Rubber-Steel Interface Failure in Pipeline

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Steel Equipment Lined with Rubber

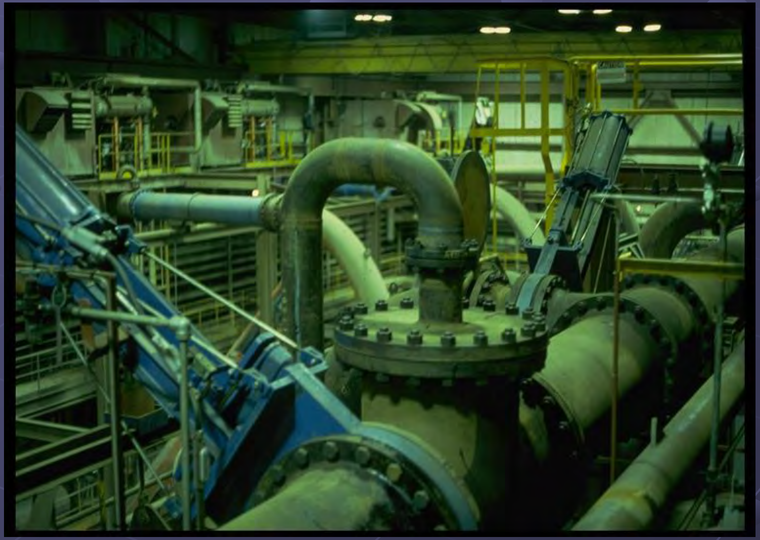
Equipment for mining and chemical industry (examples)

- Tanks
- Pump parts
- Separators
- Cyclons
- Screens
- Pipelines
- Rollers

Steel Equipment Lined with Rubber

Rubber liners increase equipment life span in extreme service conditions eg:

- High slurry wear
- High impact
- Corrosion
- Aggressive environment



Steel Equipment Lined with Rubber

Premature equipment failure is not always detected and is rarely evaluated in-depth for its cause

Objective

The objective of this presentation is to create awareness in scientific and technical societies about certain issues in bonding rubber to steel that may lead to premature interface and rubber failure.

