General Considerations in Failure Analysis of Rubber

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ARDL

Passion for Problem Solving

Akron Rubber Development Laboratory

- Independent Testing Laboratory
- Founded In 1962 By C.R. Samples
- Experienced Rubber and Analytical Chemists and Engineers, approximately 100 employees
- Continuing Investment In Technology

ACCREDITED
A Testing Lab
Certificate Numbers 255.01 & 255.02

ISO 9001:2015
Registered

- Compounding and Mixing
- Physical Testing
- Chemical Testing
  - Reverse Engineering
  - Medical/Pharmaceutical
  - Microbial testing
- Engineering
  - Oil industry testing (RGD)
  - Modeling
  - Tire testing
  - Wiper blade testing
  - Dynamic viscoelastic testing
- Microscopy
  - EDX
  - SEM
  - Dispersion
- Plastic Testing
- Failure Analysis and Legal
- Consulting
  - Problem Solving
  - Compound and Test Development
  - Prototyping

Why do objects fail?

- Misapplication
- Abuse
- Lack of maintenance
- Manufacturing defect
- Design defect
- End of service life

The Importance of the Scientific Method

1. Observing
2. Gathering facts, identifying patterns
3. Developing a hypothesis that fits the facts
4. Testing the hypothesis
5. Repeat steps 1-4 as necessary
6. Finalizing and validating conclusions

Low Speed Tire with Sidewall Bulge

Interface D

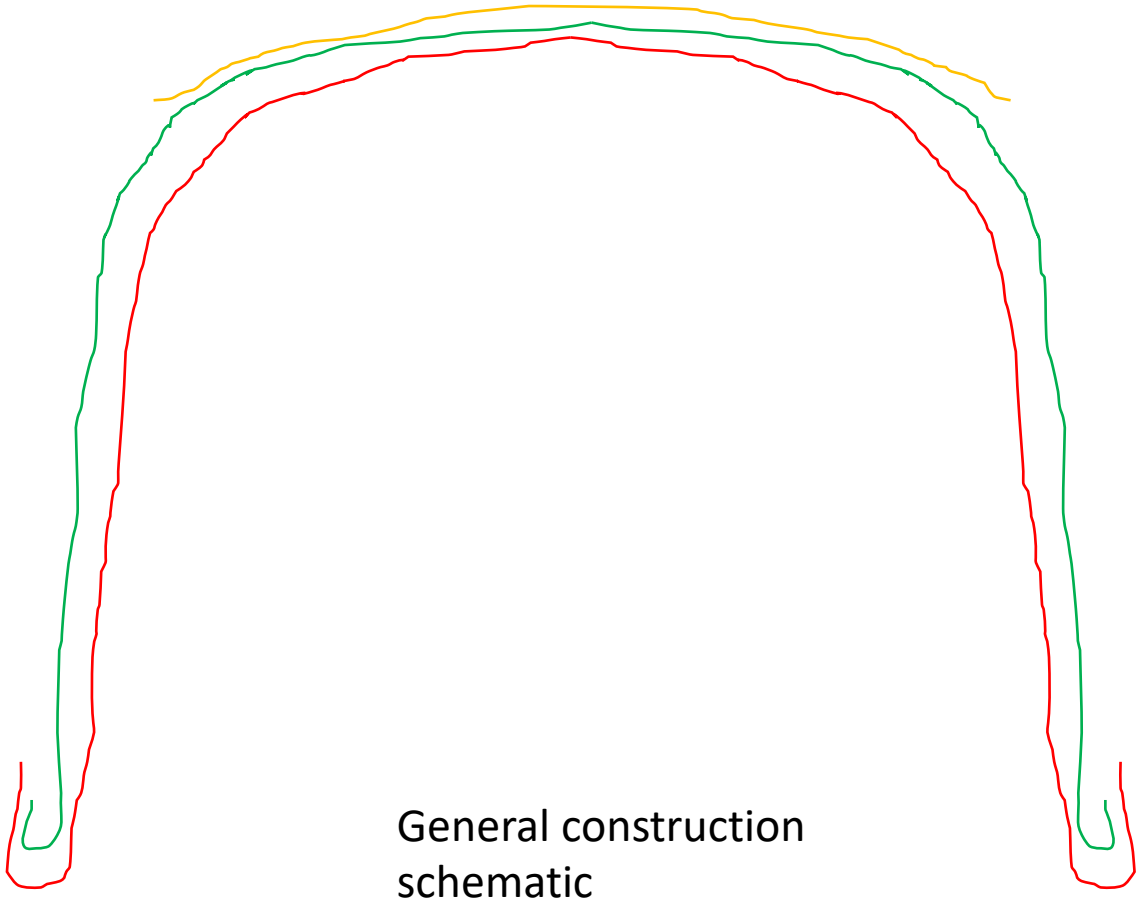
Interface A

Serial Side (SS)

Opposite Serial Side (OSS)

Low Speed Tire with Sidewall Bulge

Low Speed Tire with Sidewall Bulge



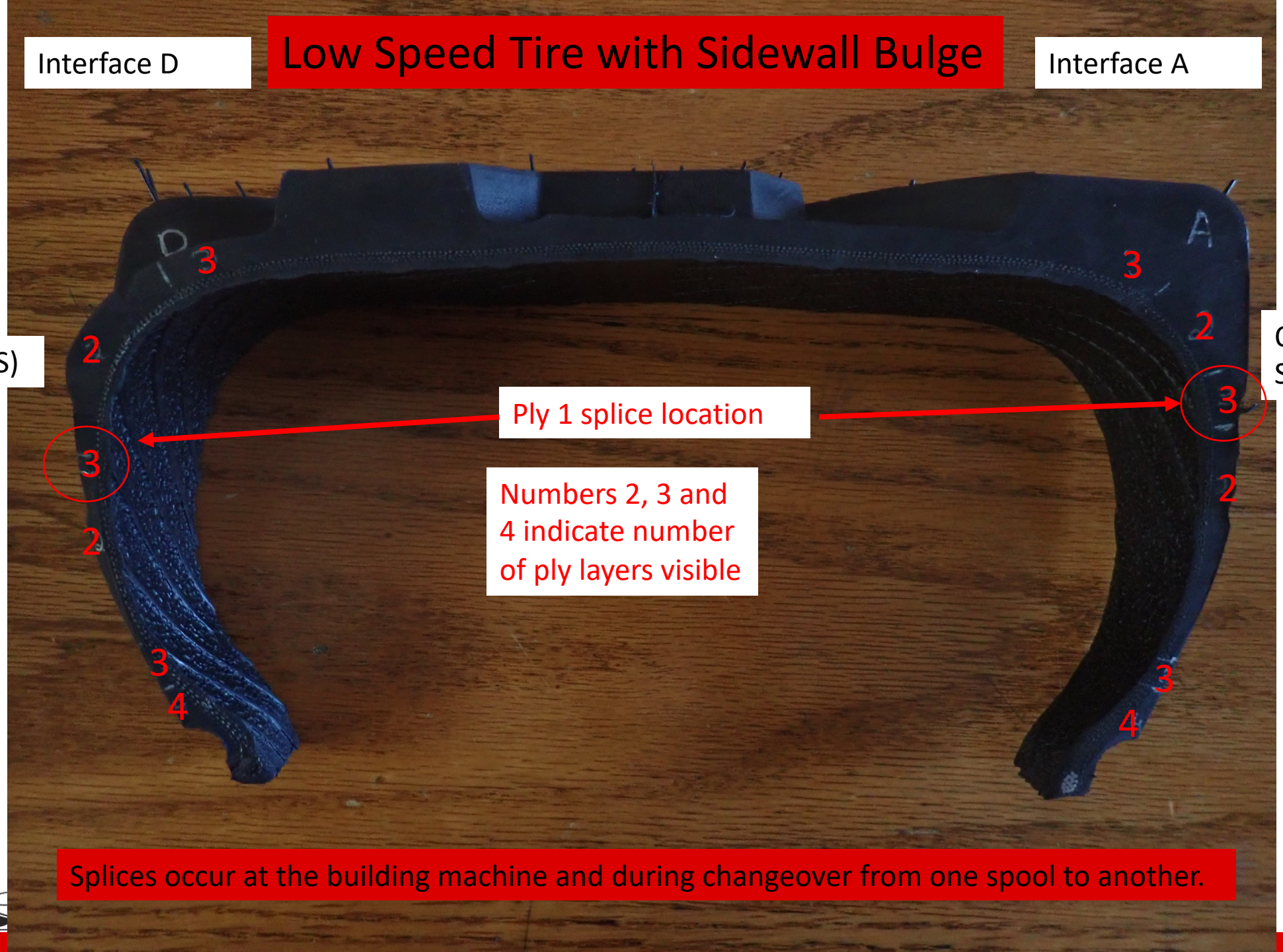
General construction schematic

- Ply 1 in red
- Ply 2 in green
- Ply 3 in orange

Low Speed Tire with Sidewall Bulge

Interface D

Interface A



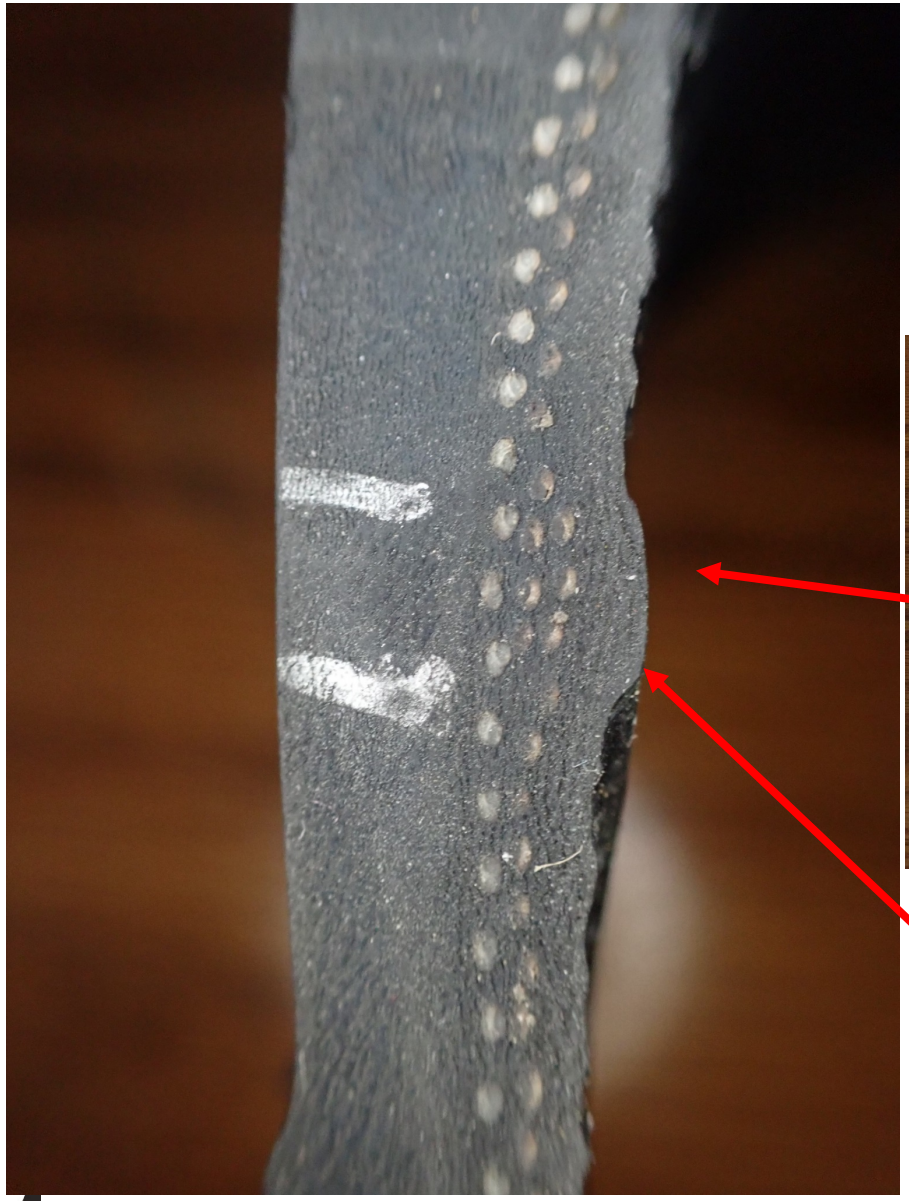
Serial Side (SS)

Opposite Serial Side (OSS)

Ply 1 splice location

Numbers 2, 3 and 4 indicate number of ply layers visible

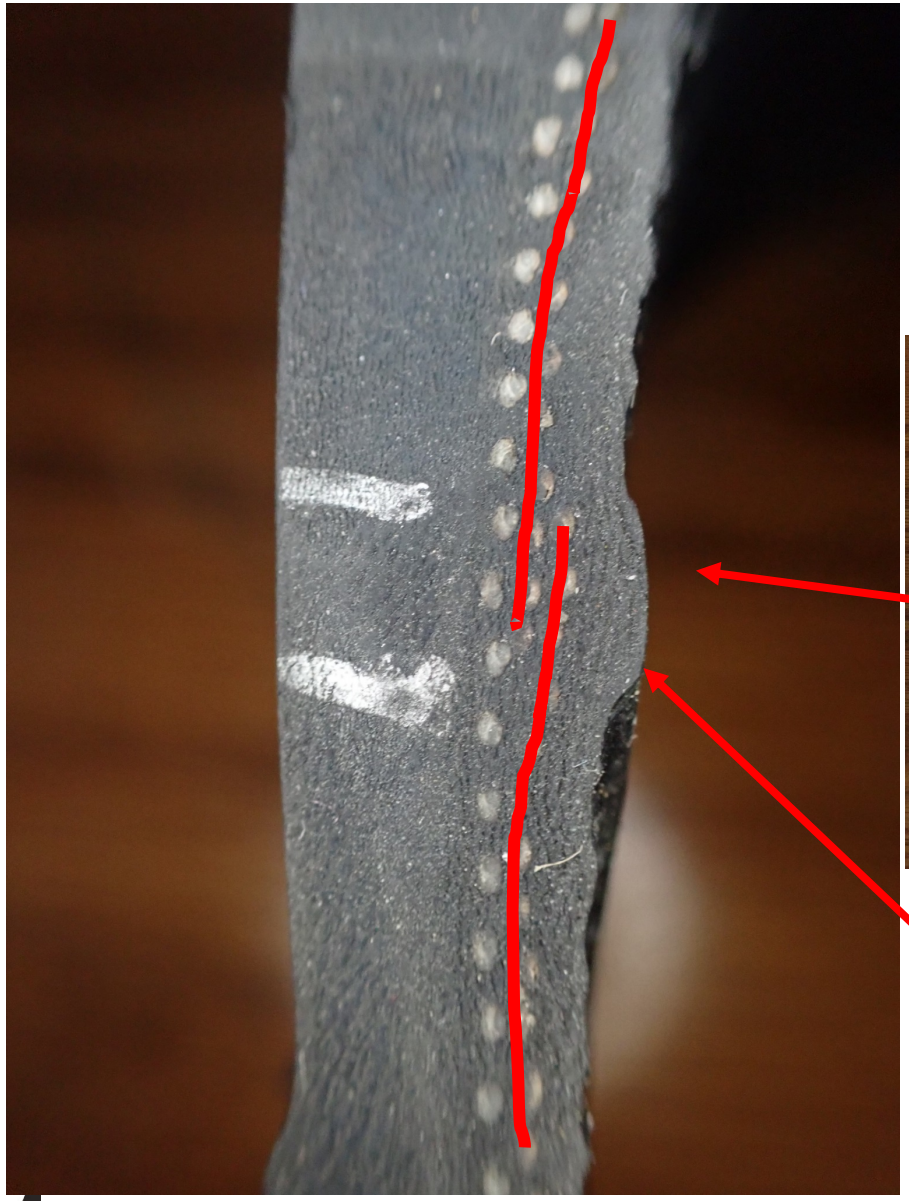
Splices occur at the building machine and during changeover from one spool to another.



Interface D splice-~3 cord overlap

Overall gauge in splice areas is increased by inner liner rib.

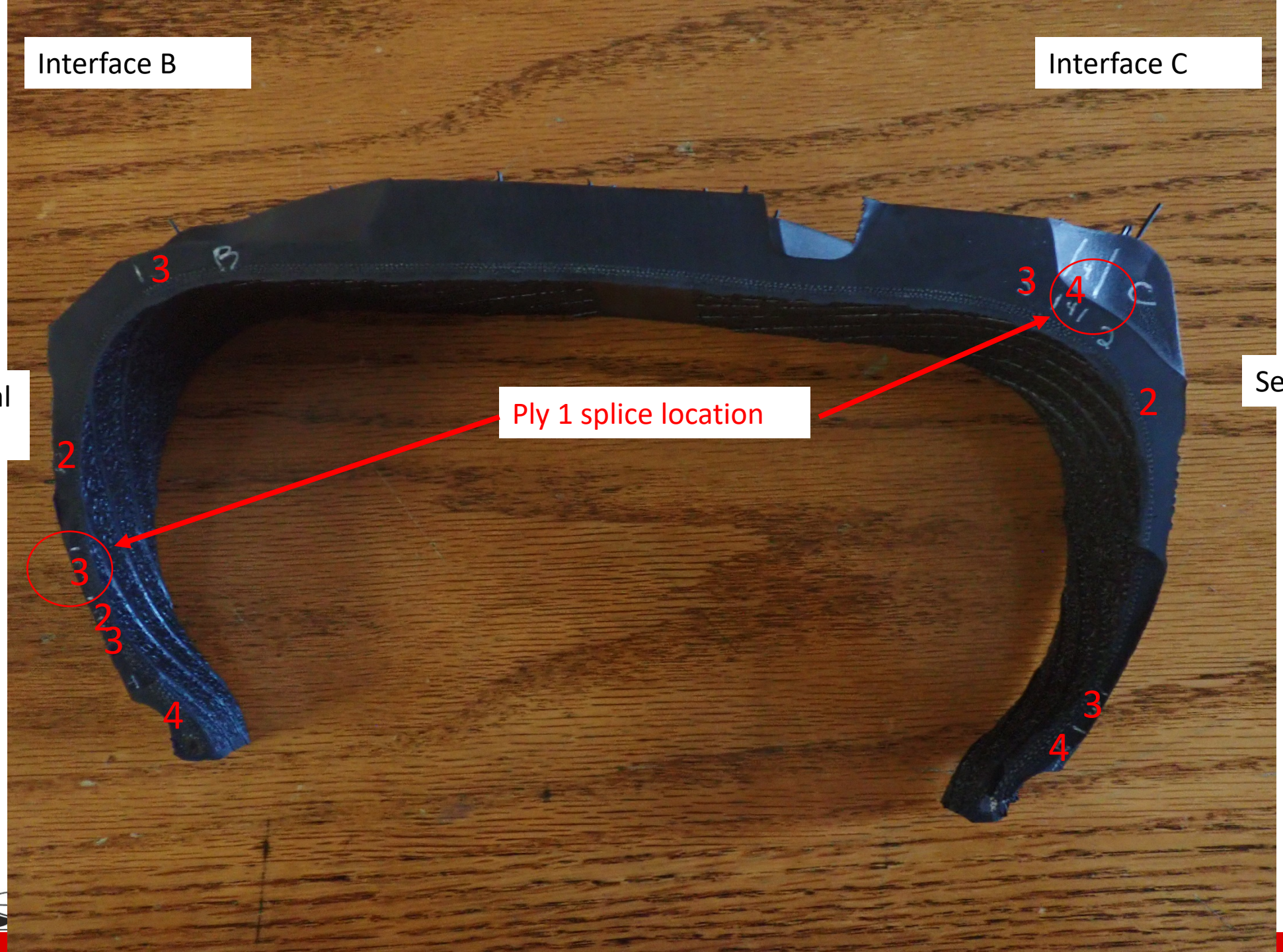
Interface A splice-~8 cord overlap

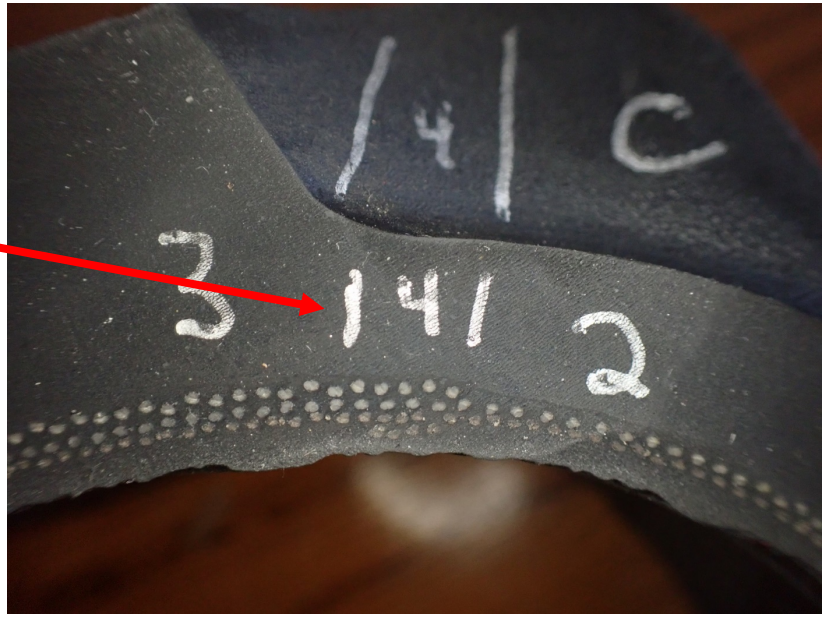


Overall gauge in splice areas is increased by inner liner rib.

