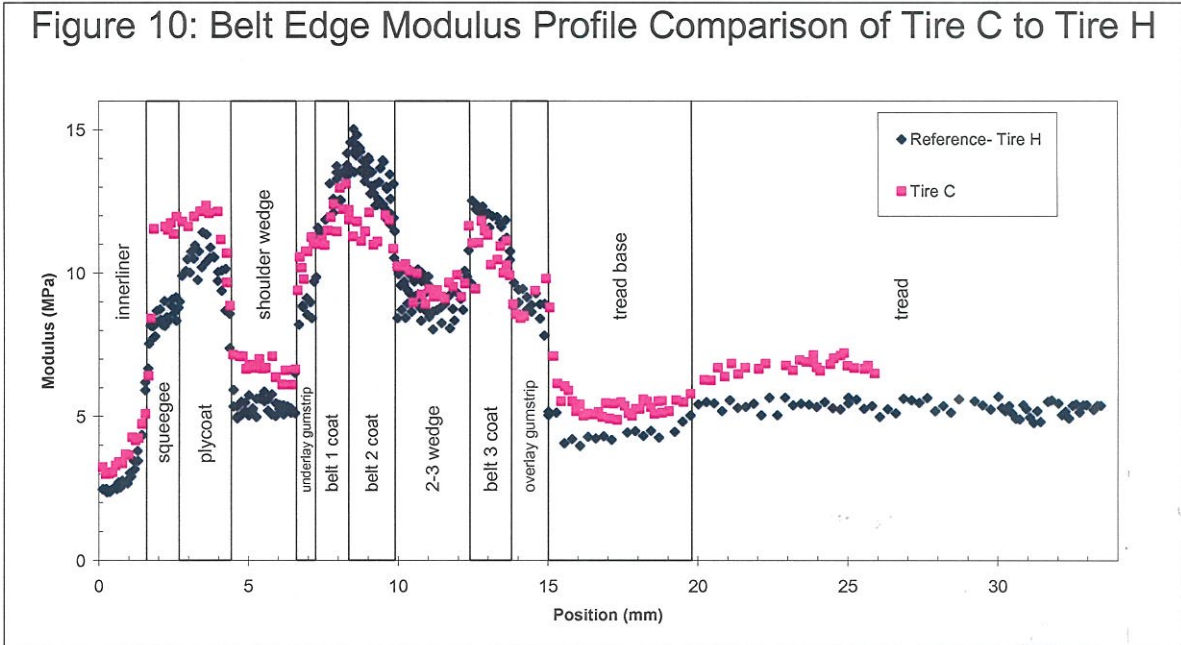
The belt edge modulus profile of tire I is shown in Figure 8. The results were compared to Tire H. Oxidative hardening was observed in all components except belt-3-coat. The modulus change in belt-3-coat was probably dominated by mechanical softening.



The belt edge modulus profile of tire F is shown in Figure 9. The results were compared to Tire H. Oxidative hardening was observed in all components except belt-1-coat, belt-2-coat, 2-3 wedge, belt-3-coat, and overlay gumstrip. The modulus changes in those components were probably dominated by mechanical softening.