Pipeline Failure

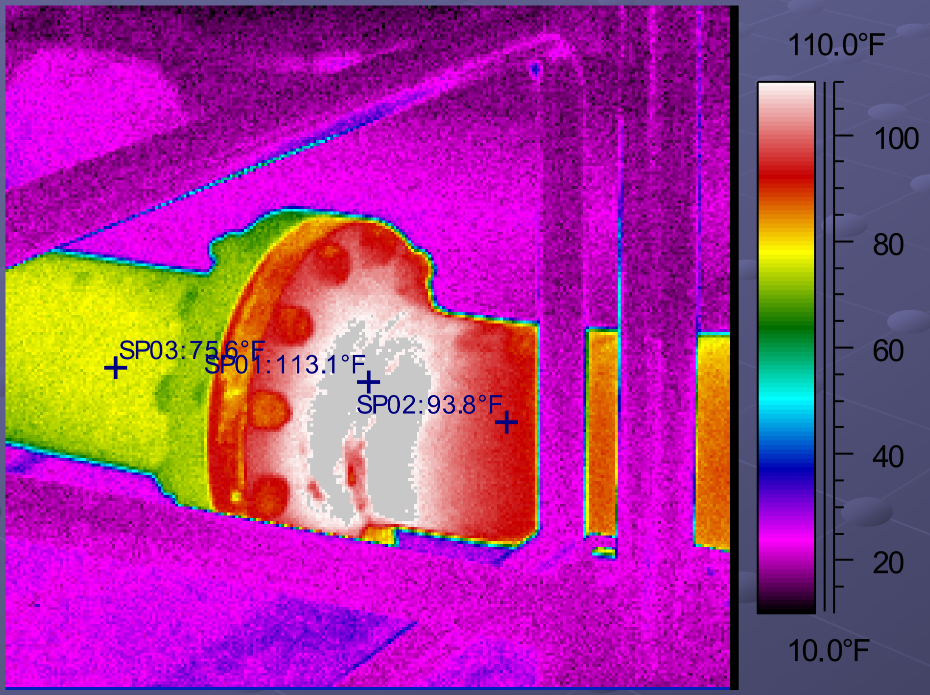
Pipeline Construction

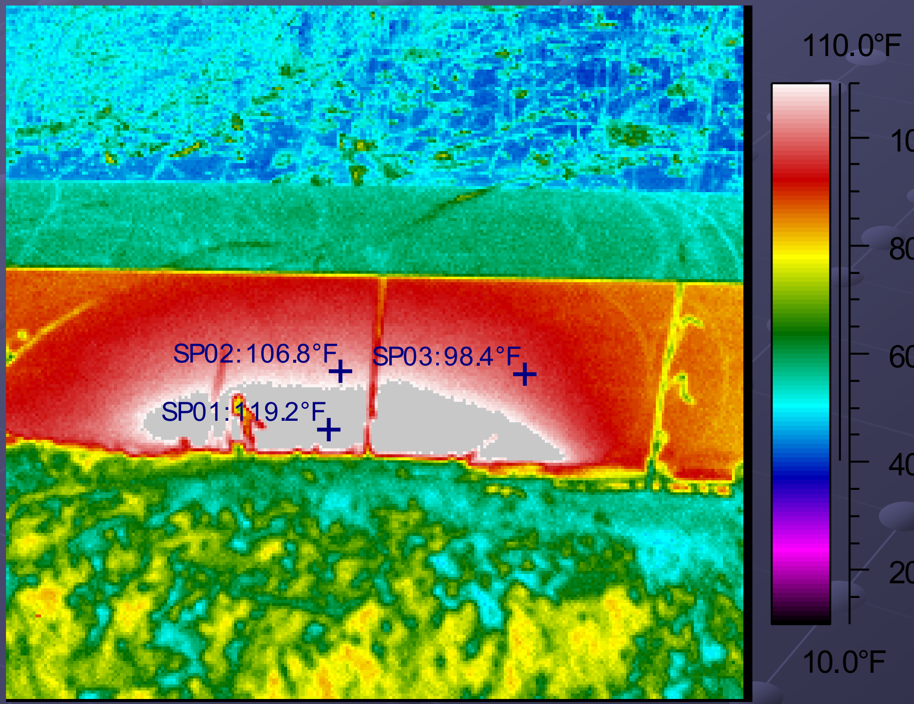
- Over 10 km long
- 200 mm (6”) ID
- 12.5 m (40’) long spools
- 6 mm (1/4”) natural rubber liner

Service Conditions

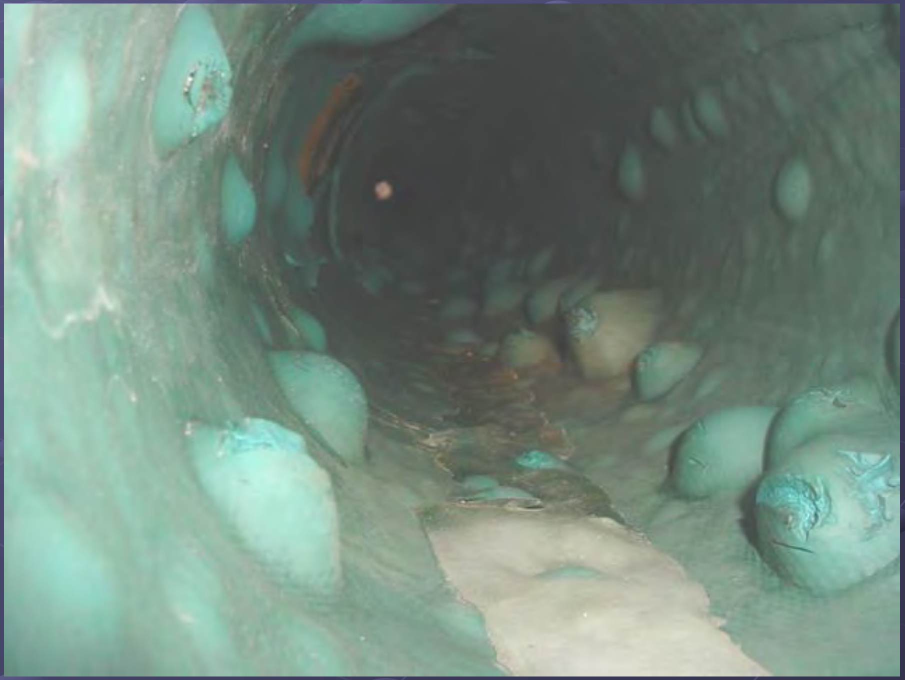
- Exposed to exterior environment
- Transporting gypsum slurry
- Slurry temperature approximately 50^{o}C (122^{o}F)

Pipeline Failure – Failure Detection
Infrared Inspection





Pipeline Failure – Spool Inspection



Pipeline Failure - Laboratory Evaluation

- Water analysis (ICP, ion chromatography)
- Rubber analysis
  - Chemical
  - Mechanical properties
  - Water absorption
- Optical and SEM inspection
  - Interface structure
  - Interface materials EDX analysis
- Interface materials reactivity with water