Interface D splice-~3 cord overlap

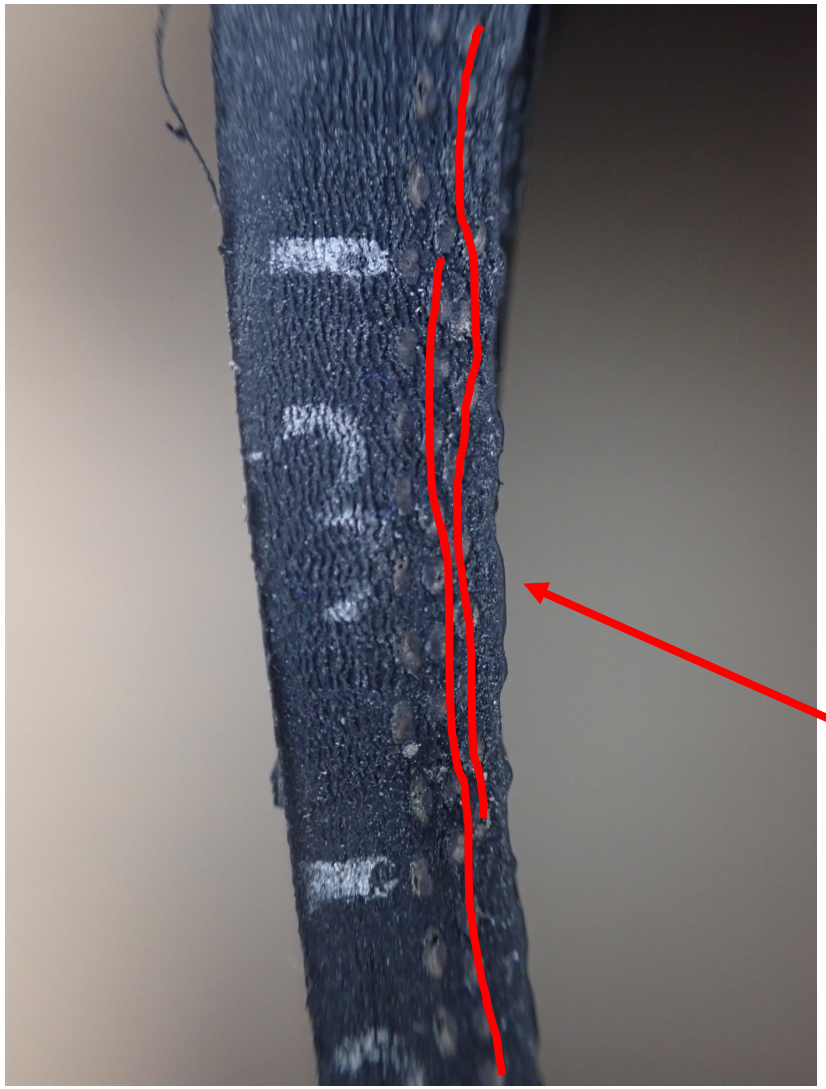
Interface A splice-~8 cord overlap

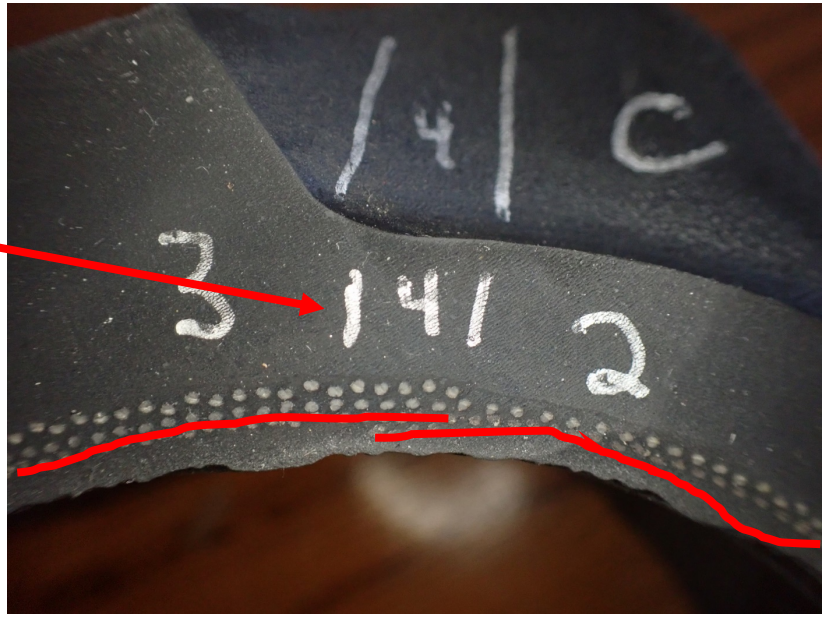

Interface B
Interface C
Opposite Serial Side (OSS)
Serial Side (SS)
Ply 1 splice location
3
B
3
4
2
2
3
2
3
4
2
3
4



Interface D splice-~8 cord overlap

Interface C splice-~3 cord overlap



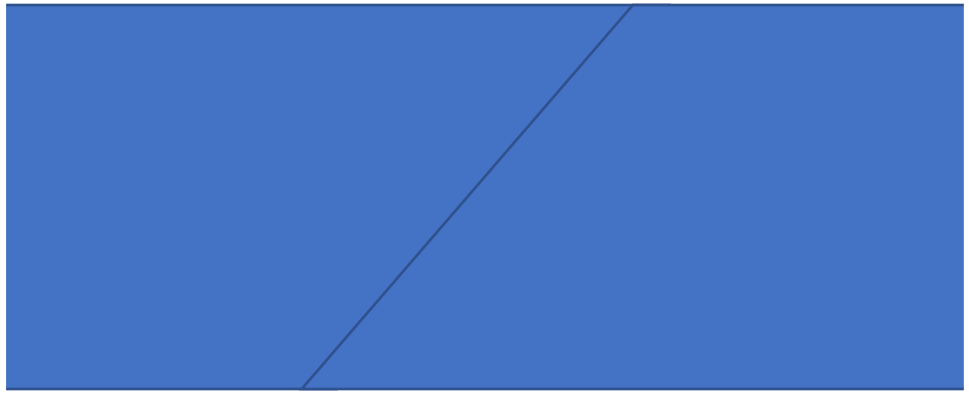


Interface D splice-~8 cord overlap

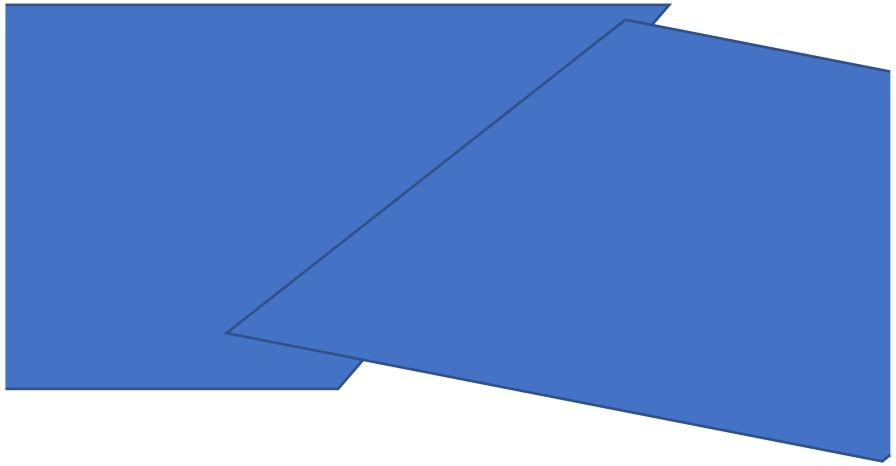
Interface C splice-~3 cord overlap

Low Speed Tire with Sidewall Bulge

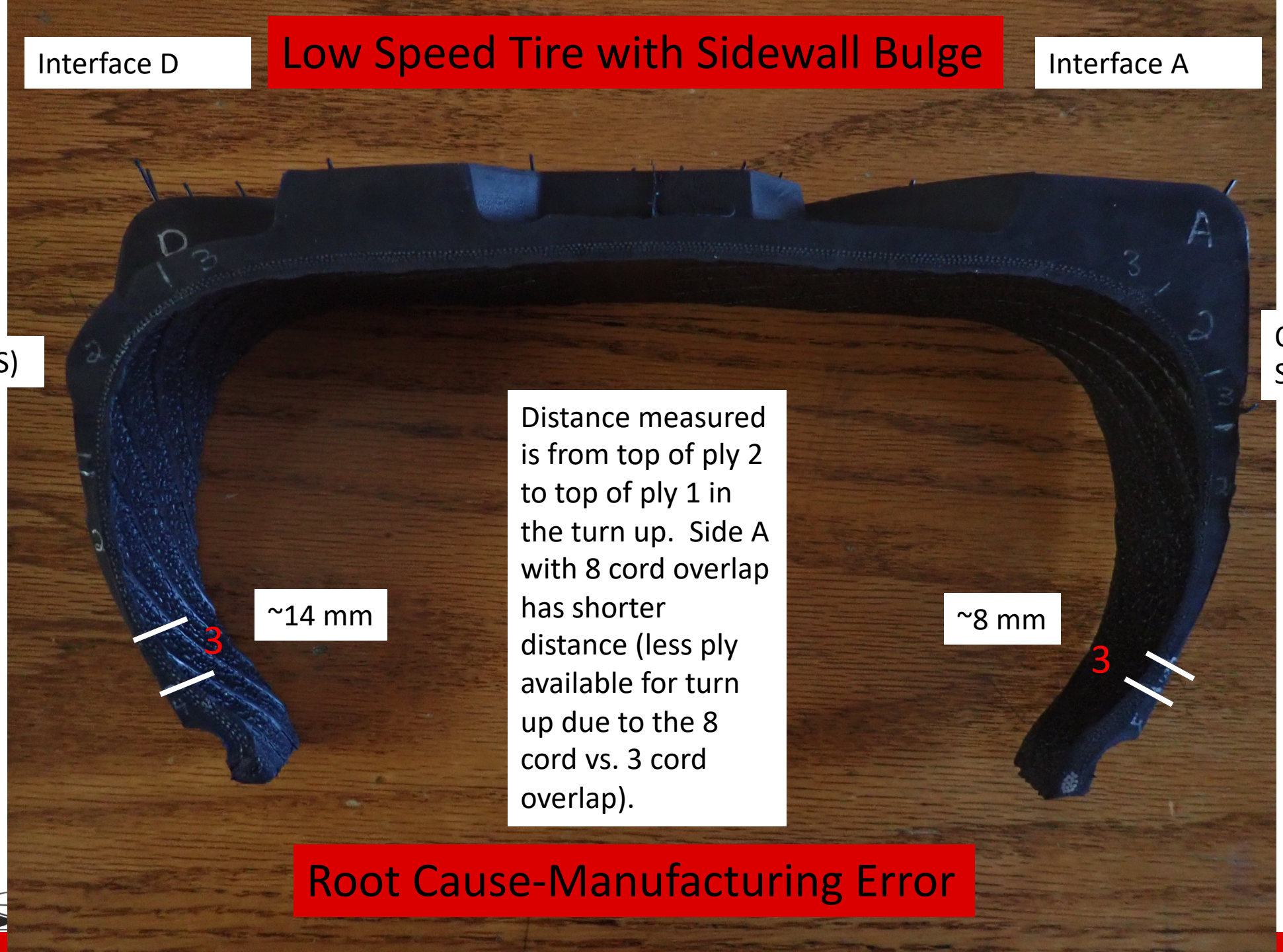
Proper Splice



Improper Splice

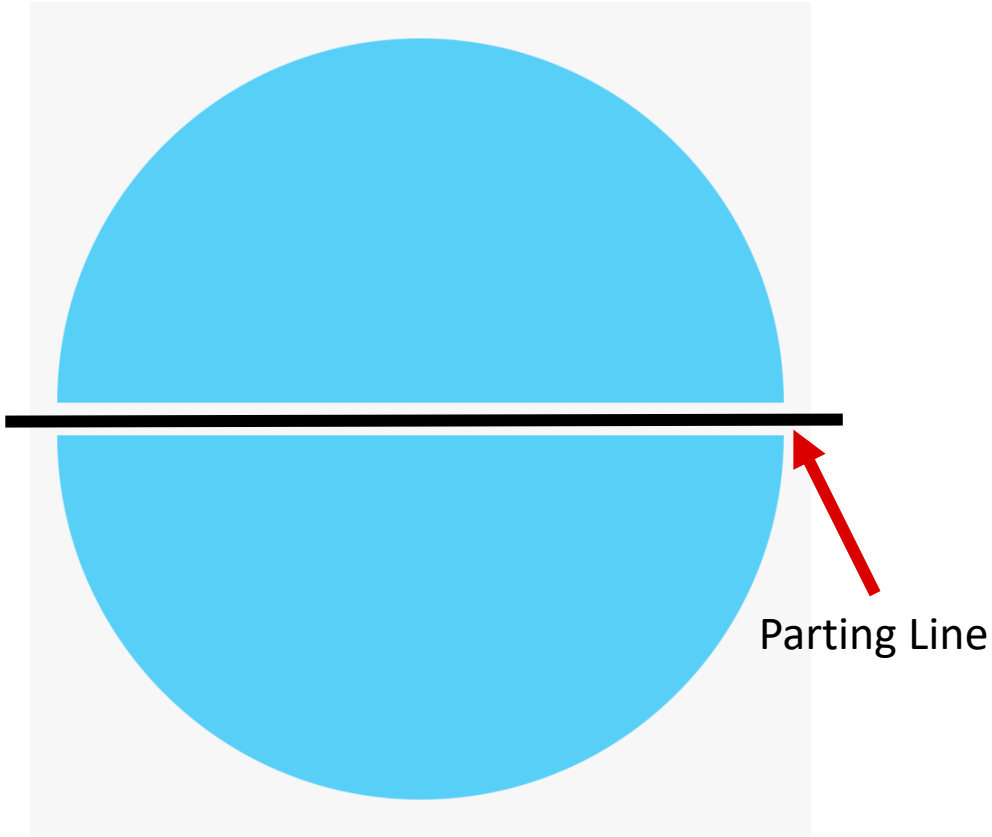


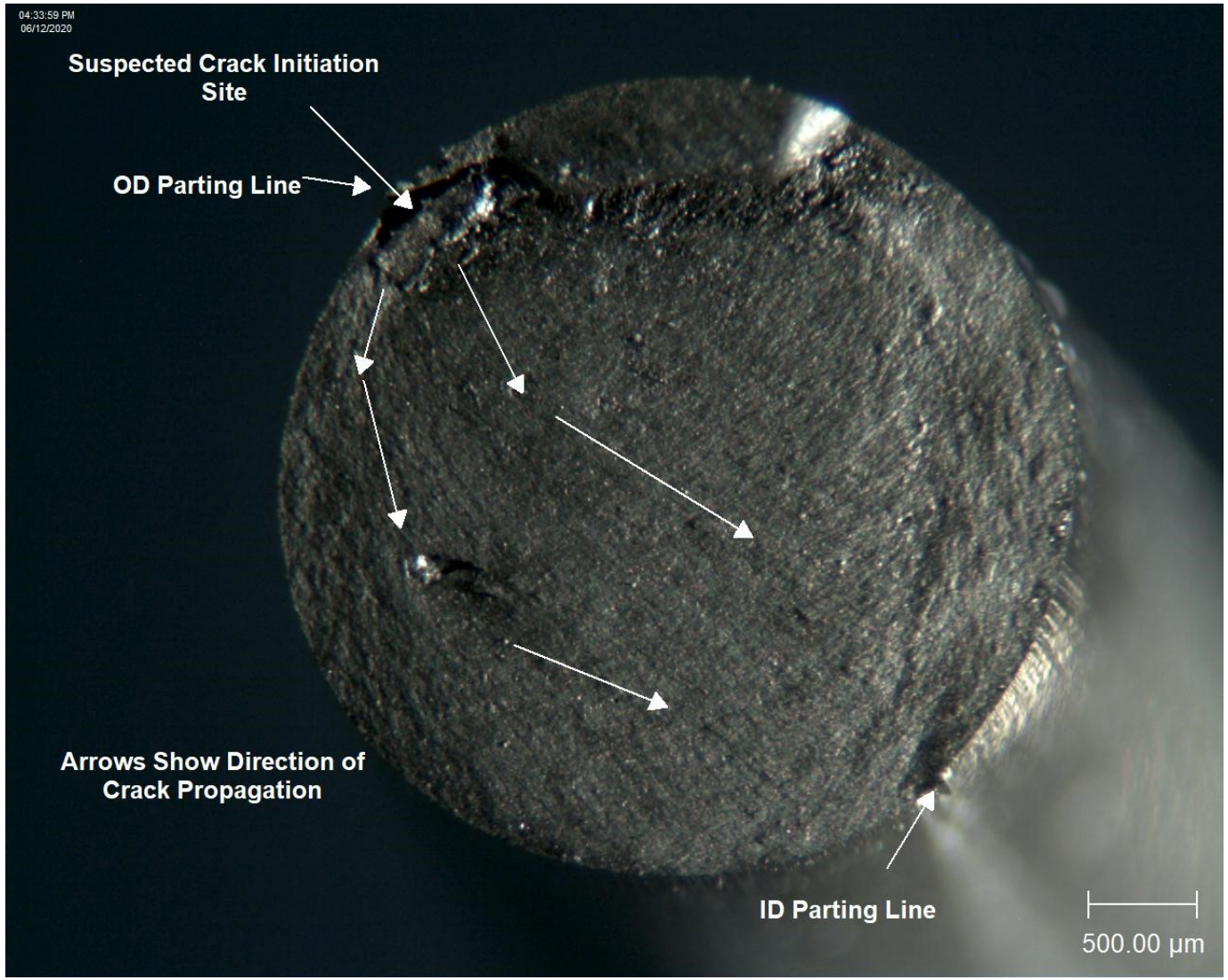
Low Speed Tire with Sidewall Bulge



Root Cause-Manufacturing Error

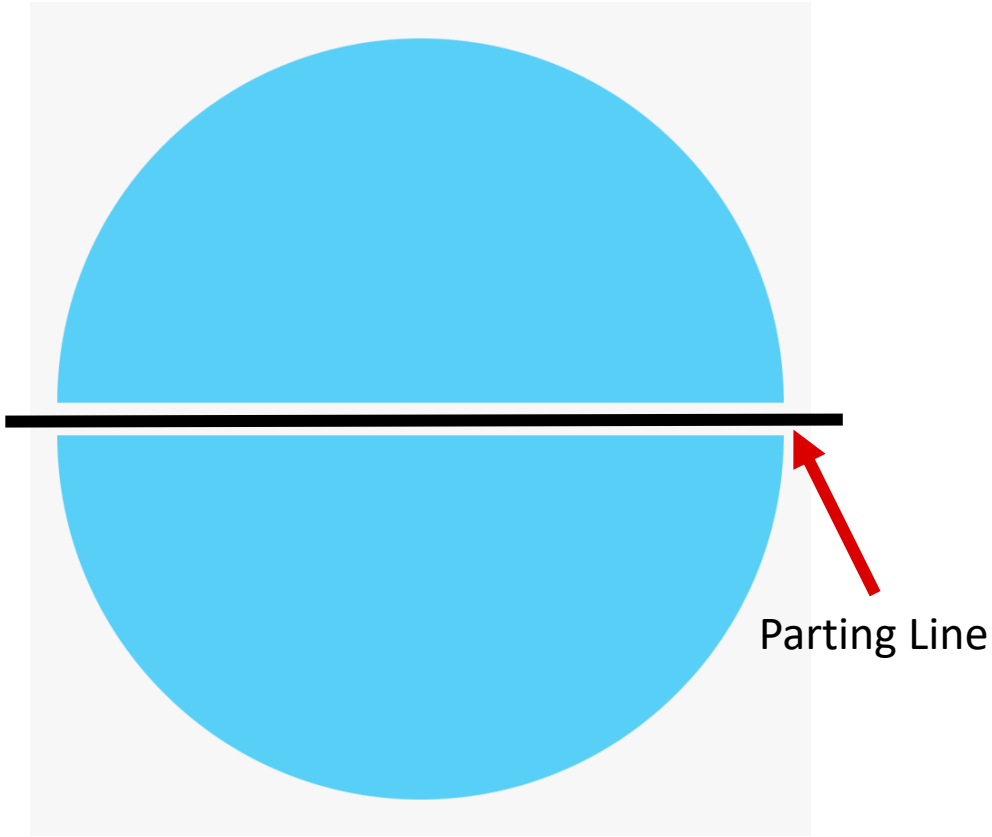
Speaking of O-rings…….