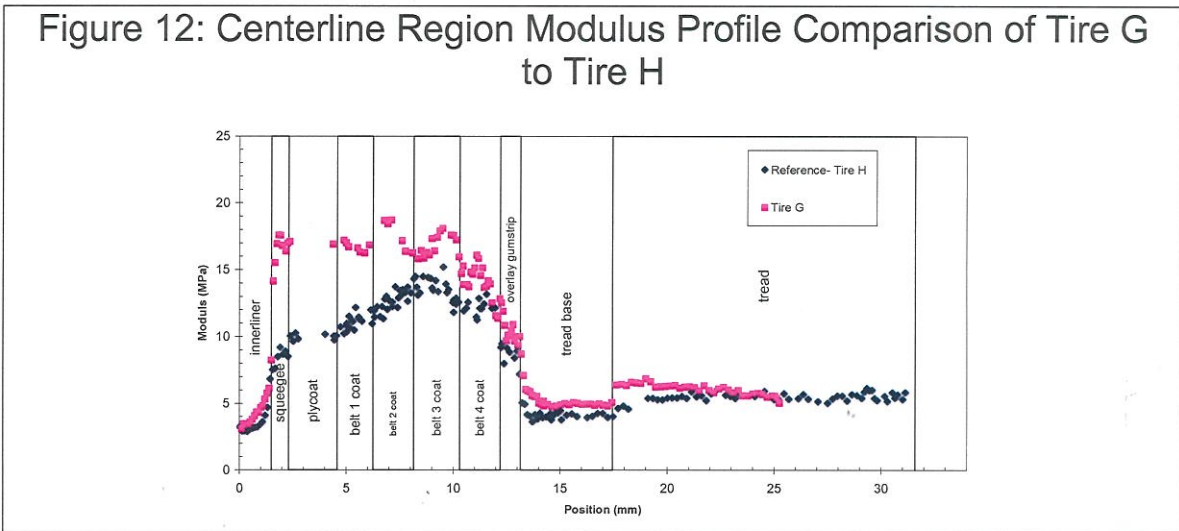
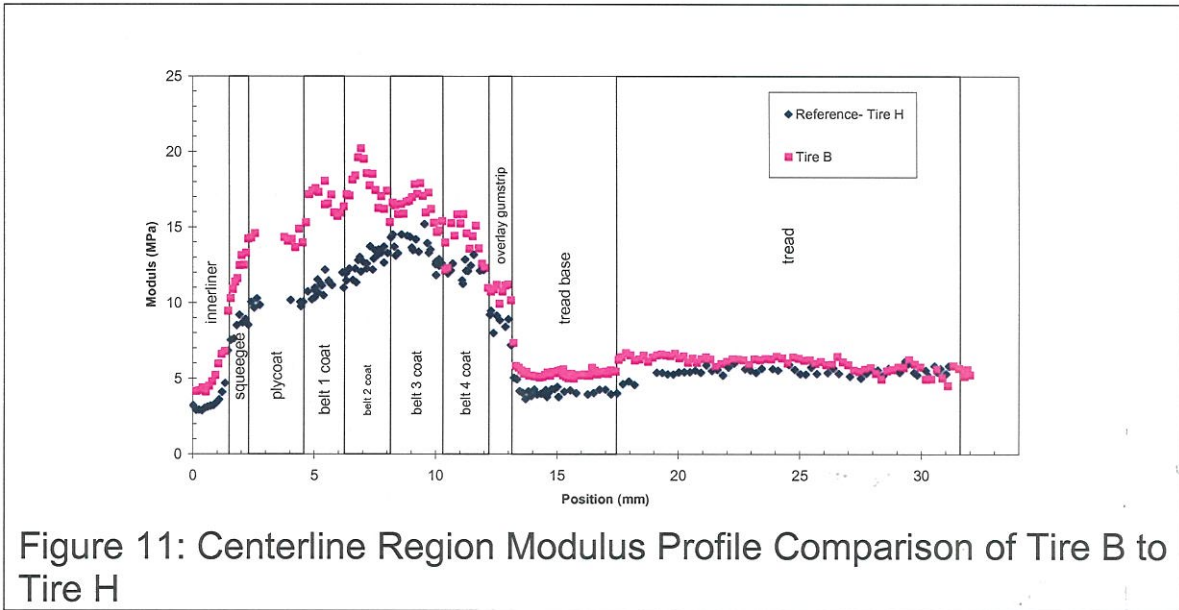


The belt edge modulus profile of tire C is shown in Figure 10. The results were compared to Tire H. Oxidative hardening was observed in all components except belt-1-coat, belt-2-coat, 2-3 wedge, and belt-3-coat. The modulus changes in those components were probably dominated by mechanical softening.



## Centerline Region of Wheel-tested tires

Modulus profiling was performed in the tire centerline region of wheel-tested tires (tires B and G). The modulus increased in each of the components (Figures 11 and 12). The compounds experienced large modulus increases. Presumably, oxidative hardening was significantly affecting these compounds.