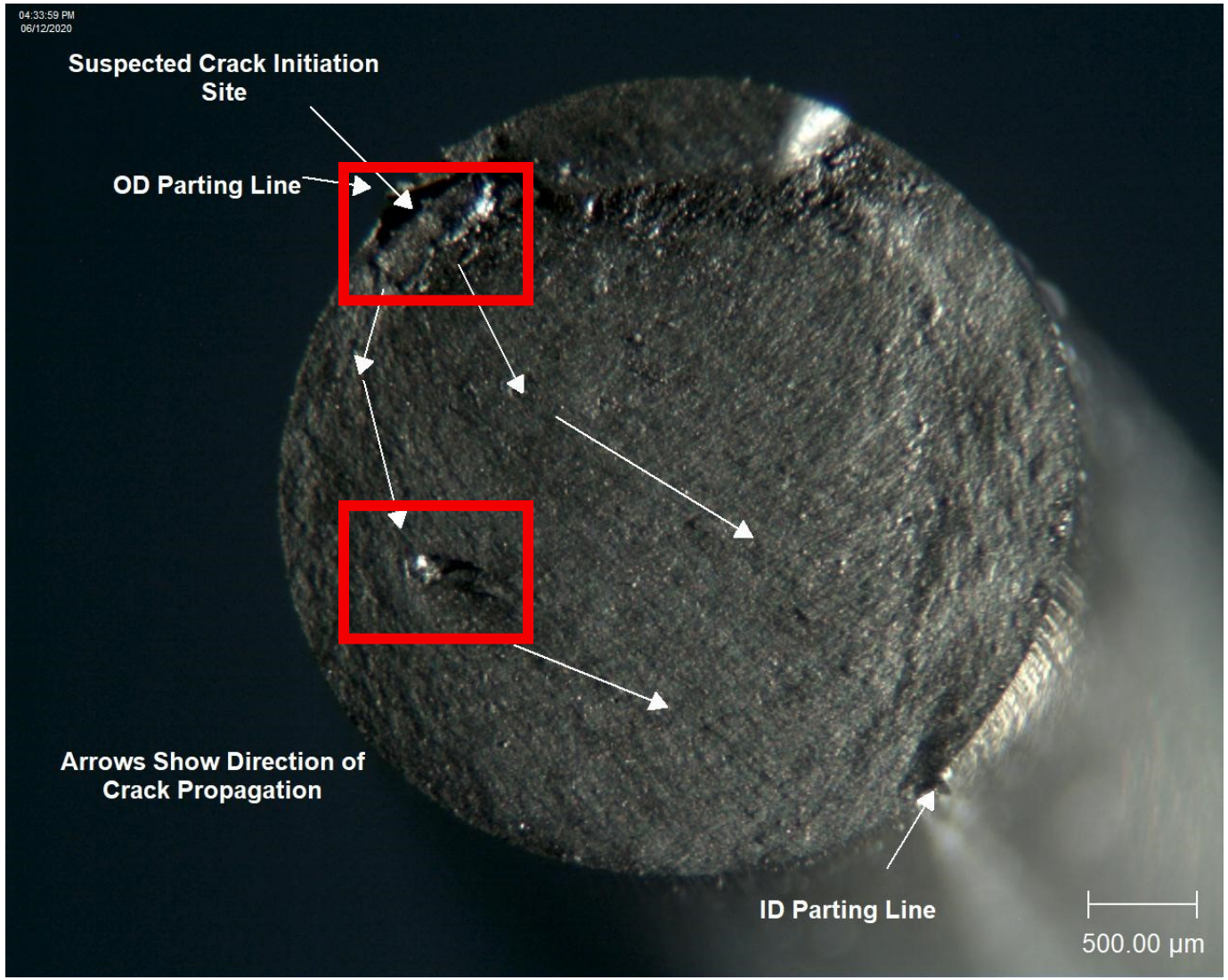




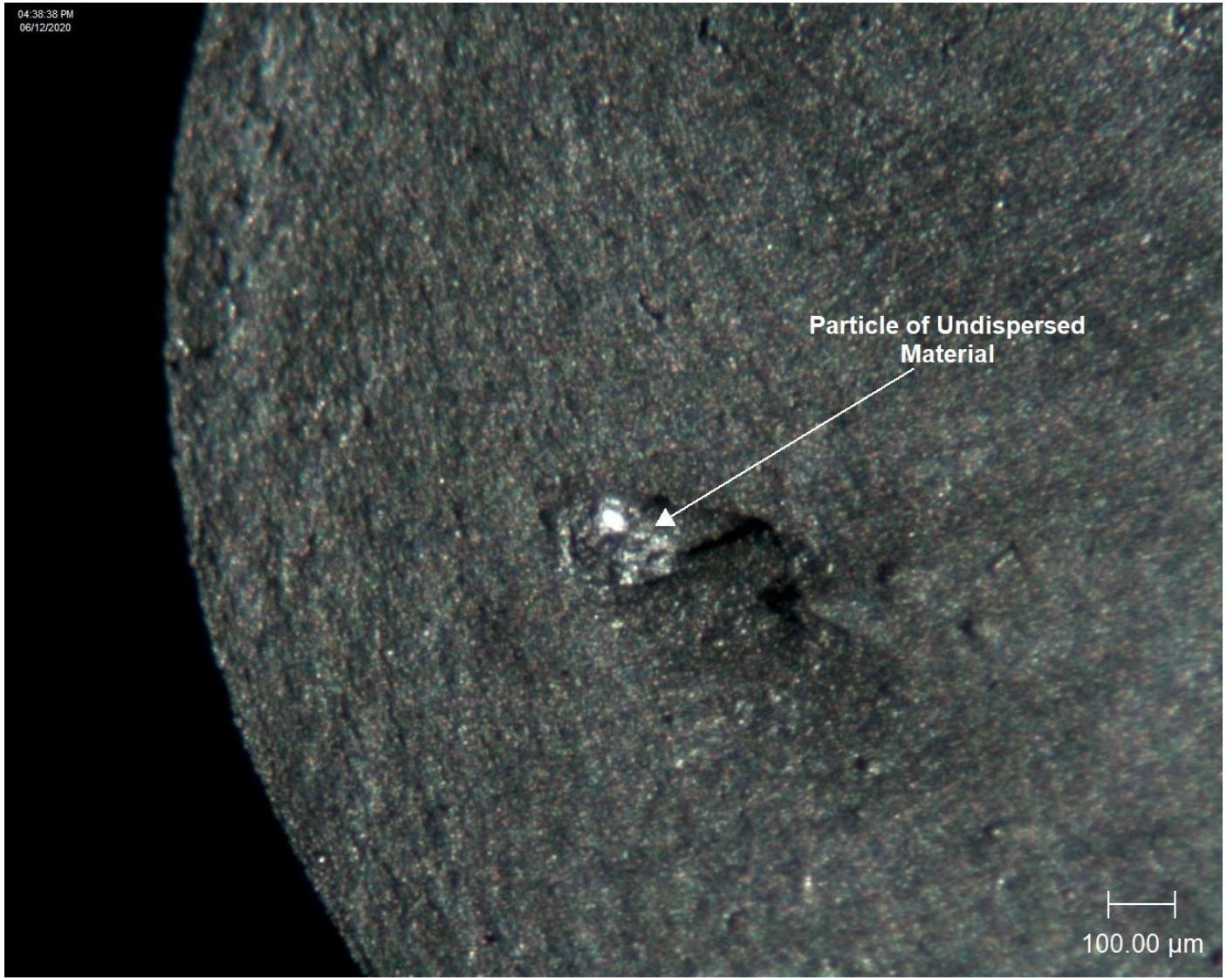
O-ring made with typical two piece compression mold

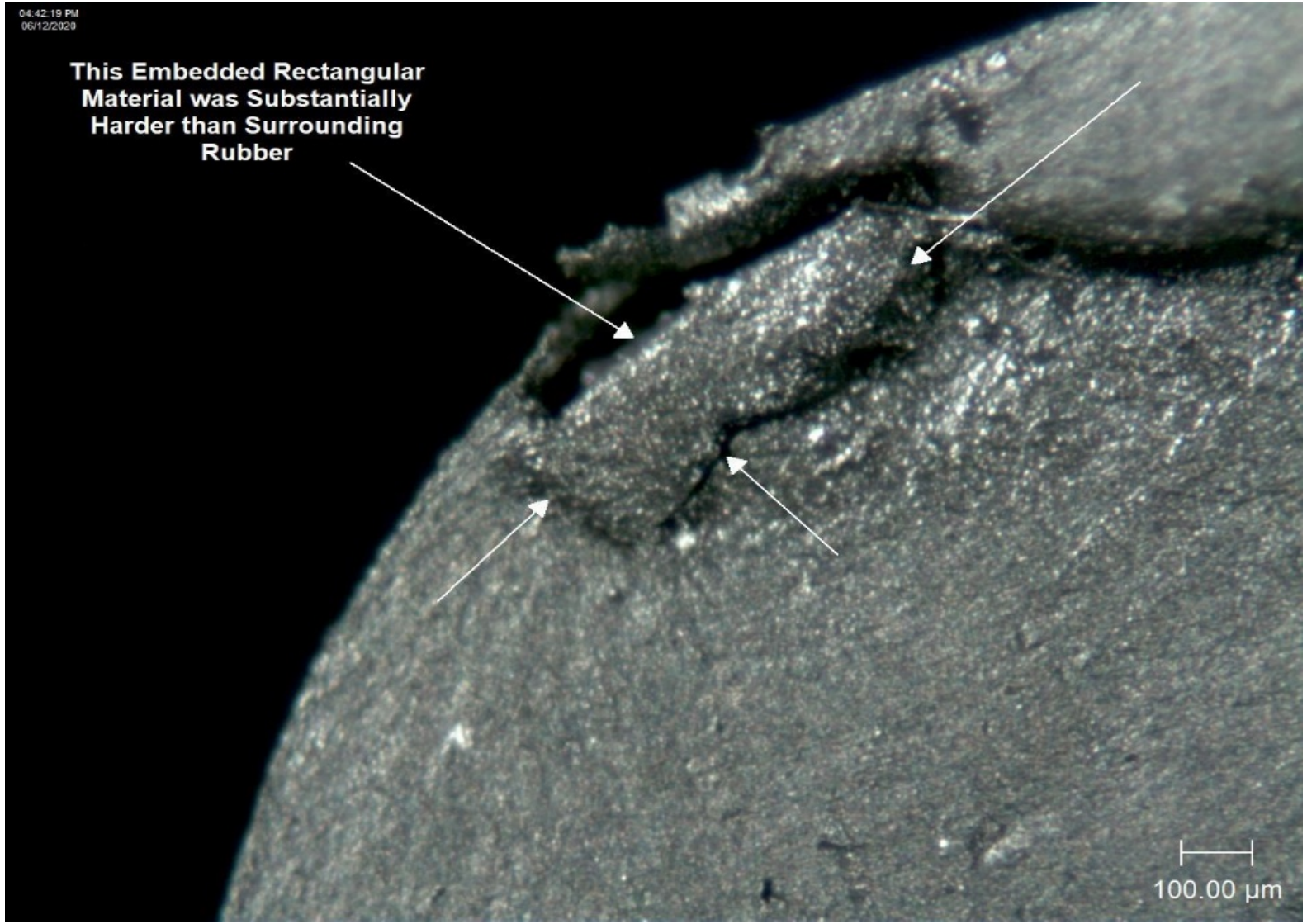
Speaking of O-rings…….



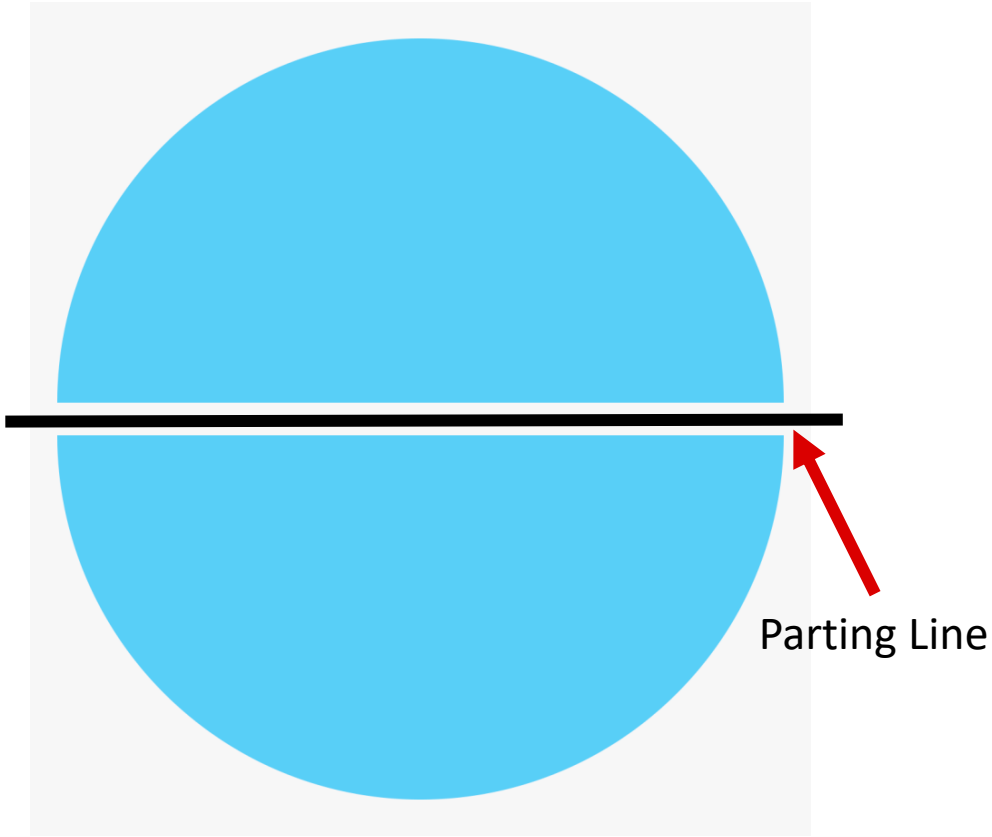


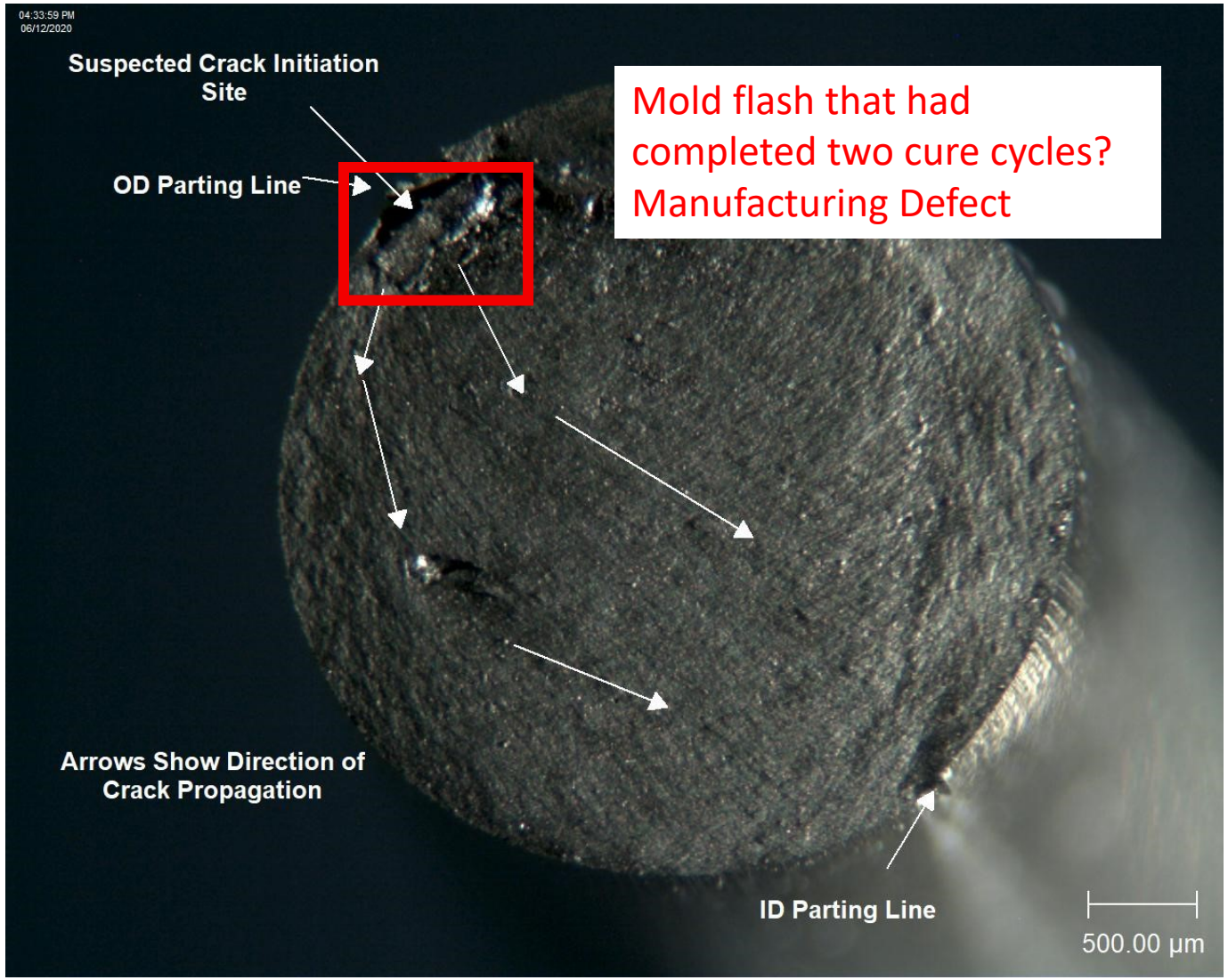
O-ring made with typical two piece compression mold


04:38:38 PM
06/12/2020
Particle of Undispersed Material
100.00 µm


04:42:19 PM
06/12/2020
This Embedded Rectangular Material was Substantially Harder than Surrounding Rubber
100.00 µm

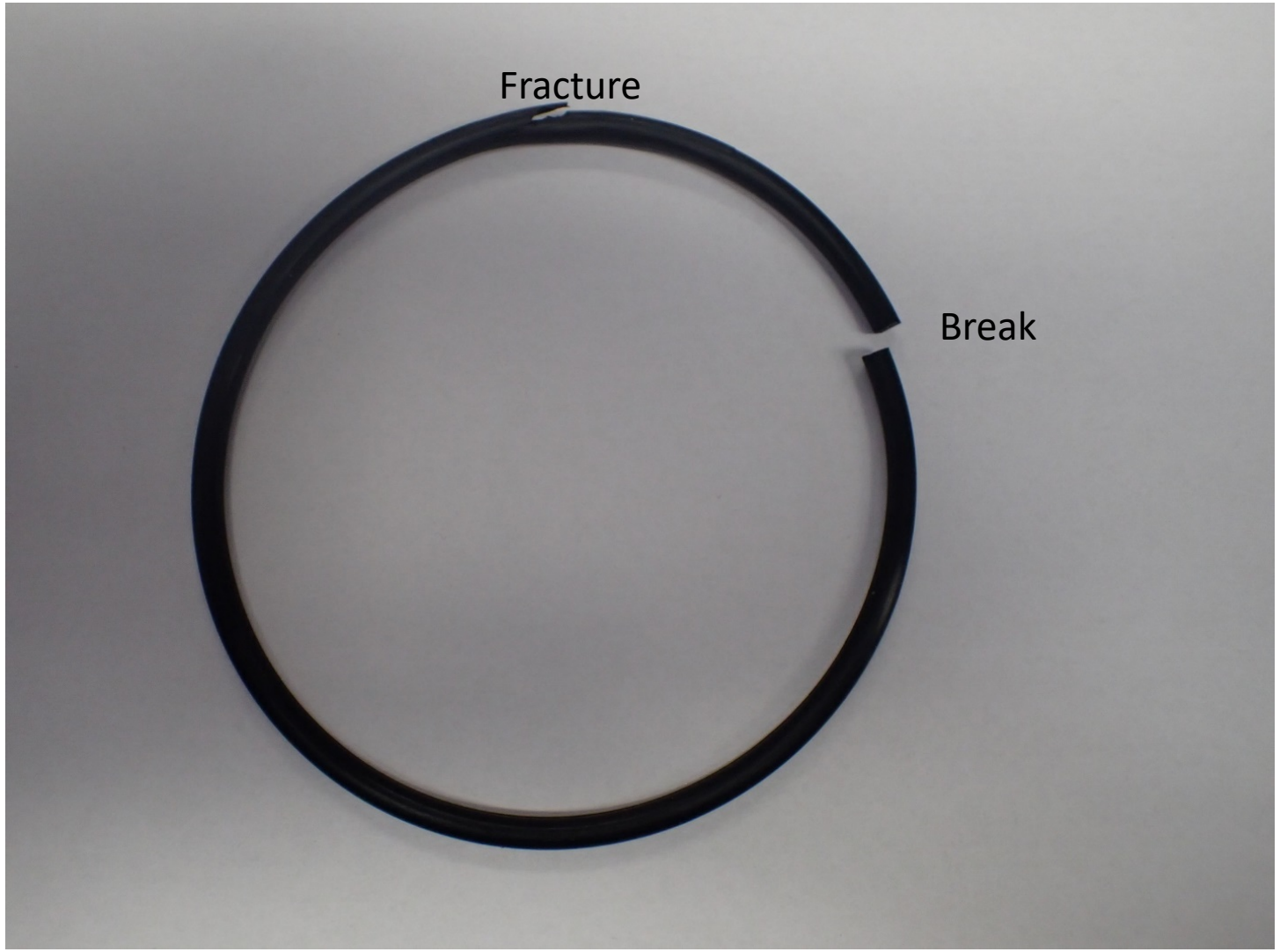
Speaking of O-rings…….





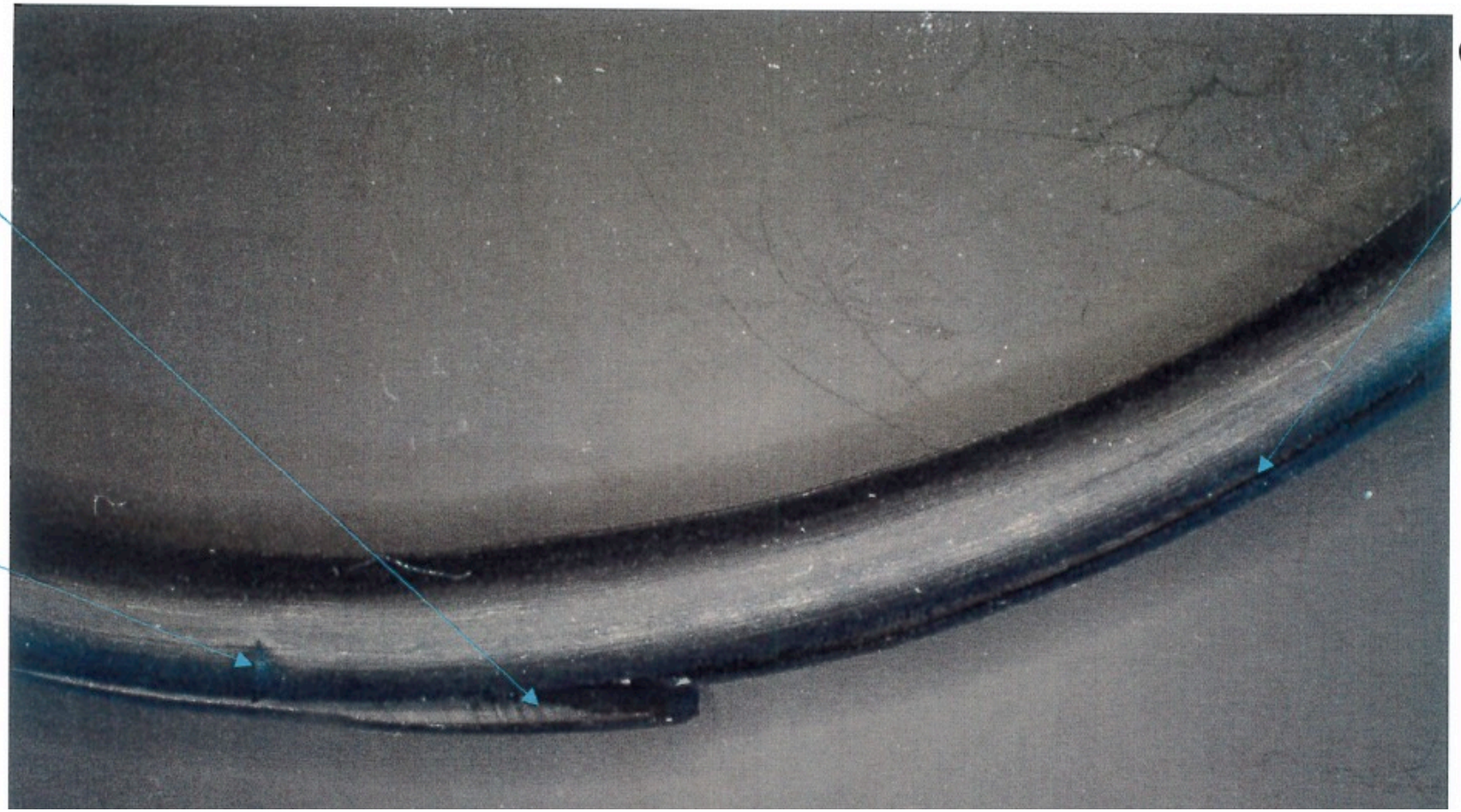
O-ring made with typical two piece compression mold

Speaking of O-rings…….Example 2



No photos available before removal from service so can't determine if any damage happened during removal.

Speaking of O-rings…….Example 2



Speaking of O-rings…….Example 2

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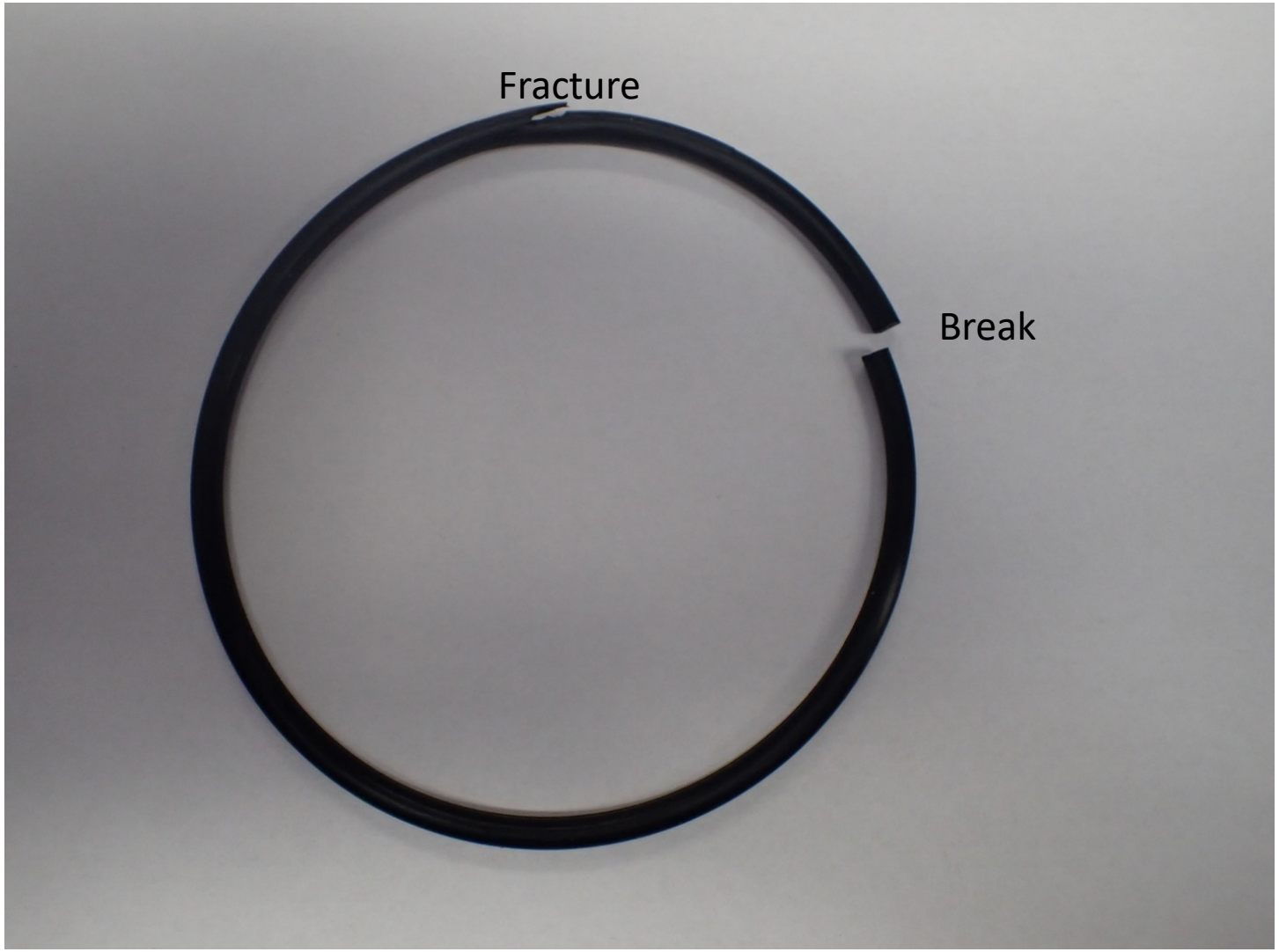


Failure Details

- Automobile Engine Oil Filter
- Filter suffered catastrophic failure ~120 miles after installation

Speaking of O-rings…….Example 2

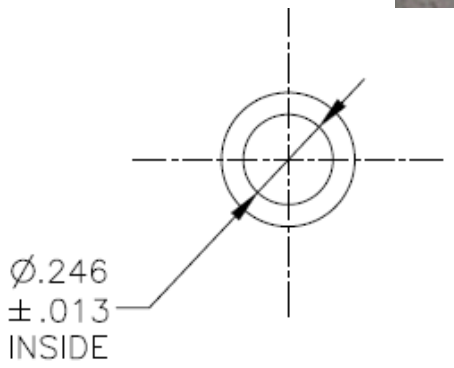
Hypothesis

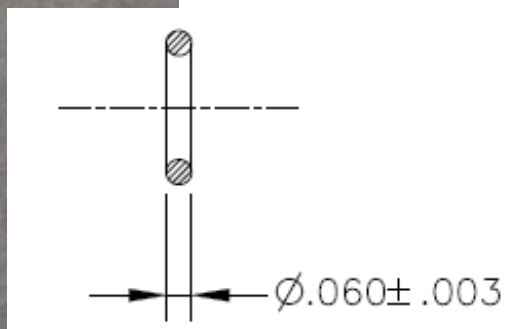
- Misalignment of O-ring into O-ring groove during installation caused smooth tear
- After reaching operating oil pressure, the smooth tear slowly propagated to cause the rough tear surface
- After ~120 miles, rough tear progresses to the point of failure
- Root cause is human error

Speaking of O-rings…….Example 4

O-Ring involved in QC hold due to dimensional deviation

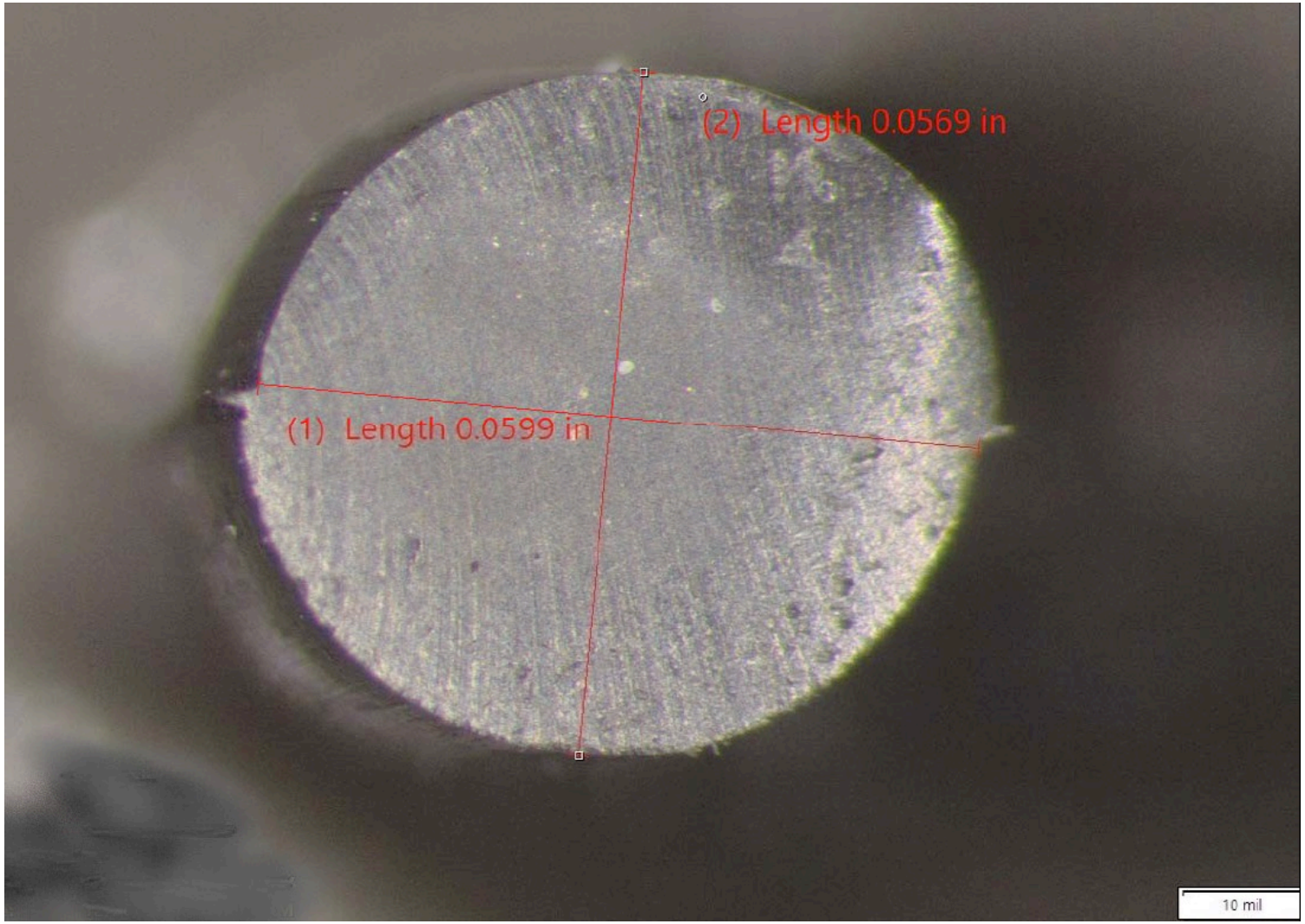
Speaking of O-rings…….Example 4





Dimensions shown in this photomicrograph are in spec

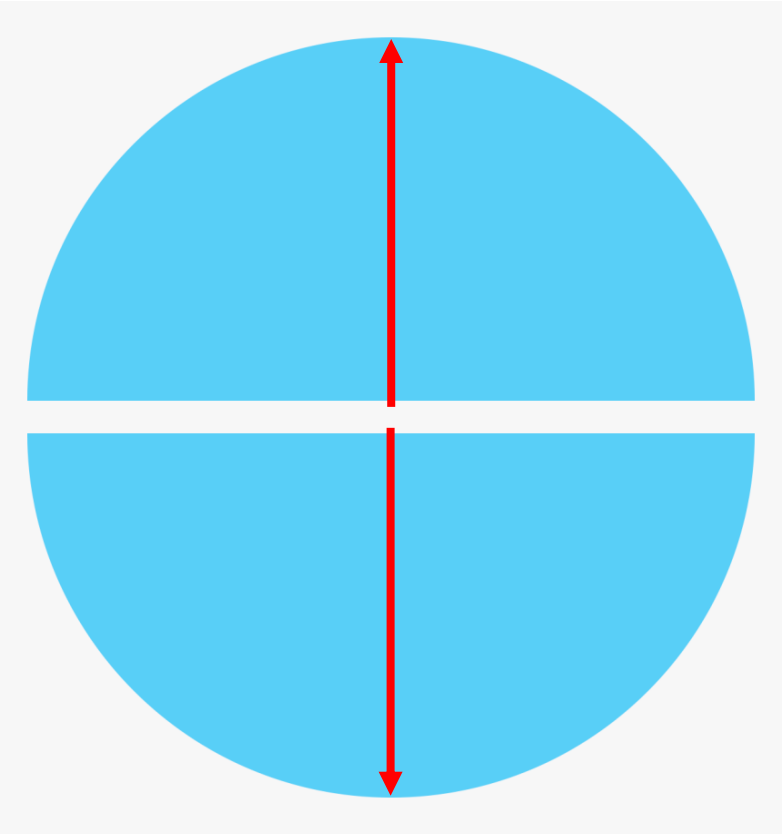
Speaking of O-rings…….Example 4

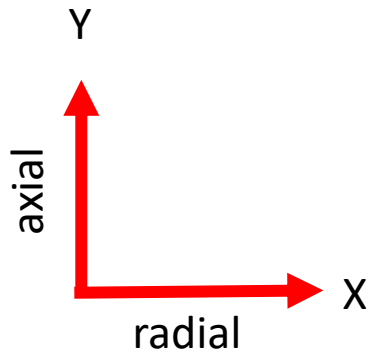


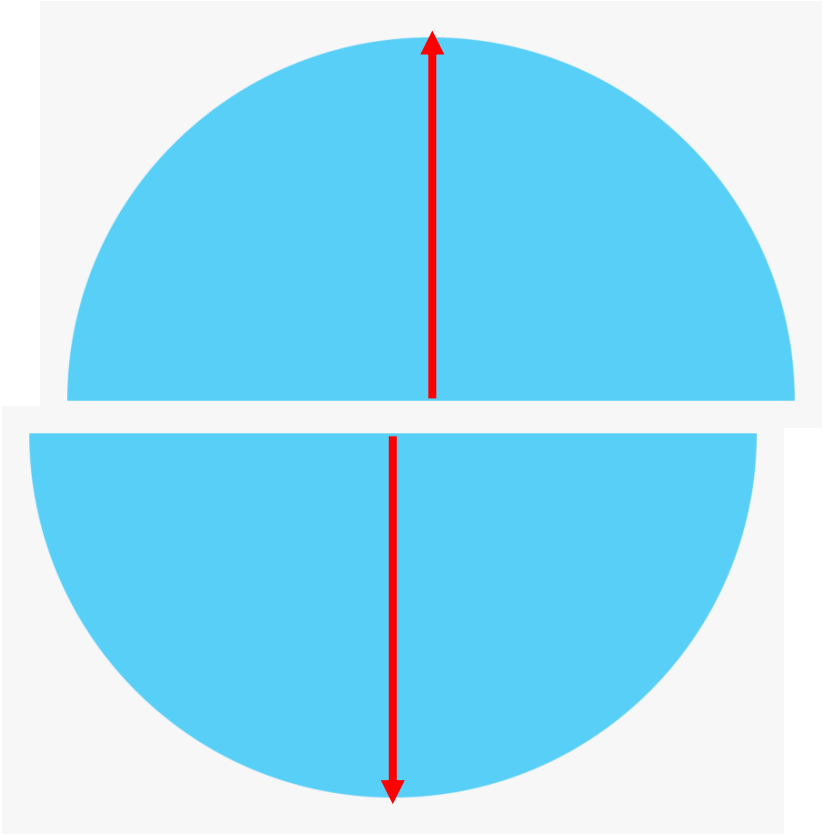
Two piece mold appears to be misaligned

Speaking of O-rings…….Example 4

Impact of misaligned mold parts



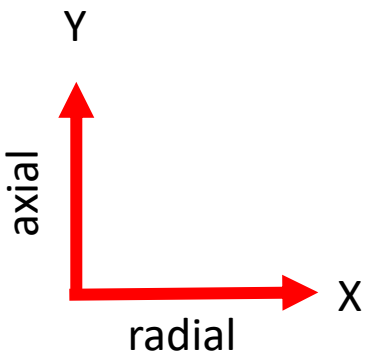


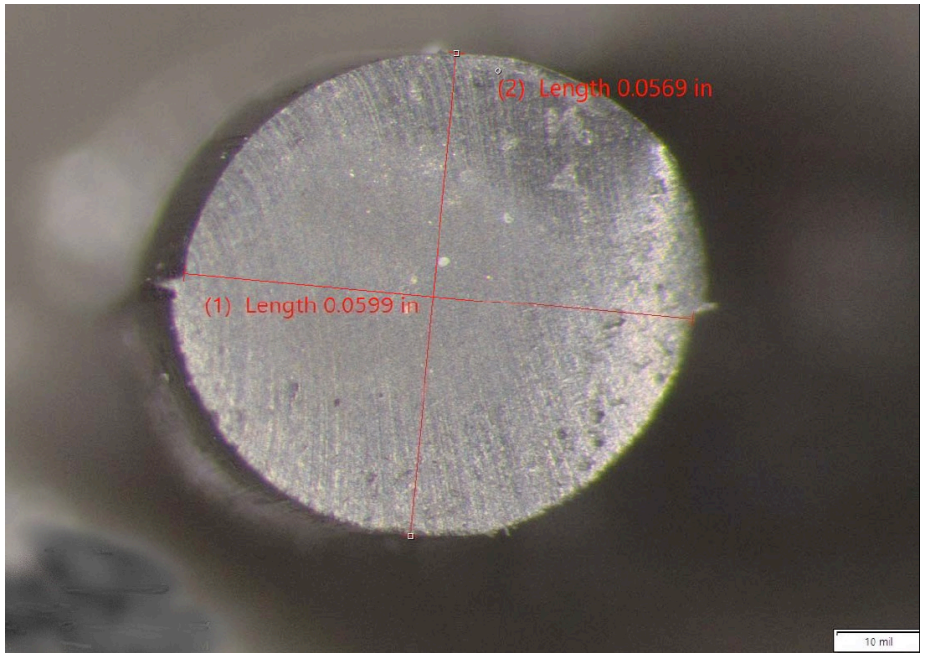


Max diameter in axial direction will be less than max diameter in radial direction