## Summary

### Belt Edge/Shoulder Region

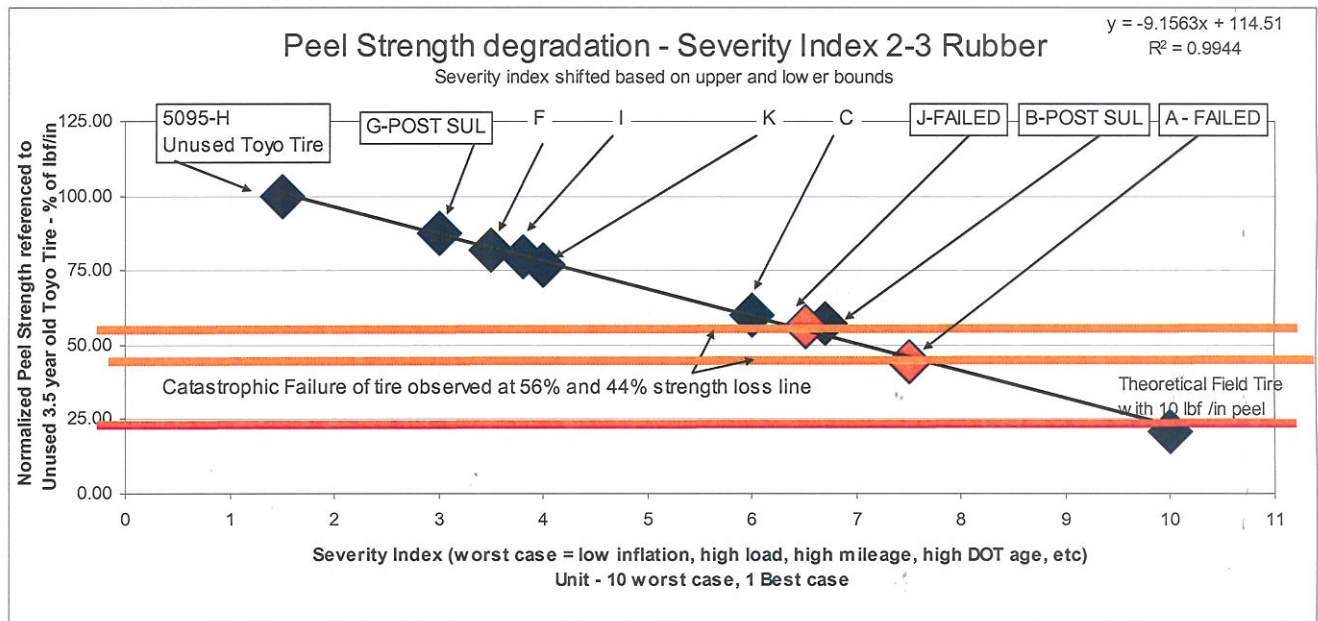
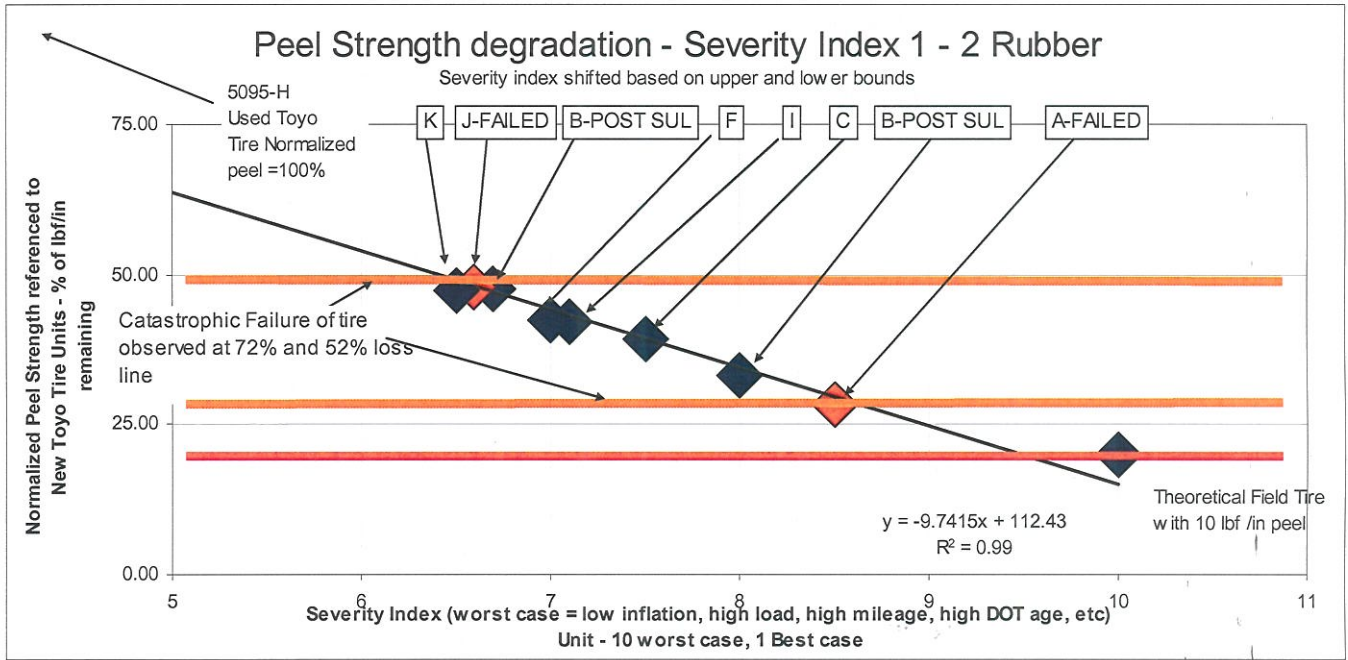
Modulus profiling was performed in the tire shoulder region at belt edges of “new (tire H)” and field tires (tires A, I, F, and C). Oxidative hardening was observed in the innerliner, ply coat, shoulder wedge, belt 1 coat, and underlay gumstrip compounds. Oxidative hardening was observed in the overlay gumstrip, tread base and tread components. Oxidative hardening was sometimes (generally) observed in belt-2 coat, 2-3 wedge, belt-3-coat, and overlay gum strip; however, the modulus changes were sometimes dominated by mechanical softening. The results indicate that for these tires, rubber degradation was primarily caused by oxidation. Clearly, the aging mechanism is predominantly oxidation. Lack of evidence of significant mechanical softening at belt edge indicates that the shear strains are in the normal range. This suggests that the tire aging occurred during shorter service runs and long parked tire conditions. These tires are different (unlike) long haul truck tires where the tire experiences long (or continuous) tire service (runs), by which oxygen permeation to internal components is limited and thermal reversion is the predominant degradation mechanism.