Speaking of O-rings…….Example 4

Top (axial) view gives only radial measurement





Cross section view gives both axial and radial measurements

Root cause-manufacturing defect

Conveyor Belt Splice Failure

Sample 1-Failed splice from Supplier A

Conveyor Belt Splice Failure

Sample 2-Intact splice from Supplier A

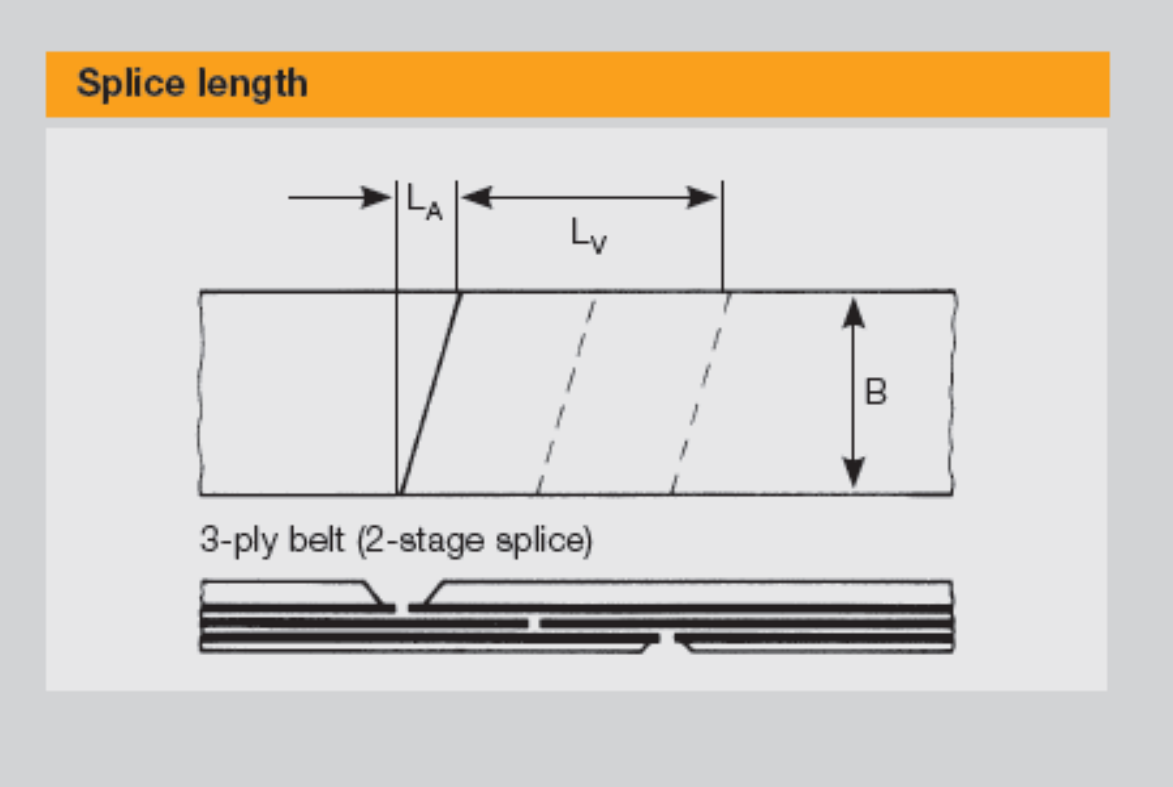
Conveyor Belt Splice Failure

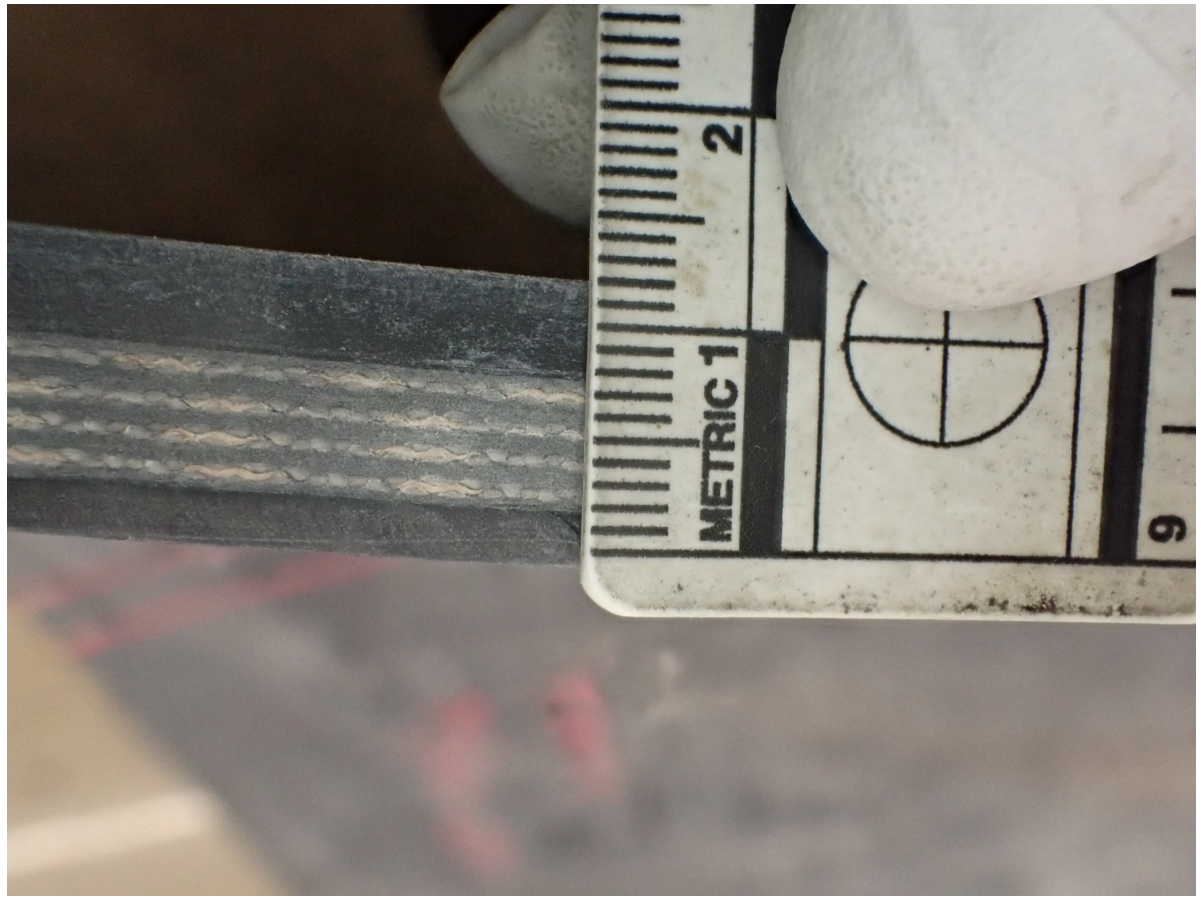
Sample 3-Intact splice from Supplier B

Conveyor Belt Splice Failure

Sample 4-Unspliced control section

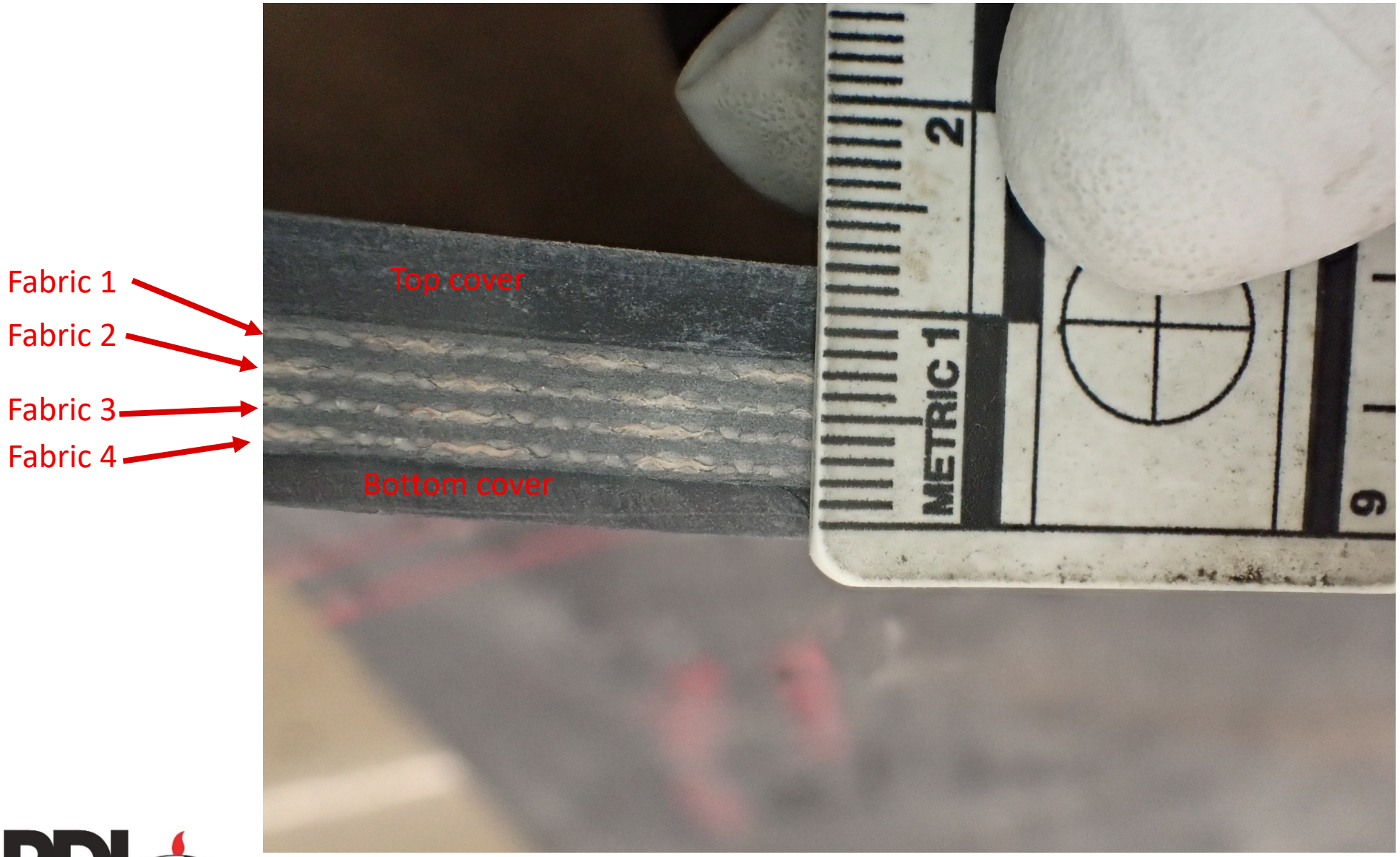
Conveyor Belt Splice Failure





4-ply belt (3-stage splice)

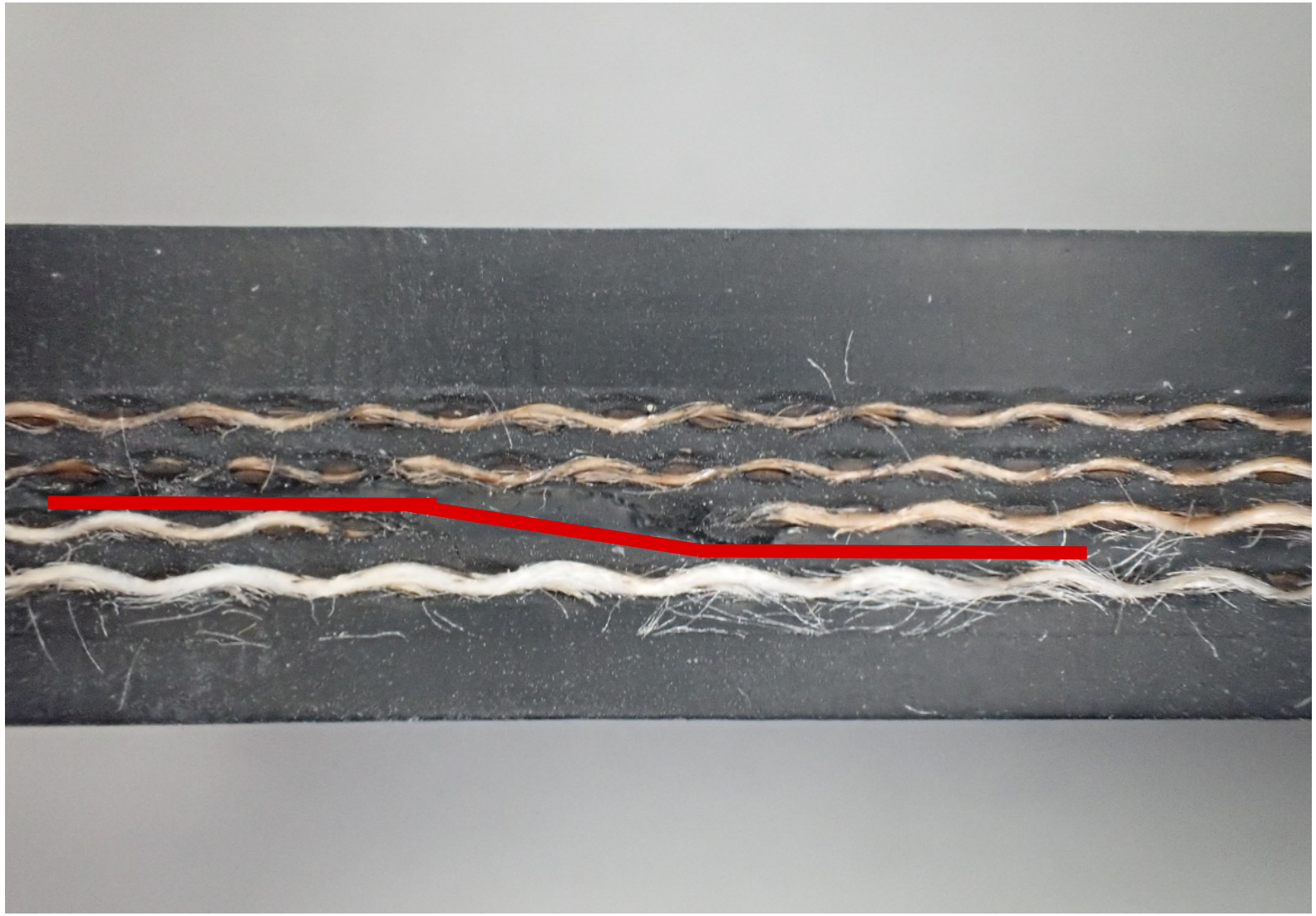
Conveyor Belt Splice Failure



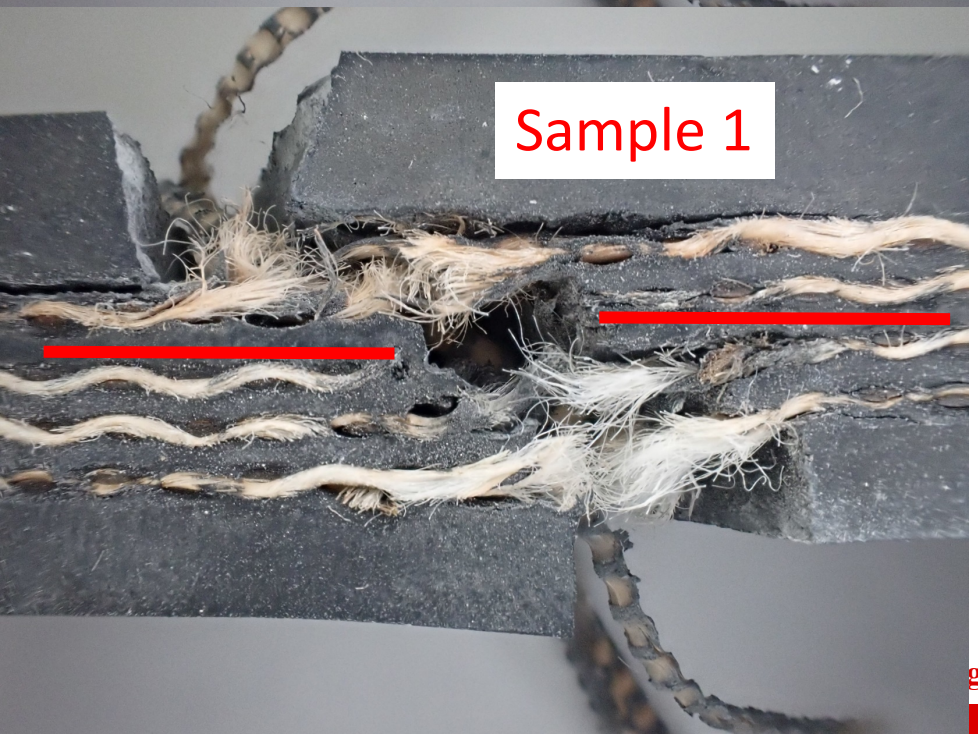
Conveyor Belt Splice Failure

Sample 2-Splice transition from F2/F3 to F3/F4

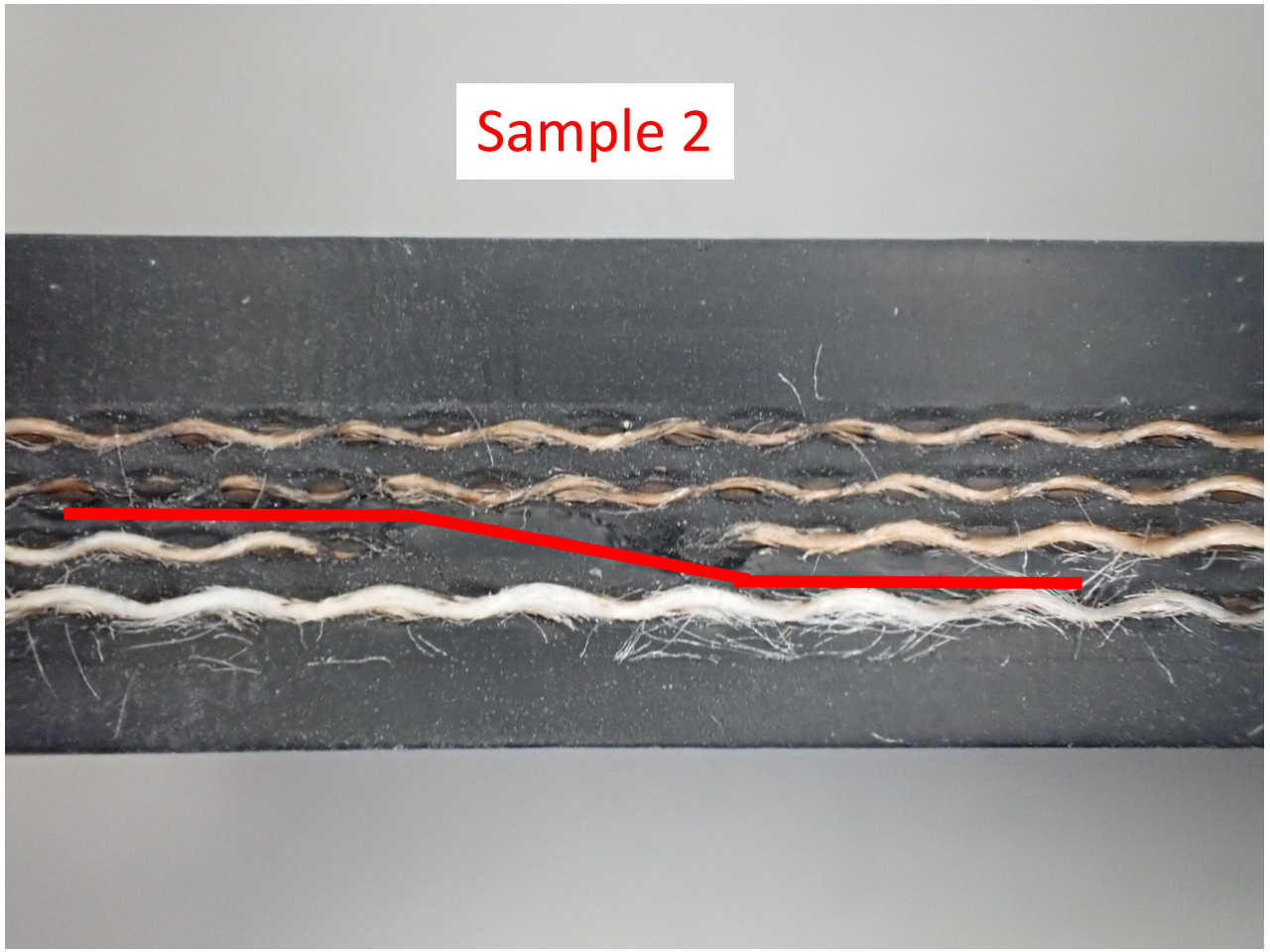
Conveyor Belt Splice Failure



Sample 2-Splice transition from F2/F3 to F3/F4



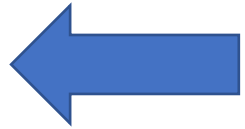
Is the splice rubber properly cured?



Sample 2-transition from fabric 2/fabric 3 splice to fabric 3/fabric 4 splice. Splice rubber marked with red lines.

Conveyor Belt Splice Failure

SAMPLE	Location of splice rubber sample	Heat of Cure, (J/g)	Splice Condition
1	F1/F2 taken from F1 surface	3.14	broken
1	F1/F2 taken from F2 surface	0.74	broken
1	F2/F3	2.49	broken
2	F3/F4	69.9	intact
2	F2/F3	3.84	intact
3	F1/F2	5.66	intact
3	F2/F3	3.52	intact

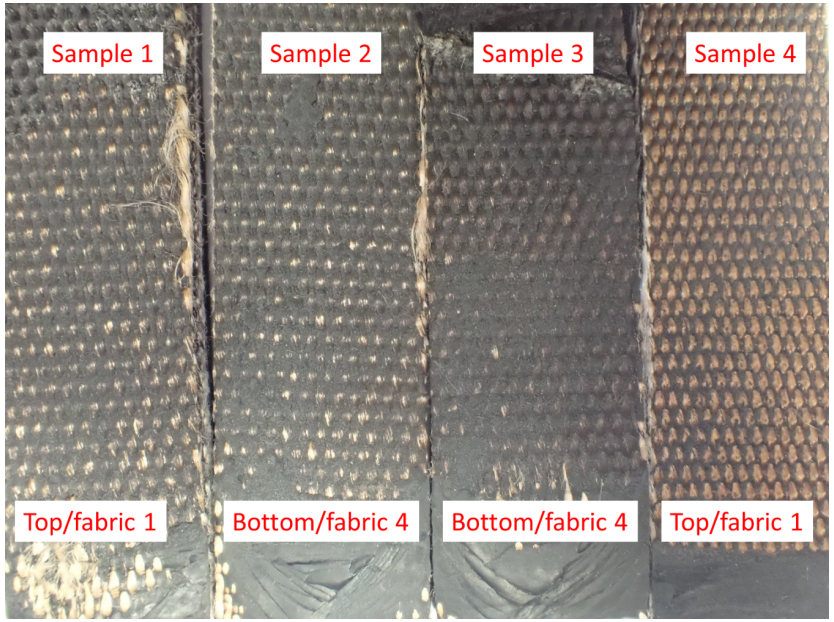


DSC state of cure data-Heat of Cure = 0 is ideal state of complete cure.
State of cure is most likely not a root cause.

Conveyor Belt Splice Failure

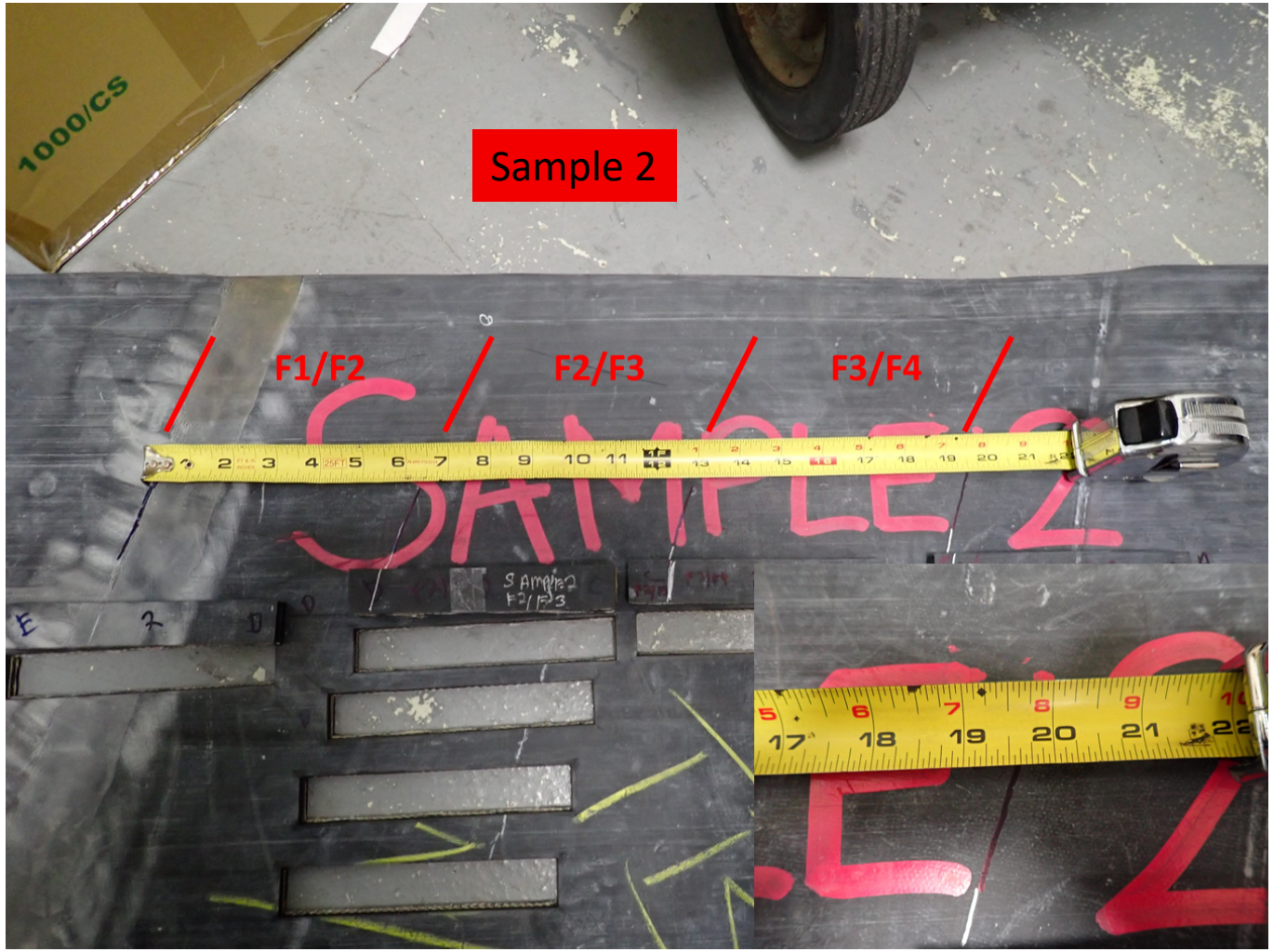
4.	ADHESION				
4.1.	Top Cover/Ply	DIN 22 102	min.	4,5	N/mm
4.2.	Between the Plies	DIN 22 102	min.	5,0	N/mm
4.3.	Bottom Cover /Ply	DIN 22 102	min.	4,5	N/mm

Sample number	Interface tested	Adhesion (N/mm)	Pass/Fail	Test method	Splice condition
1	top cover/F1	6.0	Pass	ASTM D 413	broken
2	bottom cover/F4	8.6	Pass	ASTM D 413	intact
3	bottom cover/F4	6.7	Pass	ASTM D 413	intact
4	top cover/F1	6.1	Pass	ASTM D 413	no splice
1	F2/F3	7.9	Pass	DIN 22 102	broken
2	F2/F3	5.5	Pass	DIN 22 102	intact
3	F2/F3	4.7	Fail	DIN 22 102	intact
4	F2/F3	13.3	Pass	DIN 22 102	no splice

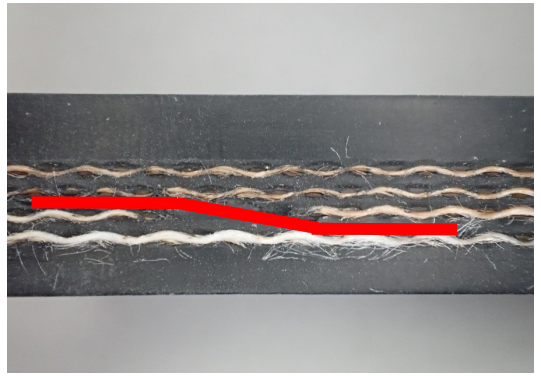


Peel adhesion testing suggests that rubber to fabric adhesion is not a root cause.

Conveyor Belt Splice Failure

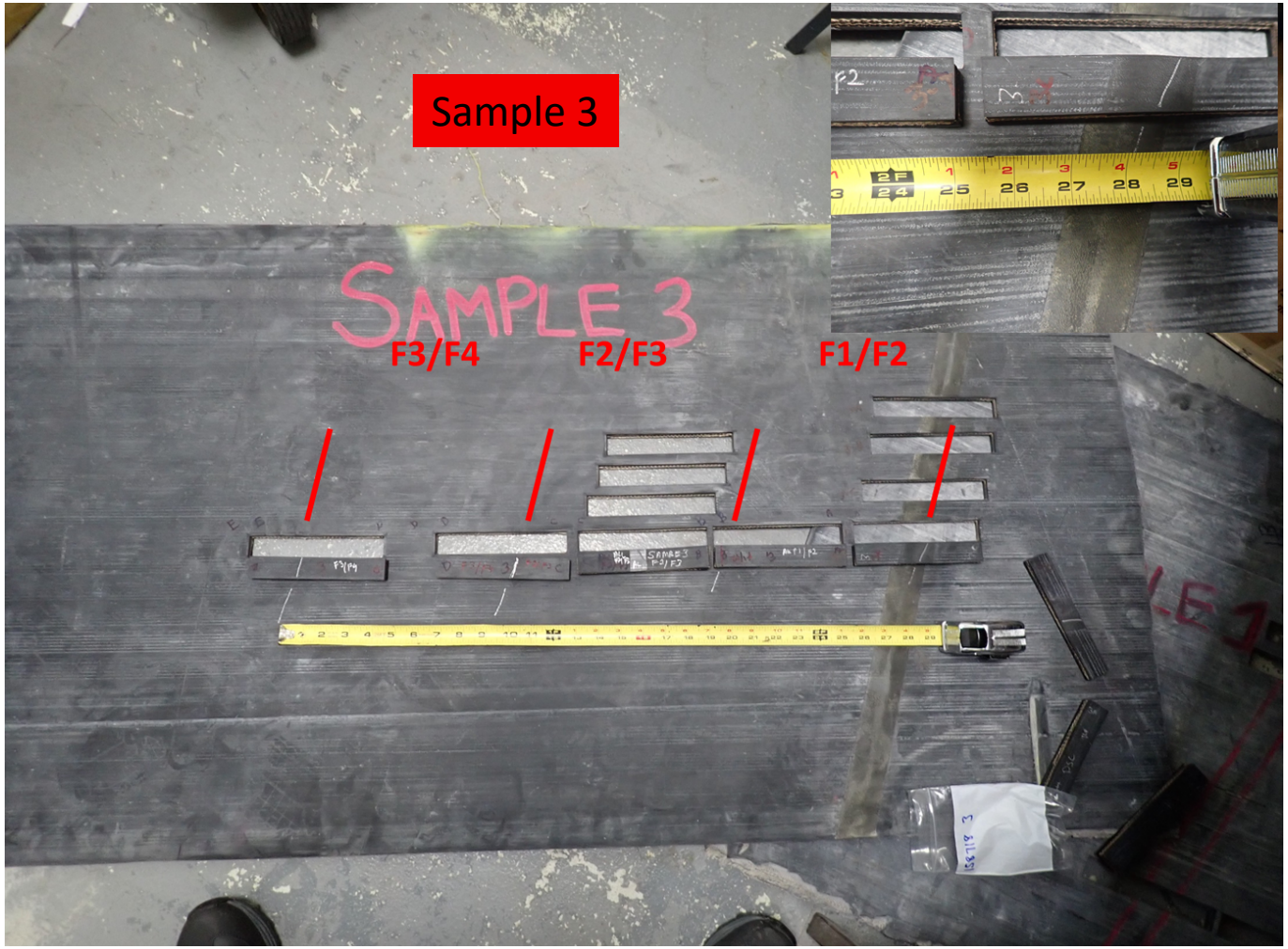


Splice Dimensions



5.	BELT SPLICE acc. to	DIN 22 102 P. 3		
5.1.	Number of Steps		3	
5.2.	Splice Length		750	mm
5.3.	Surplus per Splice (Splice Length+0,3xBelt Width)		1050	mm
5.4.	Nominal Strength of Splice	DIN 22 101 P.9.1	75,0	%

Conveyor Belt Splice Failure



Splice Dimensions

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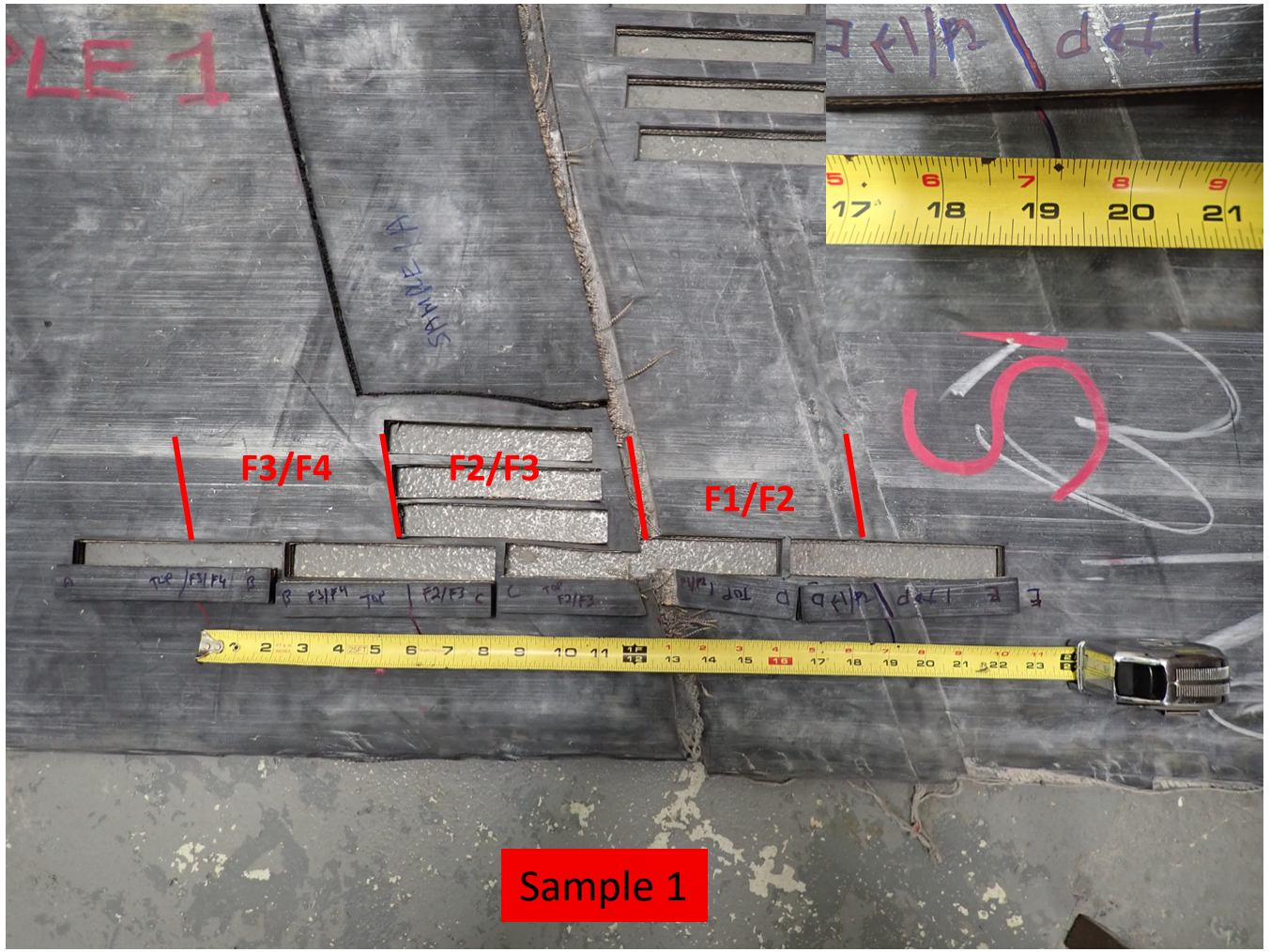
Conveyor Belt Splice Failure



Splice Dimensions

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Conveyor Belt Splice Failure

Splice Dimensions

Sample number	Splice length L_V (target = 750 mm)	Splice bevel L_A (target = 240 mm)	Splice condition
1 (Supplier A)	490 mm	203 mm	broken
2 (Supplier A)	495 mm	222 mm	Intact
3 (Supplier B)	711 mm	203 mm	intact

5.	BELT SPLICE acc. to	DIN 22 102 P. 3		
5.1.	Number of Steps		3	
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ARDL

Test

Conveyor Belt Splice Failure

Sample number	Splice Condition	Splice State of Cure	Rubber to Fabric Adhesion	Length of Splice	Breaking Strength
1					N/A
2					
3					
4	no splice	N/A		N/A	

Sample number	Splice length L_V (target = 750 mm)	Splice bevel L_A (target = 240 mm)	Splice condition
1 (Supplier A)	490 mm	203 mm	broken
2 (Supplier A)	495 mm	222 mm	Intact
3 (Supplier B)	711 mm	203 mm	intact

Root Cause-Human Error resulting in short splice length

5.	BELT SPLICE acc. to	DIN 22 102 P. 3		
5.1.	Number of Steps		3	
5.2.	Splice Length		750	mm
5.3.	Surplus per Splice (Splice Length+0,3xBelt Width)		1050	mm
5.4.	Nominal Strength of Splice	DIN 22 101 P.9.1	75,0	%

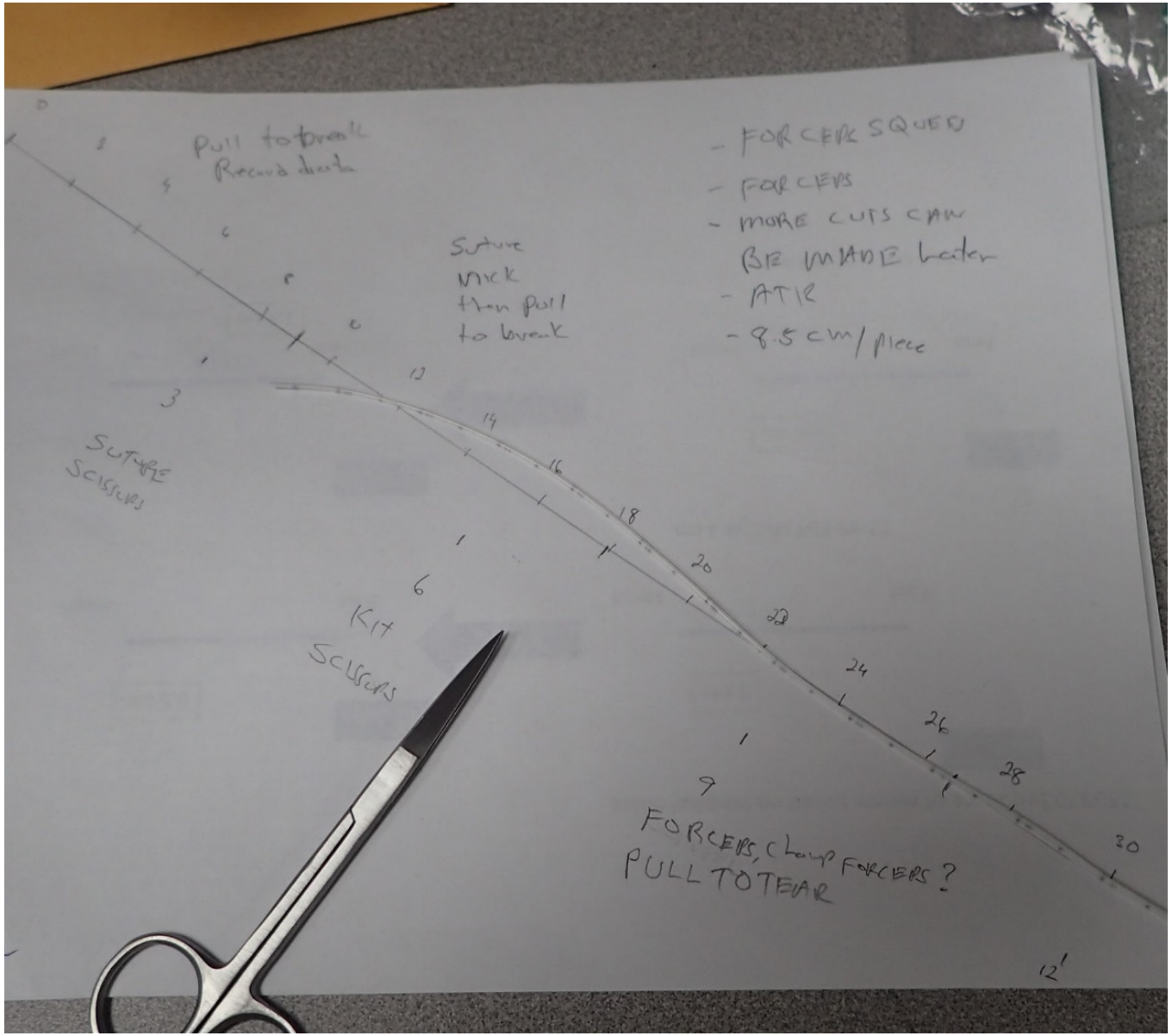
ARDL

Test

Conveyor Belt Splice Failure

Why was the splice too short?-The length of the splice was determined by the width of the available portable curing press and not by the specifications.

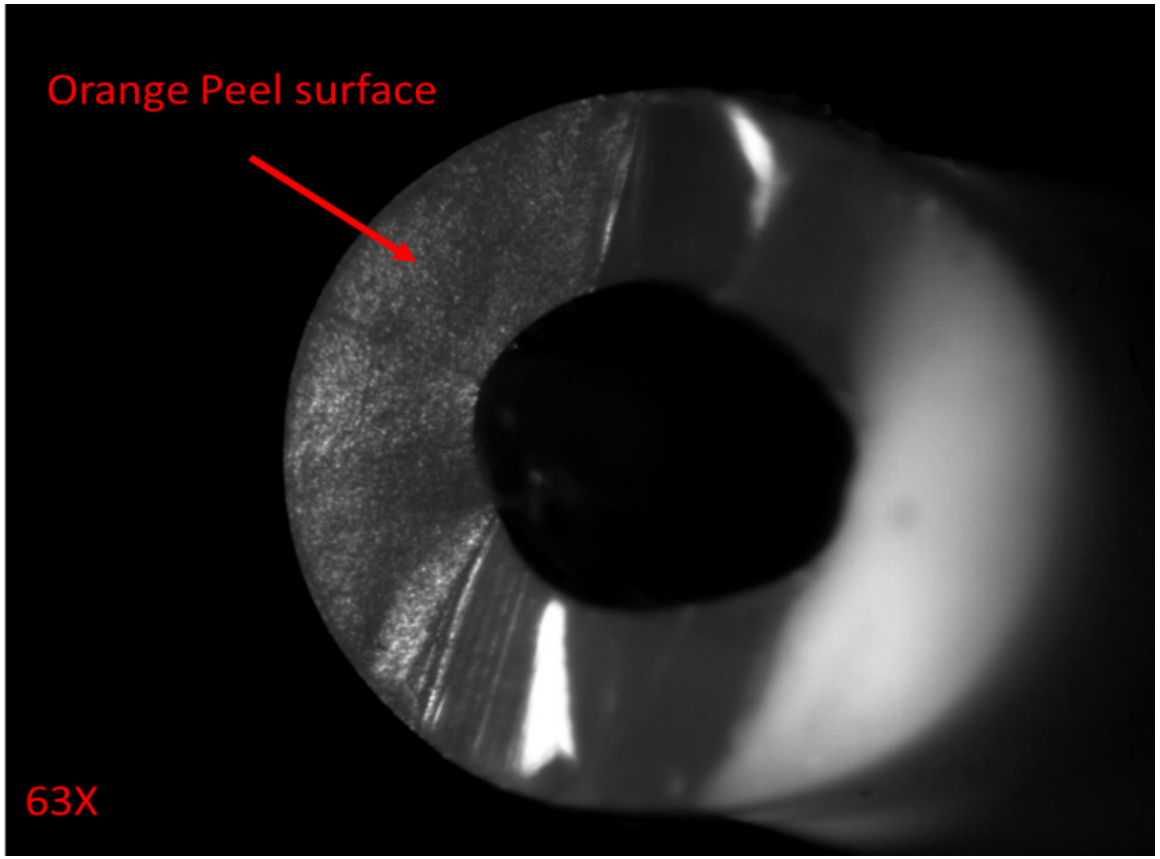
Medical Litigation Project-Silicone Umbilical Catheter

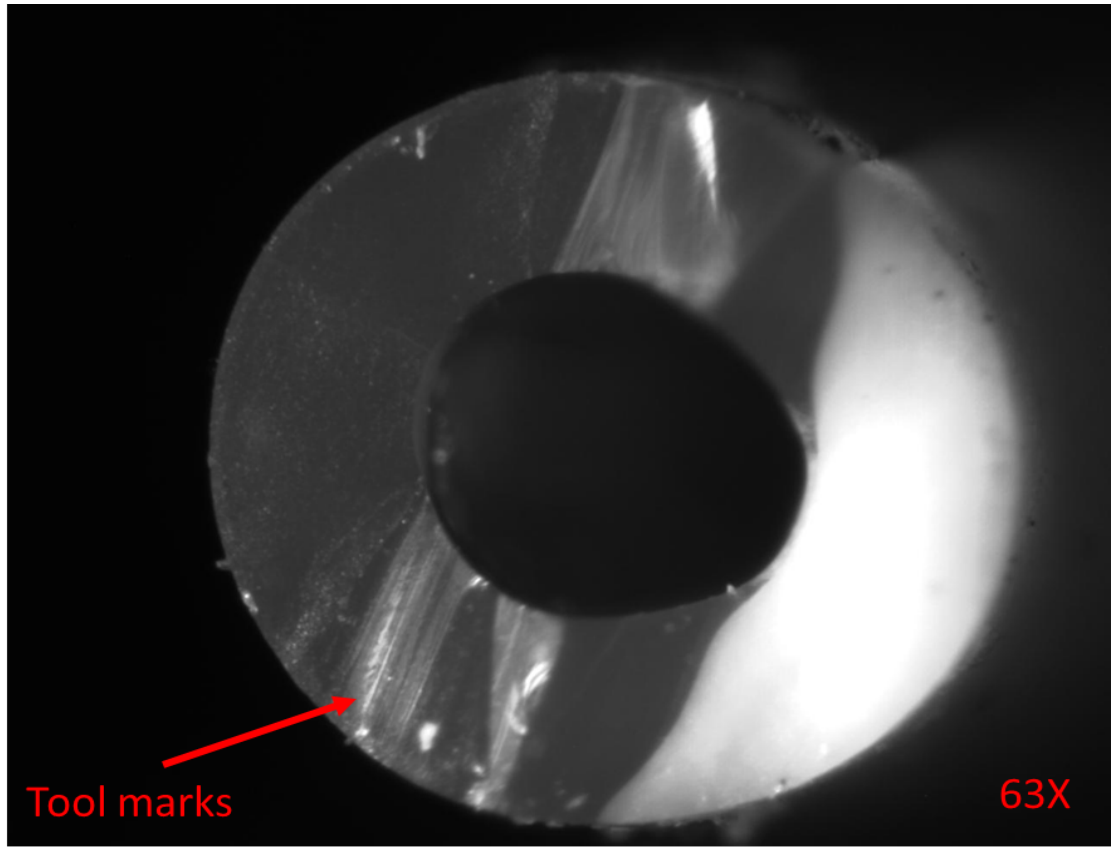


Medical Litigation Project-Silicone Umbilical Catheter

Incident Catheter point of failure, 5X Magnification.

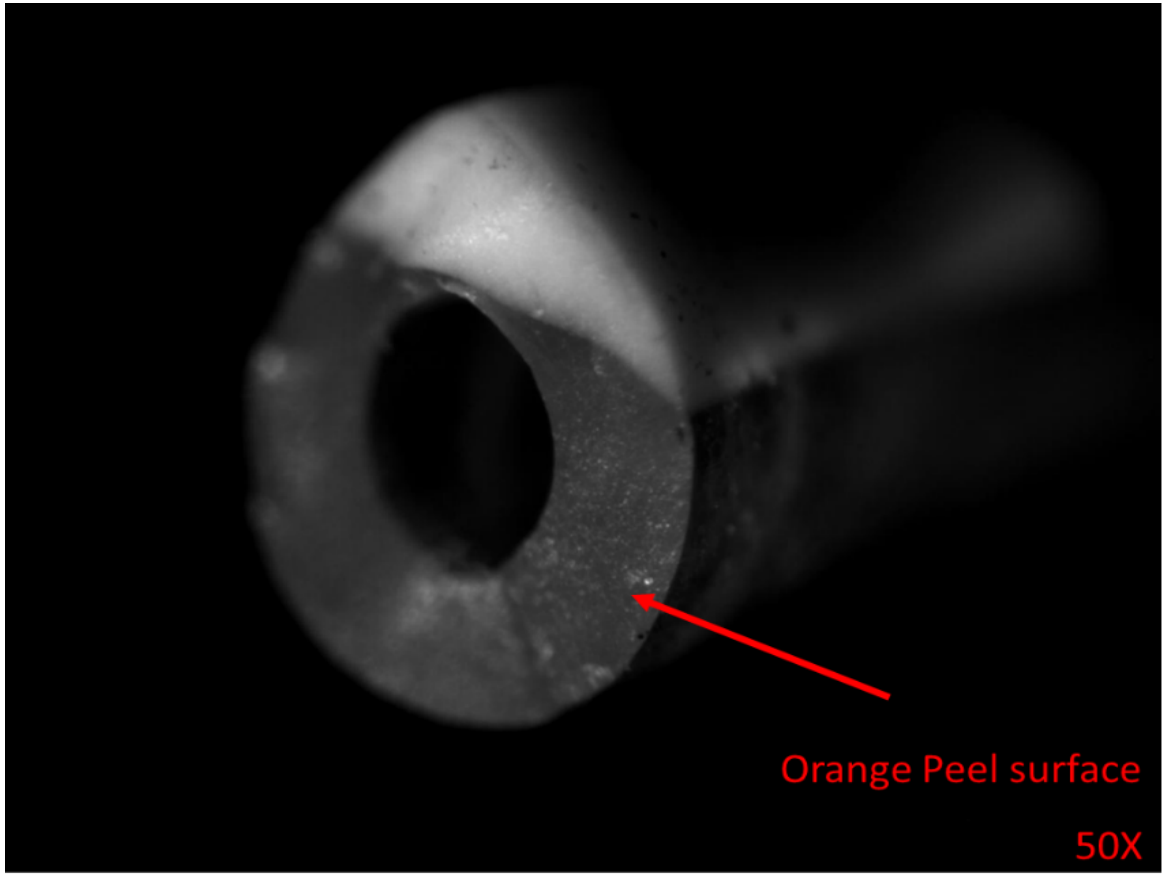
Medical Litigation Project-Silicone Umbilical Catheter