### Centerline Region

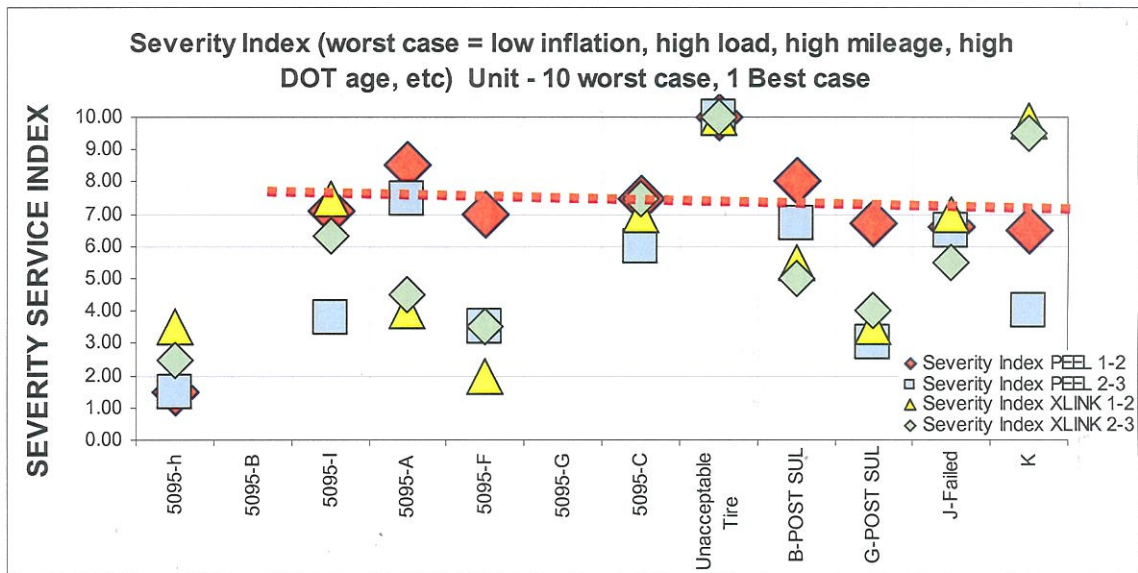
Modulus profiling was performed in the tire centerline region of “new (tire H)” and field tires (tires A and I). The overlay plots showed very large modulus increases in the squeegee, plycoat, belt-1-coat, and belt-2-coat compounds. The modulus change was especially high in belt-1-coat compound. The modulus increase is a result of oxidation. This was an unusually high level of property deterioration. The results point out that the major durability factor in this tire is probably oxidation in the belt-1-coat and belt-2-coat compounds in the centerline region. This may be associated with 1) high heat and strains in this region of the tire or 2) oxygen somehow reaching this compound (i.e., cord wicking), or 3) a combination of the two.

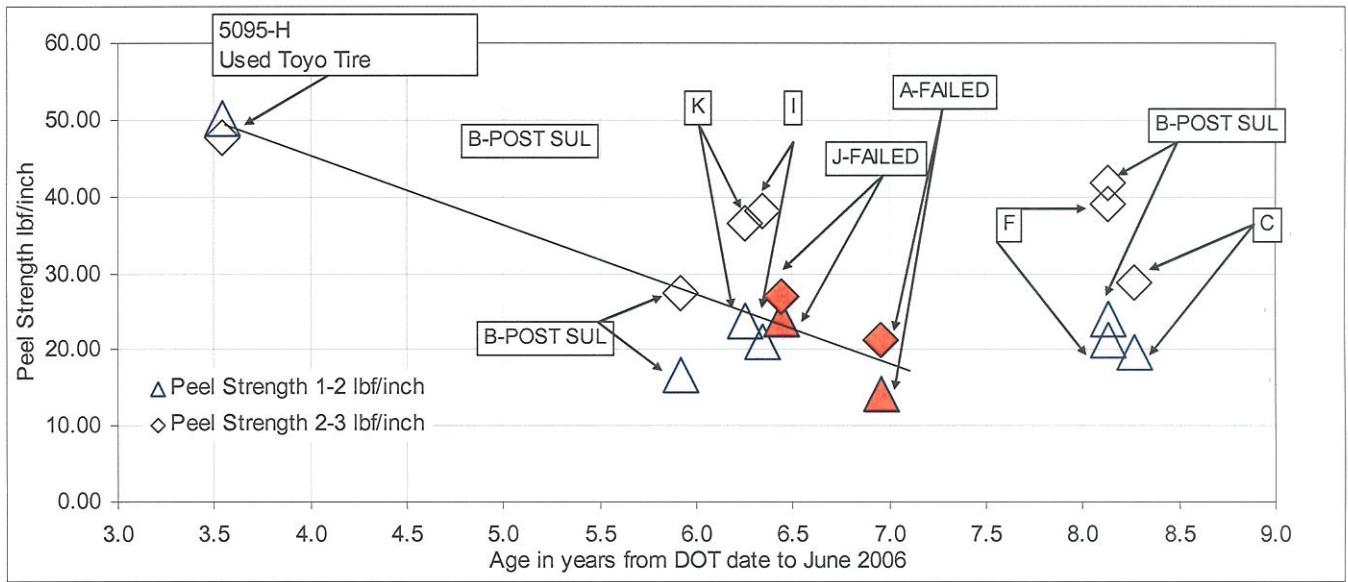
The compounds in wheel-tested tires experienced large modulus increases. Presumably, oxidative hardening was significantly affecting these compounds.