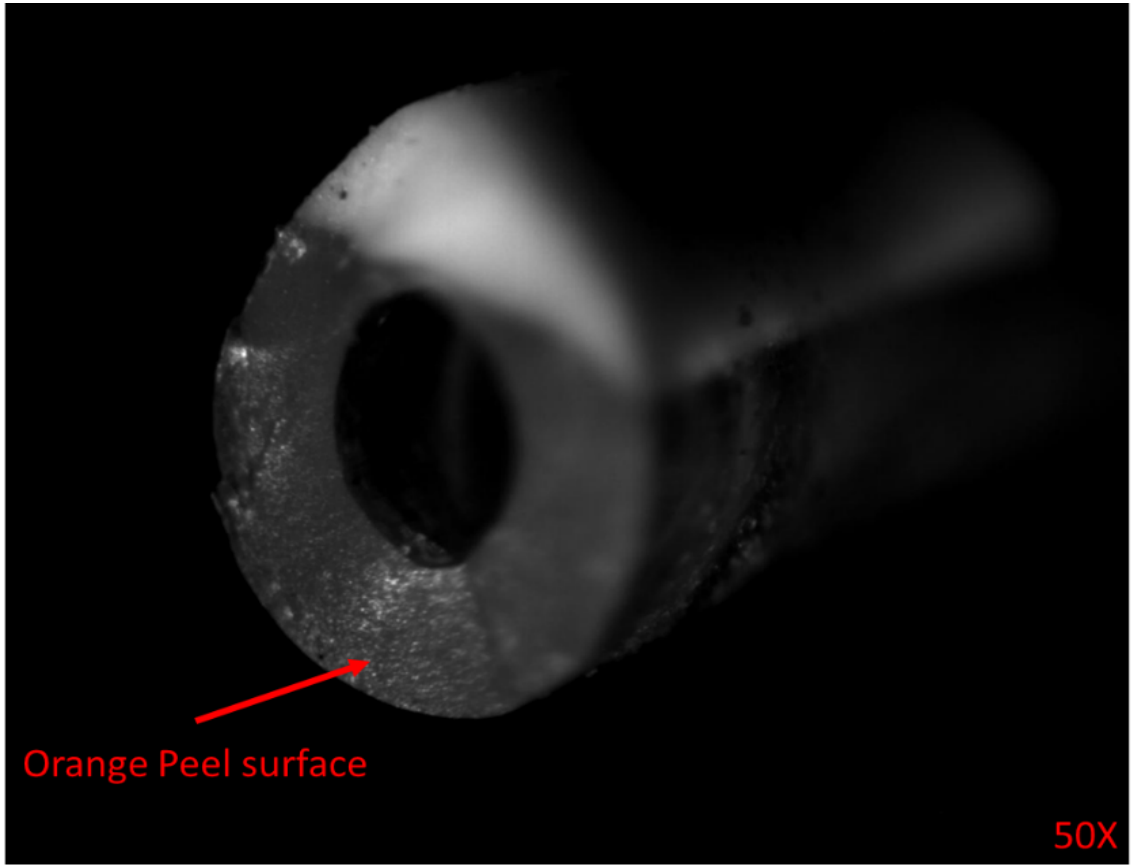




Fracture surface features of Incident Catheter

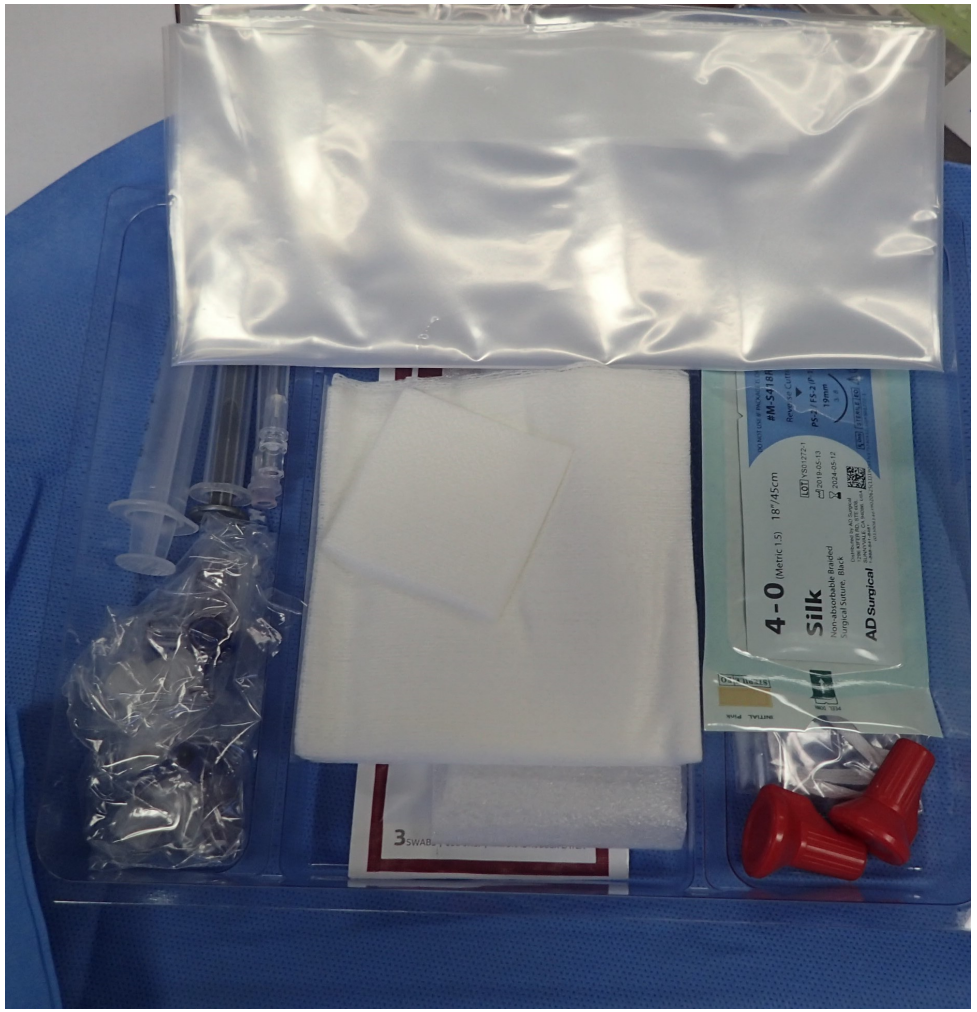
Medical Litigation Project-Silicone Umbilical Catheter





Surface features of Exemplar Catheter broken under tension

Medical Litigation Project-Silicone Umbilical Catheter

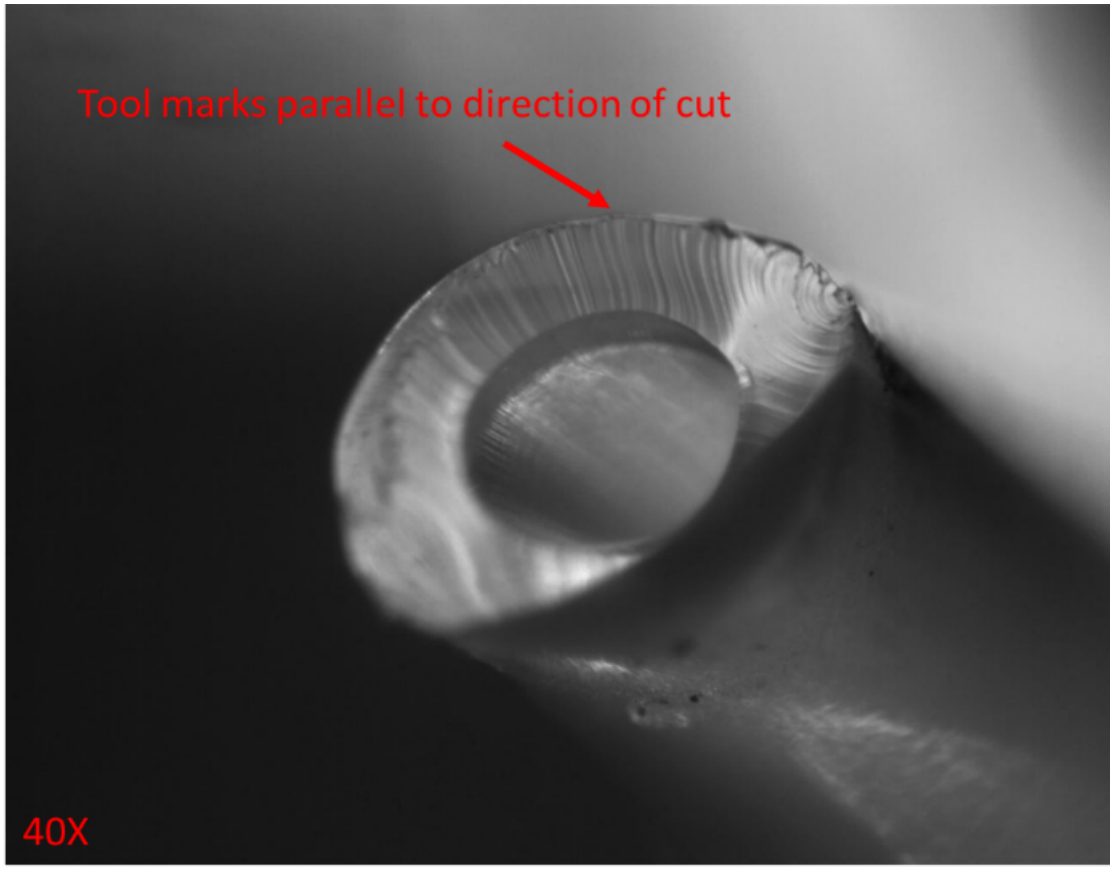


Medical supply kit used with umbilical catheter

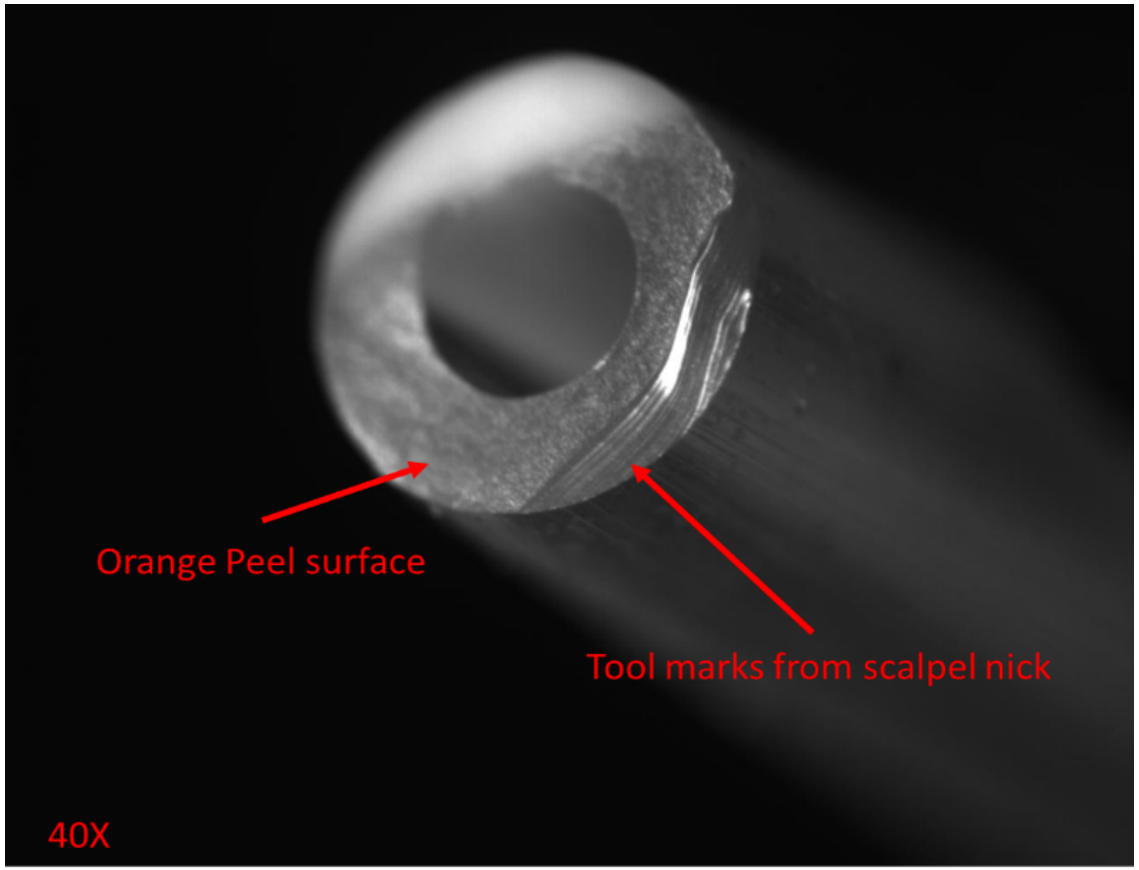
Medical Litigation Project-Silicone Umbilical Catheter

Medical supply kit used with umbilical catheter

Medical Litigation Project-Silicone Umbilical Catheter



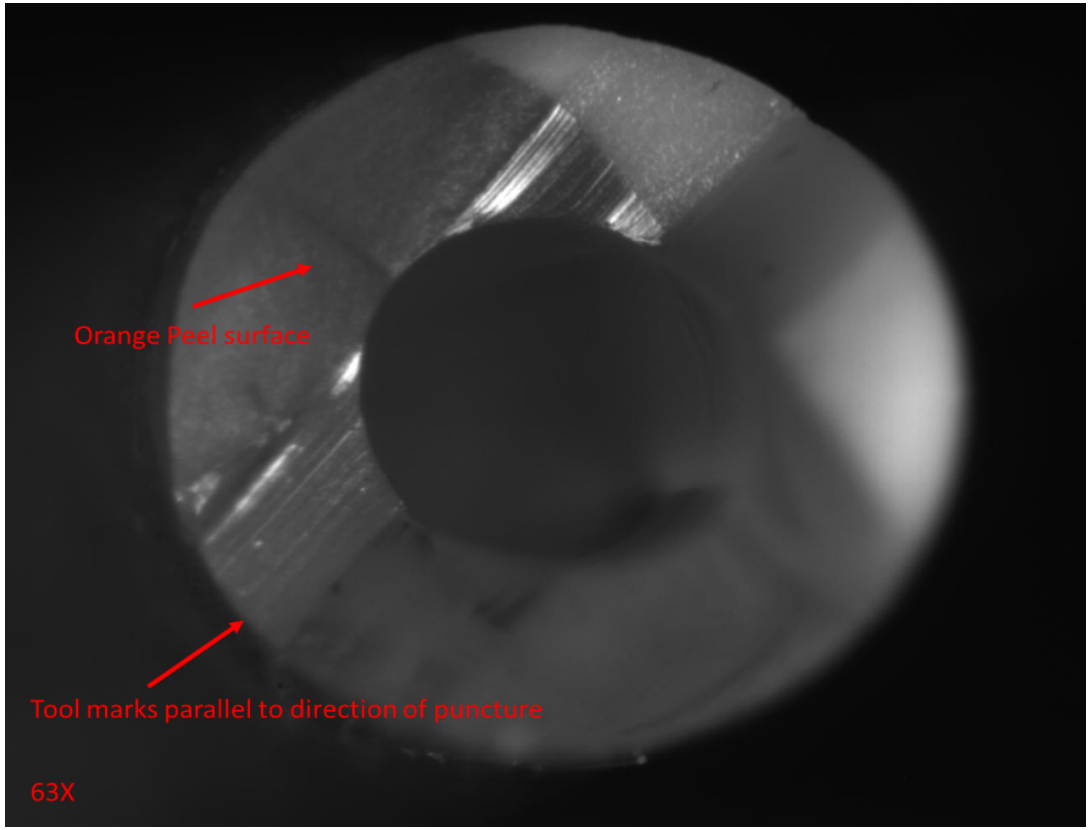
Exemplar catheter cut with scissors



Exemplar catheter nicked with scalpel and then pulled to break

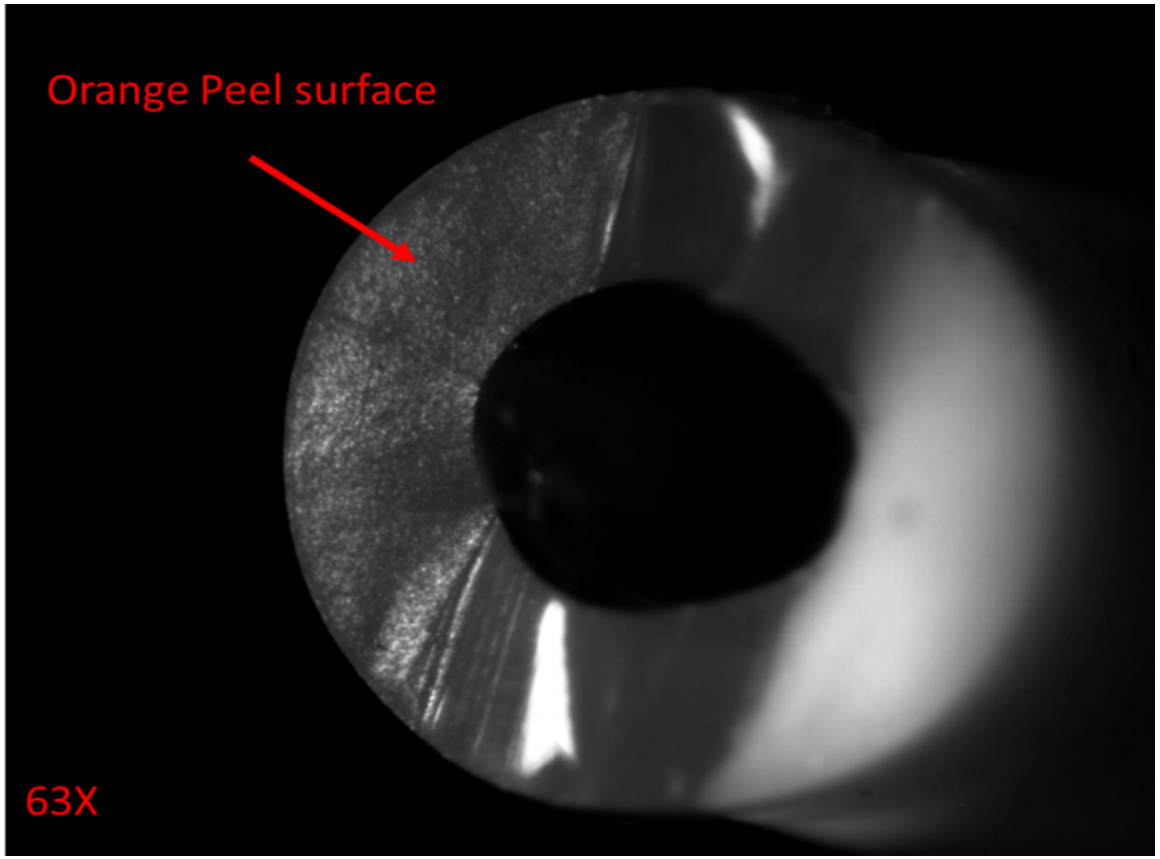
Medical Litigation Project-Silicone Umbilical Catheter

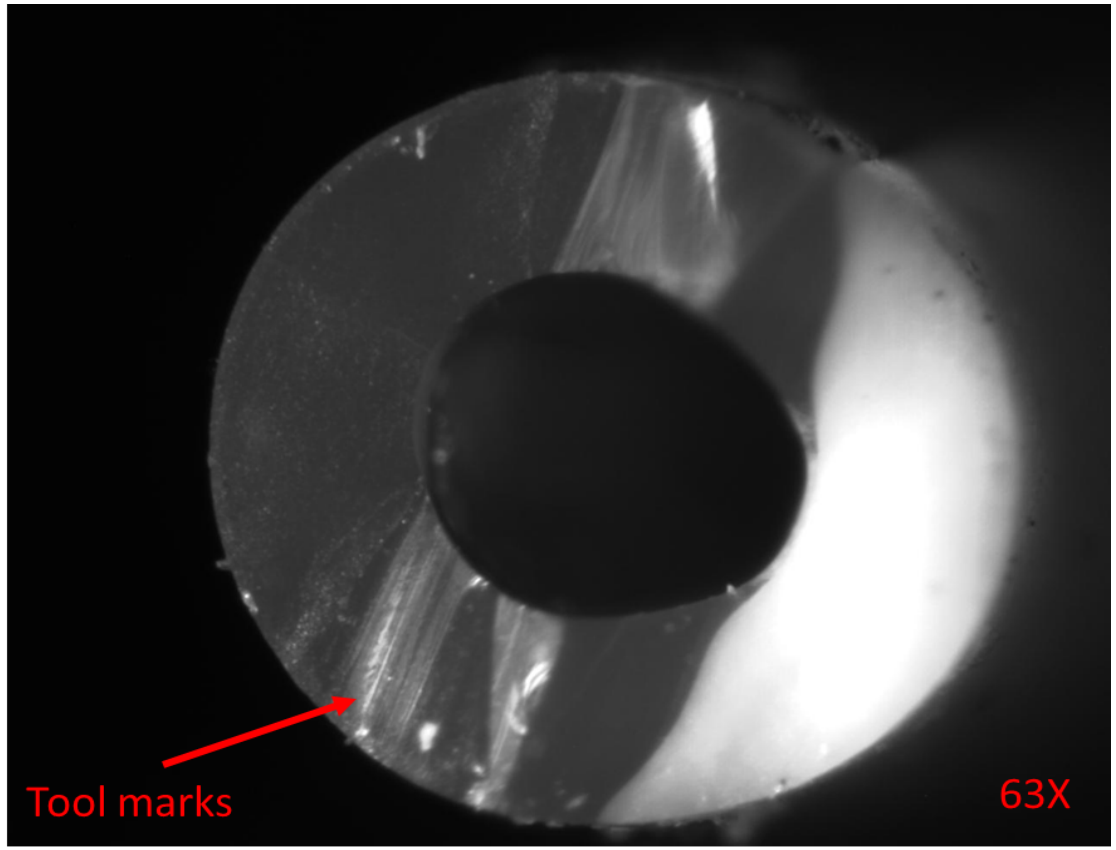
Exemplar catheter punctured with suture needle.



Exemplar catheter punctured with suture needle and pulled to break.