# Appendix G - PEEL STRENGTH-



Tire ID	DOT CODE	DOT Age in years	Severity Index PEEL 1-2	Severity Index PEEL 2-3	Peel Strength 1-2	Peel Strength 2-3
5095-h	DOT N3F2 5W11502	3.54	1.50	1.50	50.10	47.73
5095-B	DOT N3F2 5W11300	5.92				
5095-I	DOT N3F25W10800	6.35	7.10	3.80	21.07	38.10
5095-A	DOT N3F2 5W1289	6.96	8.50	7.50	14.18	21.15
5095-F	DOT N3F25W1198	8.13	7.00	3.50	21.21	39.06
5095-G	DOT N3F25W1198	8.13				
5095-C	DOT N3F2 5W1248	8.27	7.50	6.00	19.71	28.73
Unacceptable Tire			10.00	10.00	10.00	10.00
B-POST SUL	DOT N3F2 5W11300	5.92	8.00	6.70	16.57	27.29
G-POST SUL	DOT N3F25W1198	8.13	6.70	3.00	23.92	41.64
J-Failed	DOT N3F25W10300	6.44	6.60	6.50	24.06	26.88
K	DOT N3F25W11300	6.25	6.50	4.00	23.76	36.58

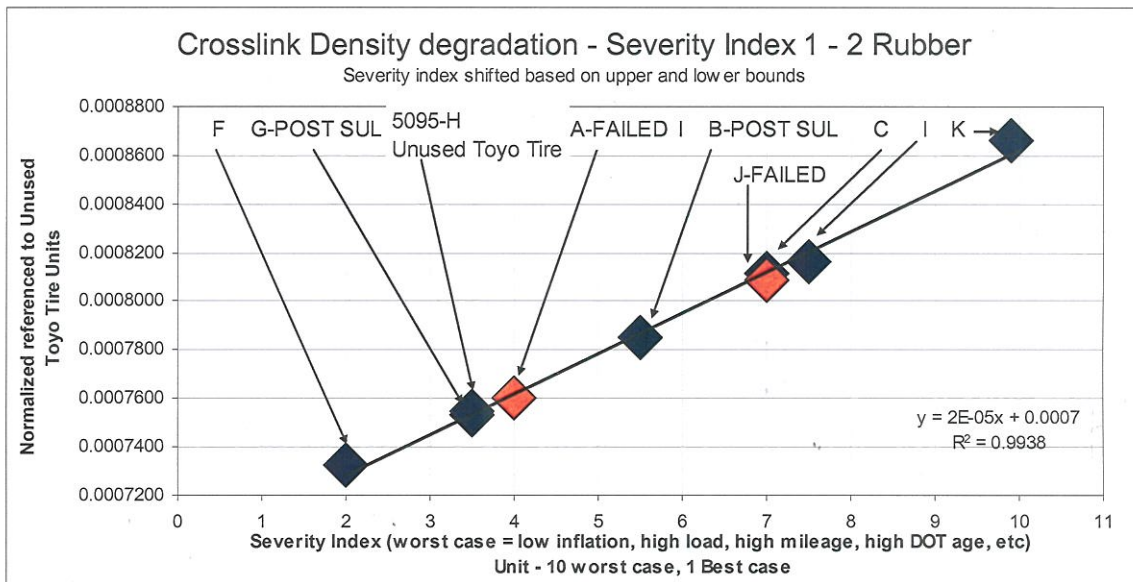


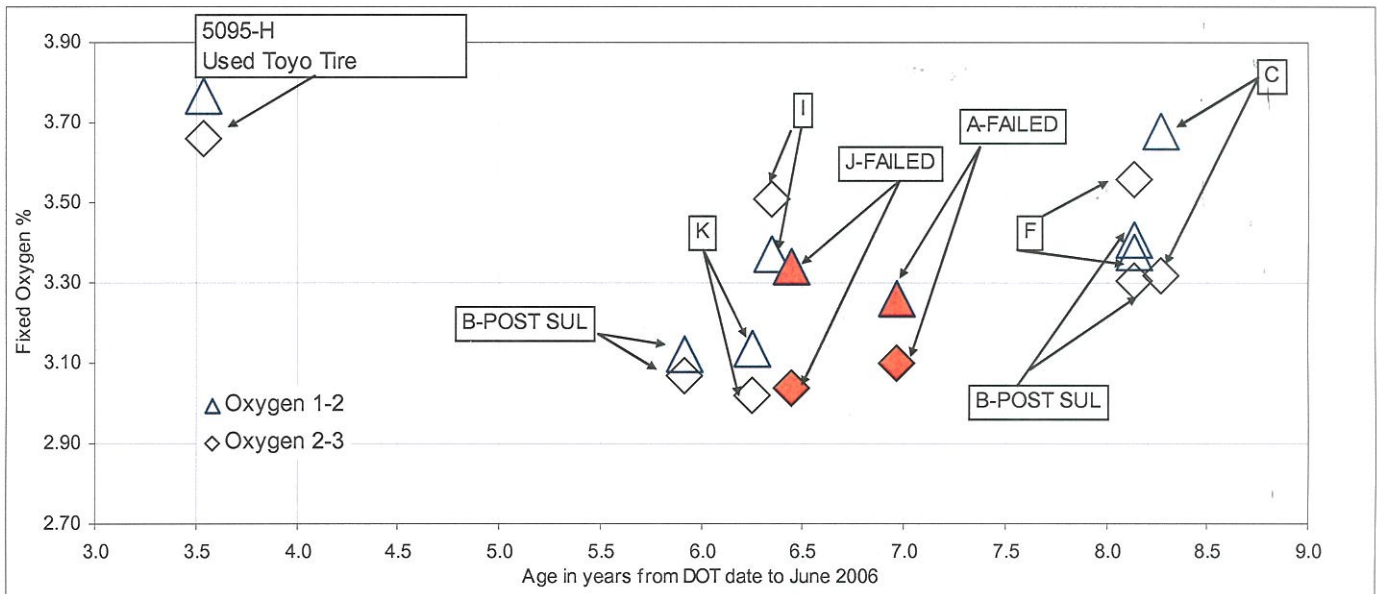
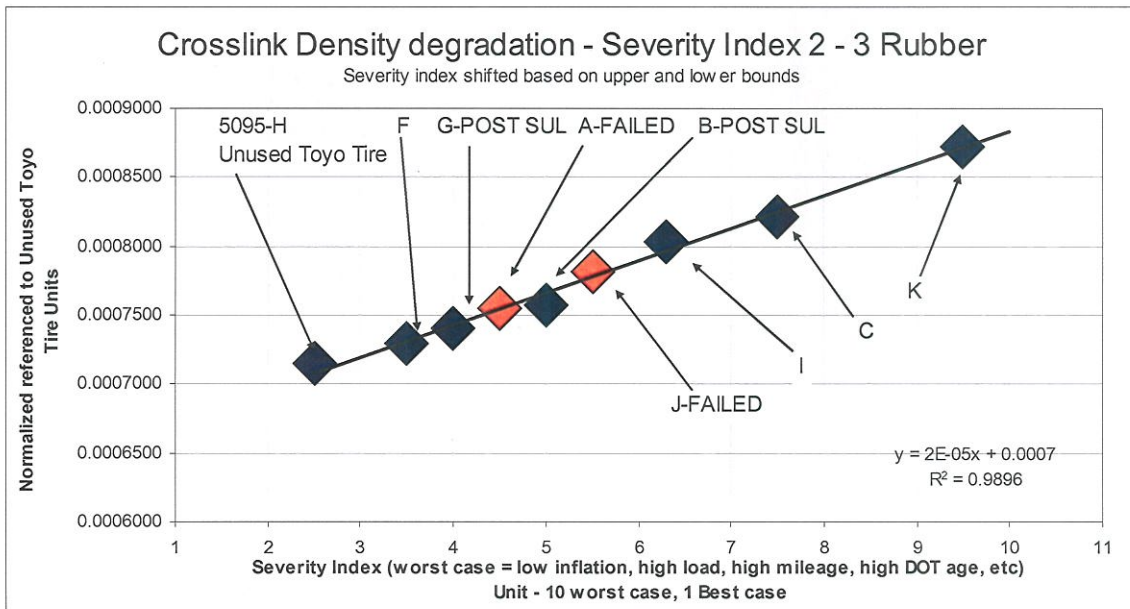


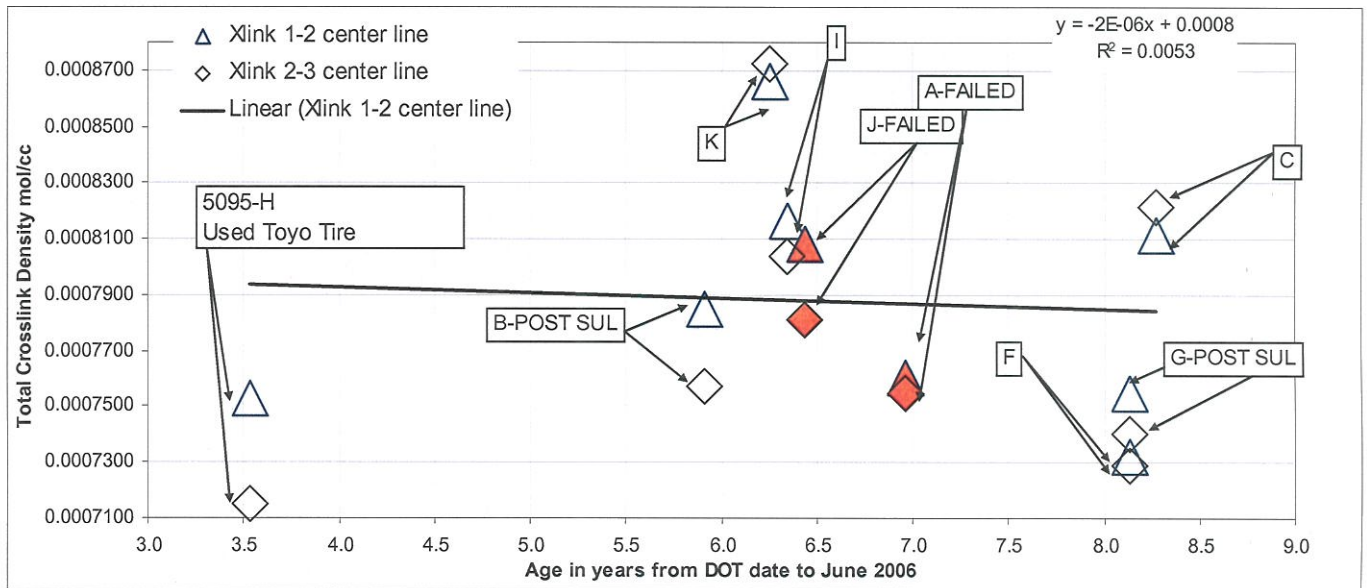
# Appendix H

## - CROSSLINK DENSITY

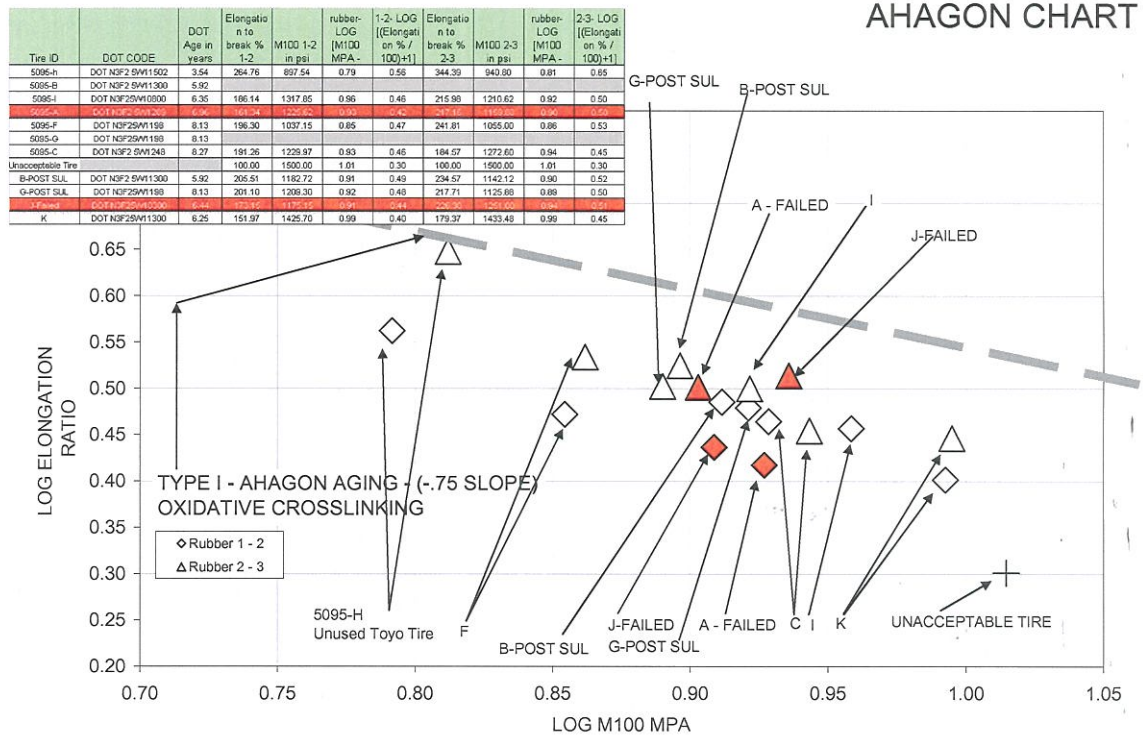
Tire ID	DOT CODE	DOT Age in years	Xlink 1-2 center line	Xlink 2-3 center line
5095-h	DOT N3F2 5W11502	3.54	0.0007531	0.0007148
5095-B	DOT N3F2 5W11300	5.92		
5095-I	DOT N3F25W10800	6.35	0.0008162	0.0008037
5095-A	DOT N3F2 5W1289	6.96	0.0007602	0.0007548
5095-F	DOT N3F25W1198	8.13	0.0007322	0.0007289
5095-G	DOT N3F25W1198	8.13		
5095-C	DOT N3F2 5W1248	8.27	0.0008111	0.0008215
Unacceptable Tire				
B-POST SUL	DOT N3F2 5W11300	5.92	0.0007849	0.0007574
G-POST SUL	DOT N3F25W1198	8.13	0.0007548	0.0007402
J-Failed	DOT N3F25W10300	6.44	0.0008083	0.0007812
K	DOT N3F25W11300	6.25	0.0008663	0.0008727