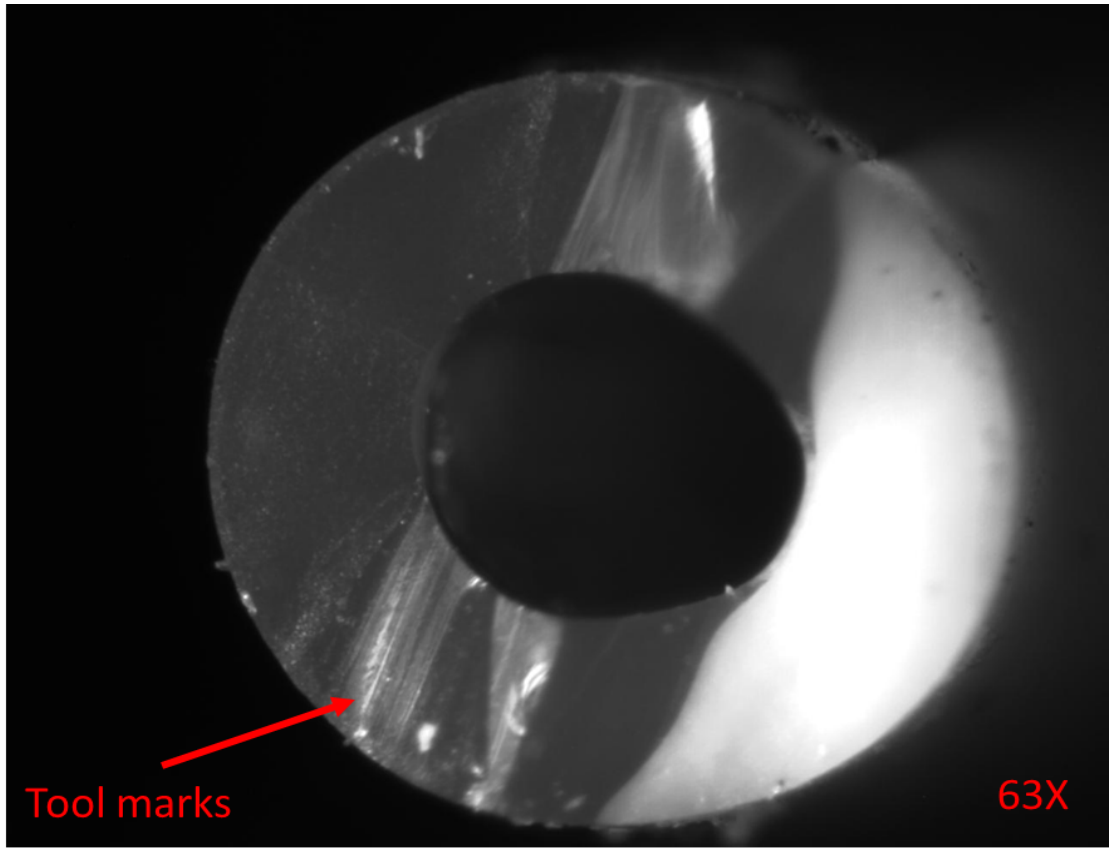
Medical Litigation Project-Silicone Umbilical Catheter



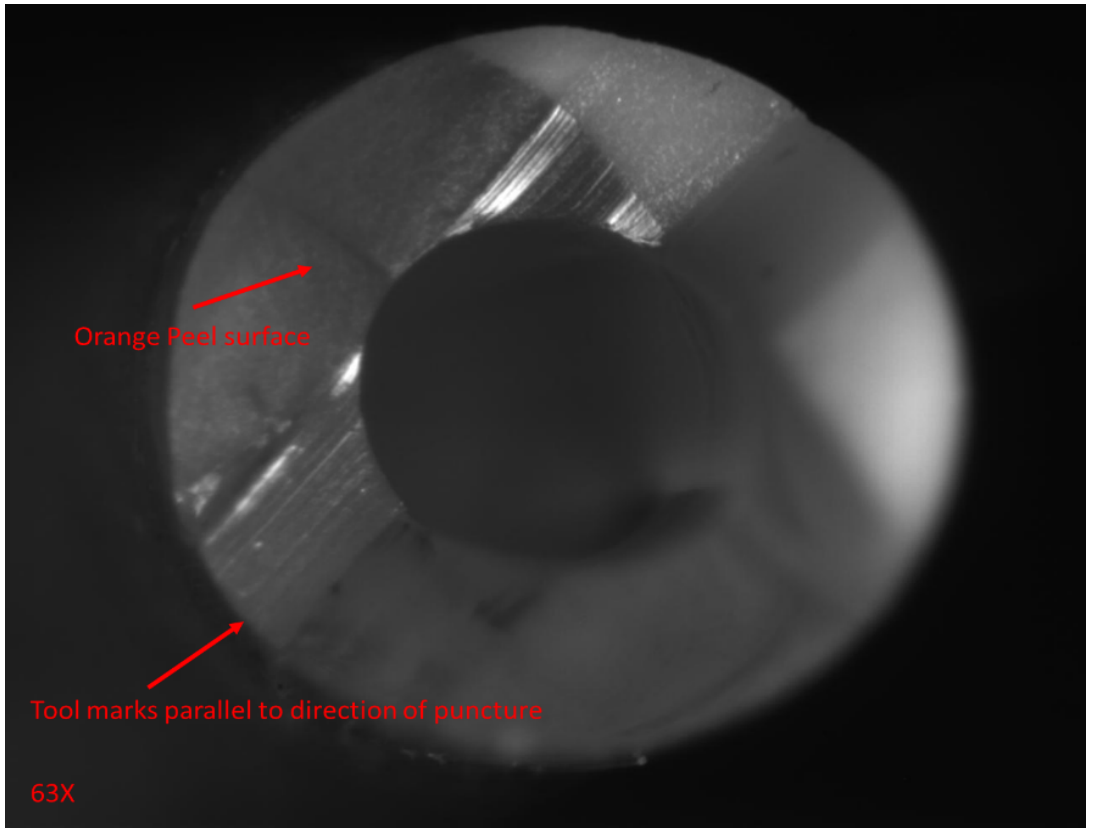


Fracture surface features of Incident Catheter

Medical Litigation Project-Silicone Umbilical Catheter

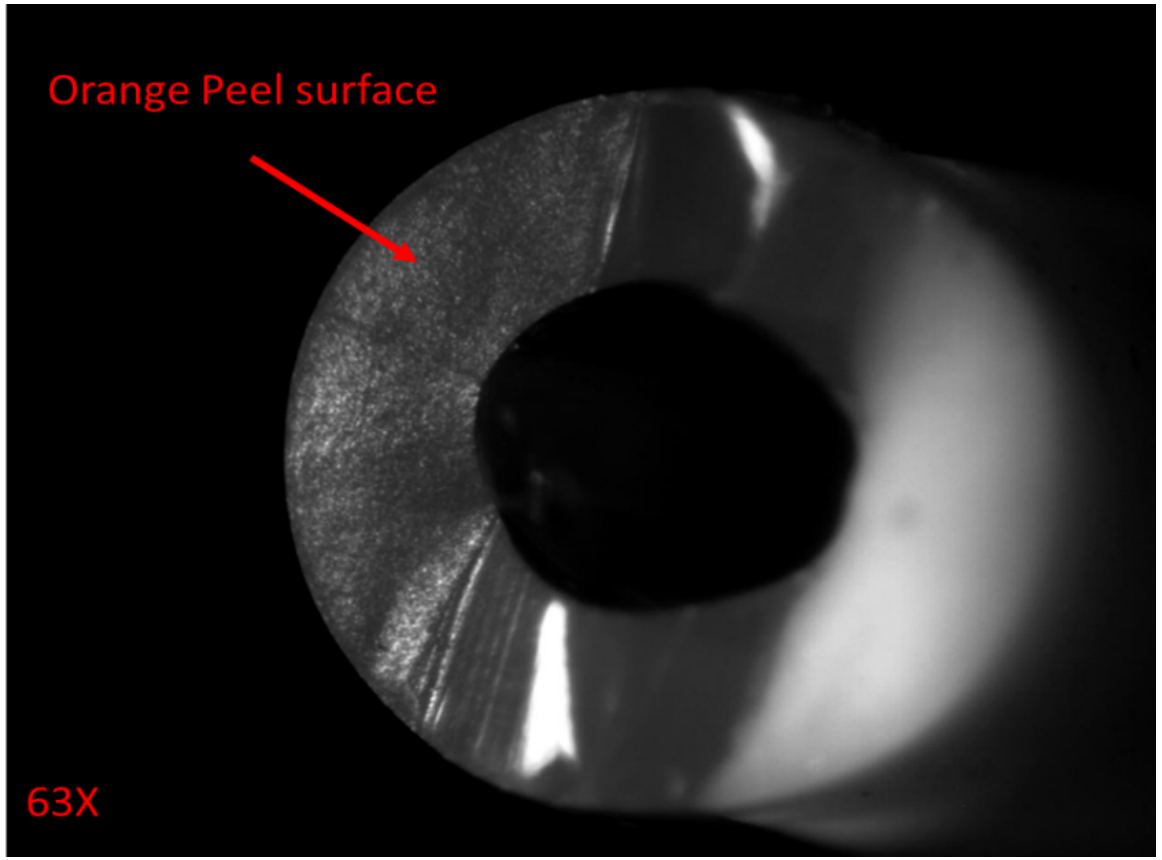


Incident catheter.

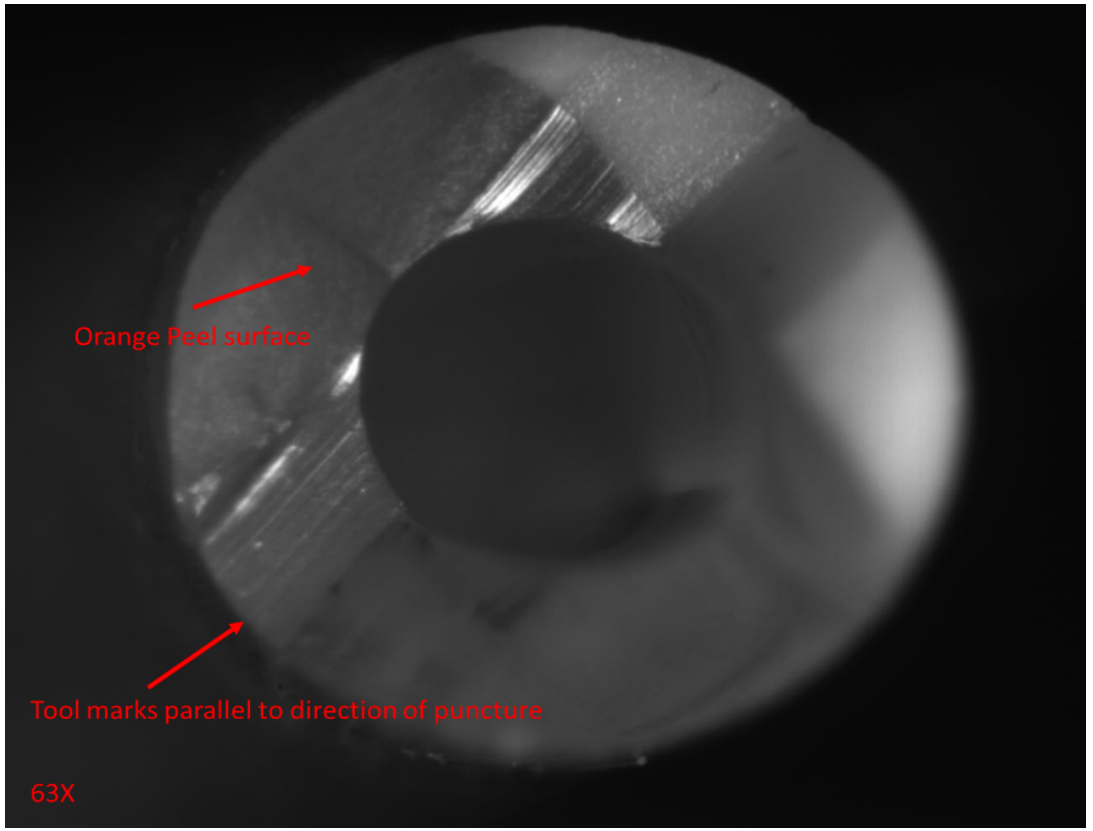


Exemplar catheter punctured with suture needle and pulled to break.

Medical Litigation Project-Silicone Umbilical Catheter



Incident catheter.



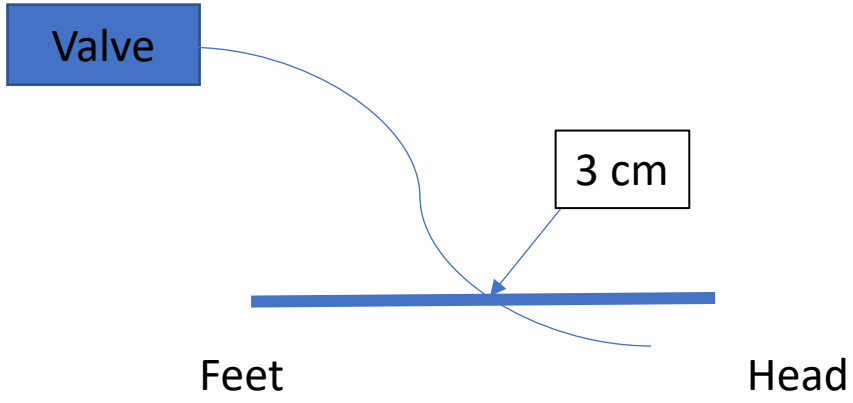
Exemplar catheter punctured with suture needle and pulled to break.

Medical Litigation Project-Silicone Umbilical Catheter

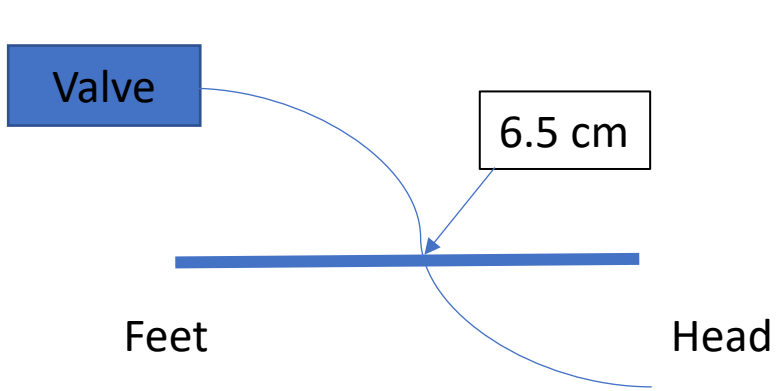
Sample	Breaking force (lbf)	Elongation (%)
Undamaged Exemplar	1.38	350%
Exemplar nicked with scalpel	0.74	17%
Exemplar punctured with suture needle	0.70	24%

Sample	Length of a 1 inch piece at break
Undamaged Exemplar	4 ½ inches
Exemplar nicked with scalpel	~1 3/16 inches
Exemplar punctured with suture needle	~1 ¼ inches

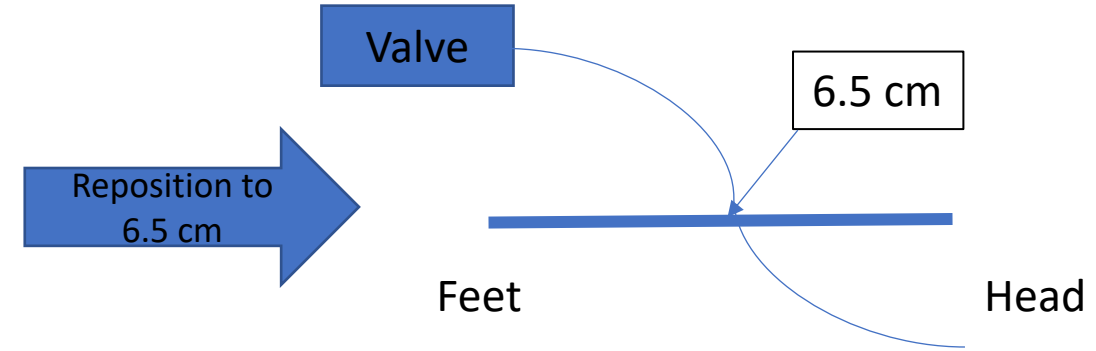
Sequence of events based on hospital notes

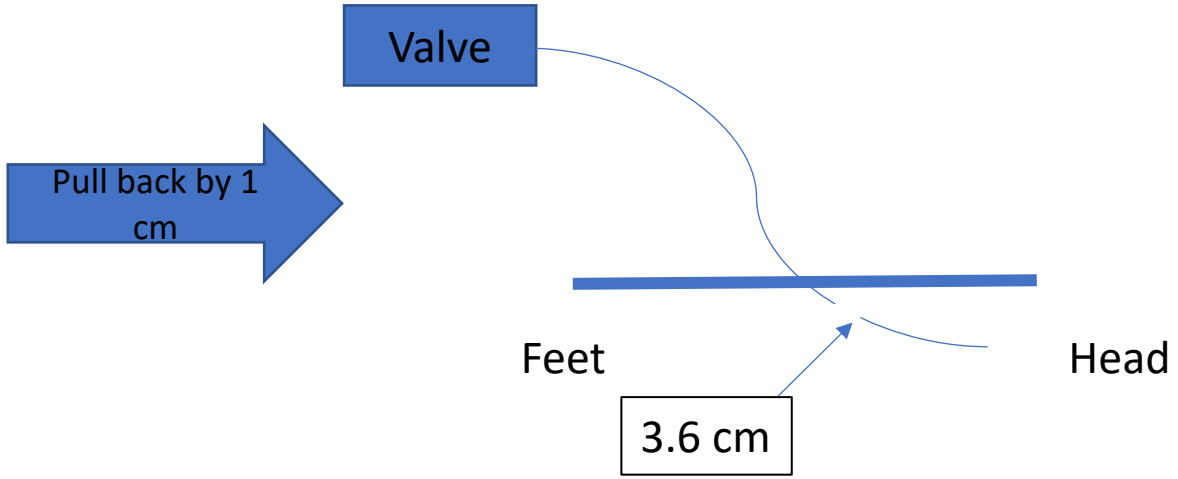


12:49 EDT UVC at 3 cm



12:54 EDT UVC at 6.5 cm





Construction Project Litigation Matter

General Approach

1. Identify polymers and hope for an exotic synthetic rubber
2. Identify compound components and try to date antioxidants, plasticizers, accelerators, etc.

Can ARDL estimate the age of the material?

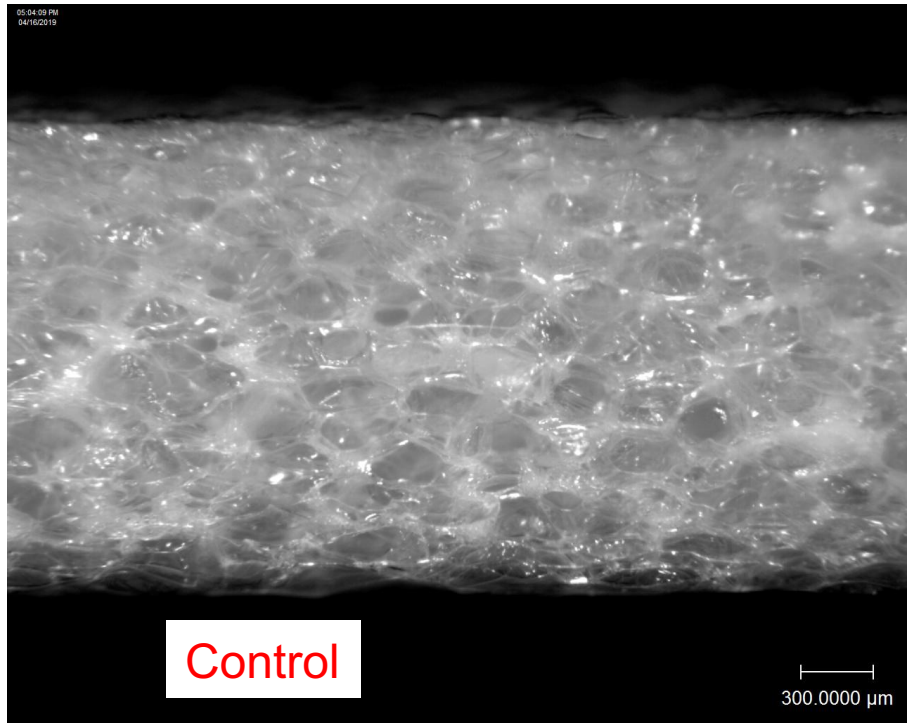
Construction Project Litigation Matter

Polymer identification by FT-IR was selected as first step.

Construction Project Litigation Matter

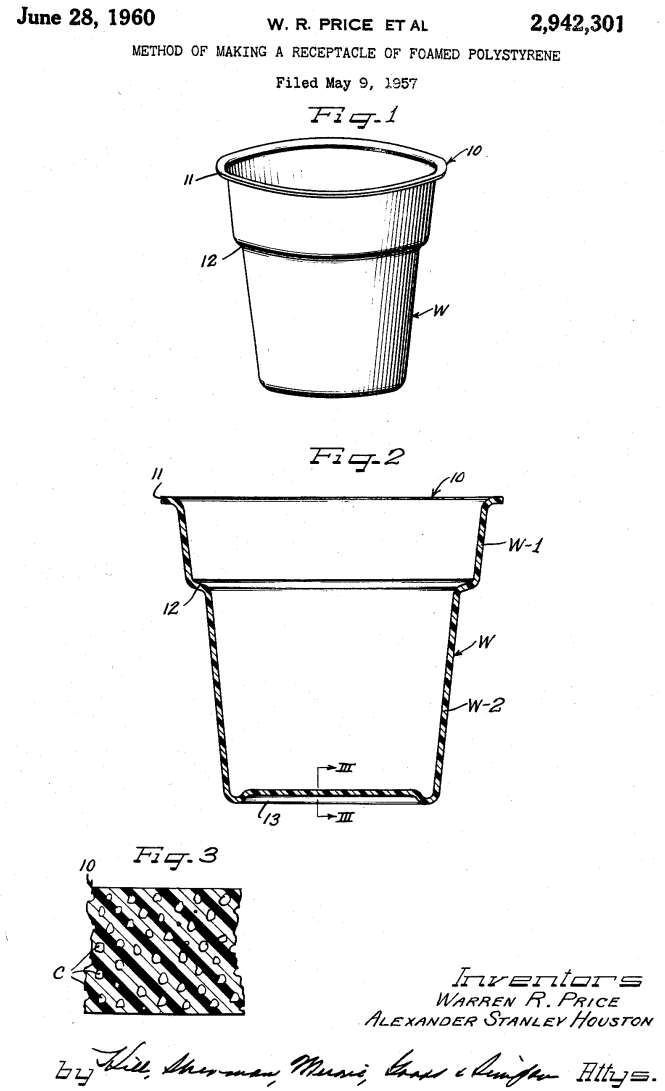
Expanded polystyrene dinner plate???

Construction Project Litigation Matter



Construction Project Litigation Matter

EPS = Expanded Polystyrene


June 28, 1960 W. R. PRICE ET AL 2,942,301

METHOD OF MAKING A RECEPTACLE OF FOAMED POLYSTYRENE

Filed May 9, 1957

Fig. 1

Fig. 2

Fig. 3

Inventors
Warren R. Price
Alexander Stanley Houston

by ... Attys.

"No earlier than 1960" was enough to make our client happy!

The material was deposited no earlier than 1960 based on first patent for EPS used as a cup.

It is highly likely the material was deposited after 1969 based on the introduction of EPS for foam bowls.

It is probable that the material was deposited after 1978 based on the first reference to EPS used for foam dinner plates.

Thank you!

Why do objects fail?

- Misapplication
- Abuse
- Lack of maintenance
- Manufacturing defect
- Design defect
- End of service life

ARDL

Rubber. Plastic. Latex.

The Importance of the Scientific Method

1. Observing
2. Gathering facts, identifying patterns
3. Developing a hypothesis that fits the facts
4. Testing the hypothesis
5. Repeat steps 1-4 as necessary
6. Finalizing and validating conclusions

ARDL

Rubber. Plastic. Latex.

ARDL Teammates-Passion for Problem Solving