## - TENSILE TESTING -



Tire ID	DOT CODE	DOT Age in years	Elongation to break % 1-2	M100 1-2 in psi	rubber-LOG [M100 MPA -	1-2- LOG [(Elongation on % / 100)+1]	Elongation to break % 2-3	M100 2-3 in psi	rubber-LOG [M100 MPA -	2-3- LOG [(Elongation on % / 100)+1]
5095-h	DOT N3F2 5W11502	3.54	264.76	897.54	0.79	0.56	344.39	940.80	0.81	0.65
5095-B	DOT N3F2 5W11300	5.92								
5095-I	DOT N3F25W10800	6.35	186.14	1317.85	0.96	0.46	215.98	1210.62	0.92	0.50
5095-A	DOT N3F2 5W11289	6.96	161.34	1225.62	0.93	0.42	217.16	1159.88	0.90	0.50
5095-F	DOT N3F25W1198	8.13	196.30	1037.15	0.85	0.47	241.81	1055.00	0.86	0.53
5095-G	DOT N3F25W1198	8.13								
5095-C	DOT N3F2 5W1248	8.27	191.26	1229.97	0.93	0.46	184.57	1272.60	0.94	0.45
Unacceptable Tire			100.00	1500.00	1.01	0.30	100.00	1500.00	1.01	0.30
B-POST SUL	DOT N3F2 5W11300	5.92	205.51	1182.72	0.91	0.49	234.57	1142.12	0.90	0.52
G-POST SUL	DOT N3F25W1198	8.13	201.10	1209.30	0.92	0.48	217.71	1125.88	0.89	0.50
J-Failed	DOT N3F25W10300	6.44	173.15	1175.15	0.91	0.44	226.30	1251.00	0.94	0.51
K	DOT N3F25W11300	6.25	151.97	1425.70	0.99	0.40	179.37	1433.48	0.99	0.45

Tire and Rubber layer ID	TENSILE - Average Elongation to break in %	TENSILE - Average Modulus at 25% psi	TENSILE - Average Modulus at 50% psi	TENSILE - Average Modulus at 100% psi	TENSILE - Average Modulus at break elongation-psi
	5SS/5OSS	5SS/5OSS	5SS/5OSS	5SS/5OSS	5SS/5OSS
averageA-2-3	217.16	381.55	618.25	1159.88	2582.64
averageA-1-2	161.34	396.31	650.95	1225.62	2003.04
averageC-1-2	191.26	402.62	659.49	1229.97	2292.26
averageC-2-3	184.57	441.23	702.10	1272.60	2310.48
averageF-1-2	196.30	344.44	547.73	1037.15	2127.42
averageF-2-3	241.81	345.06	562.78	1055.00	2726.42
averageH-2-3	344.39	336.53	515.05	940.80	3506.33
averageH-1-2	264.76	294.17	460.13	897.54	2678.23
averageI-1-2	186.14	442.81	712.66	1317.85	2464.34
averageI-2-3	215.98	438.73	677.50	1210.62	2604.48
averageZ-1-2	342.91	316.66	497.24	930.82	3008.96
averageZ-2-3	301.89	311.44	485.73	946.93	2877.92
averageB-postrun-1-2	205.51	390.26	628.38	1182.72	2508.62
averageB-postrun-2-3	234.57	393.89	619.56	1142.12	2717.62
averageG-postrun-1-2	201.10	386.83	625.60	1209.30	2540.62
averageG-postrun-2-3	217.71	393.25	614.54	1125.88	2524.24
averageJ-1-2	173.15	366.89	590.81	1175.15	2122.08
averageJ-2-3	226.30	392.39	648.95	1251.00	2924.58
averageK-1-2	151.97	455.58	752.36	1425.70	2161.44
averageK-2-3	179.37	497.33	779.89	1433.48	2546.40

# References

## References

<i>Reference Number</i>	<i>Technical Paper Title</i>	<i>Authors</i>	<i>Presentation Venue</i>
1	Aging of Tire Parts during service. I Types of aging in heavy-duty tire	Asahiro Ahagon, M. Kida, and H.Kaidou	Presented at a meeting of the Rubber Division, ACS, May 1990
2	Aging of Tire Parts during service. II Aging of Belt-skim rubbers in passenger tires	Hiroyuki Kaidou and A. Ahagon	Presented at a meeting of the Rubber Division, ACS, May 1990
3	Evaluation of chain scission during mixing of filled compounds	Asahiro Ahagon	
4	Oxidative aging of back filled elastomers	A. Ahagon, Hiratsuka	Presented at a meeting of the Rubber Division, ACS, Oct 1984
5	Property changes in automotive tyre components in road service	A. Ahagon	International Polymer Science and Technology, Vol. 27, No 3.,2000
6	Oxidative aging of reinforced elastomers	L. Nasdala	Universitat Hannover, Germany
7	FEA of diffusion –reaction in tires	Norman Welson	Stevens institute of tech, Rubber world Publication Oct 1993
8	The chain end distributions and crosslink characteristics in black filled rubbers	Asahiro Ahagon	