Laboratory Evaluation
Blister water analysis

Ion	Concentration mg/c		
	Blister water	Rubber A	Pipeline slurry
Calcium	17	4.6	440-500
Copper	<0.1	<0.1	NA
Iron	**492**	<0.1	NA
Manganese	**250**	<0.01	NA
Potassium	26	2.1	20-30
Sodium	41	8.5	160-210
Zinc	38	0.9	NA
Magnesium	9	0.4	1020-1150
Chloride	**827**	0.6	90-140
Bromide	**500**	ND	NA
Sulphate	78	2	5000-5500
Acetates/Formates	**500***	6	NA
pH	**4**	6	7.3-7.6

*approximation based on acetate
NA – not tested
ND – below detection limit

Laboratory Evaluation
Elementary Analysis of Rubbers

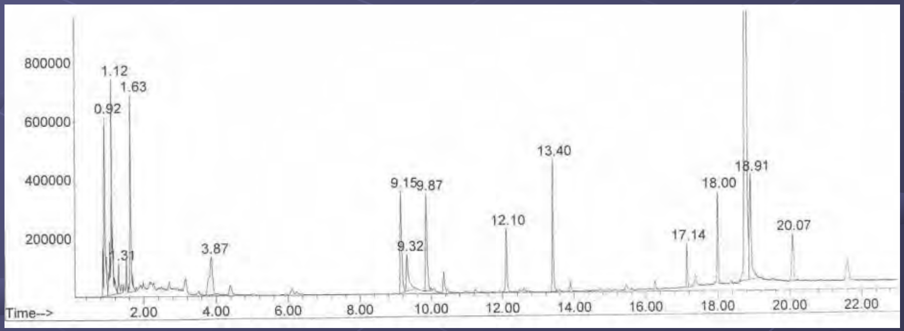
Elements	Concentration ppm		
	Failed rubber		Rubber A
	Surface	Steel interface	
Calcium	234	78	62
Iron	**129**	**200**	**61**
Manganese	**8**	**316**	**1.3**
Potassium	492	372	216
Sodium	34	276	662
Chlorine	**870**	**690**	**100**
Bromine	NA	NA	ND

NA – not tested
ND – below detection limit

Laboratory Evaluation

Acetic and Formic Acids as gaseous components released from liner rubber

Compound	Ret. time min	Concentration µg/g	
		Surface	Interface
Acetic acid	**9.14 – 9.23**	**102**	**1392**
Formic acid	**9.86 – 9.96**	**80**	**1845**



Laboratory Evaluation

Mechanical Properties of Failed Rubber Liner

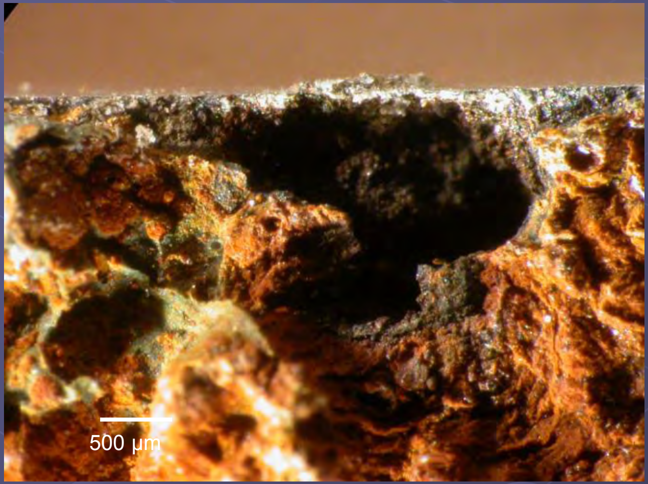
Properties	Testing Method	Units	Value
Tensile strength	ASTM D412	MPa psi	0.82 (0.06) 119 (9)
Elongation at break	ASTM D412	%	160 (20)
Hardness	ASTM D2240	Shore A	36

Laboratory Evaluation

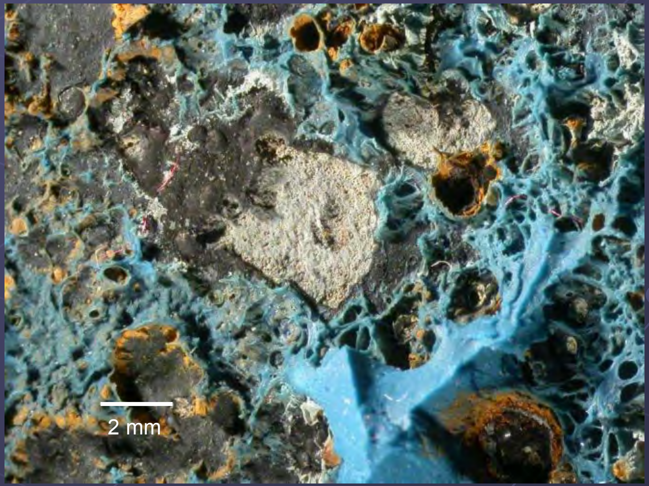
Microscopic pictures of rubber steel interface

cross-section

delaminated surface



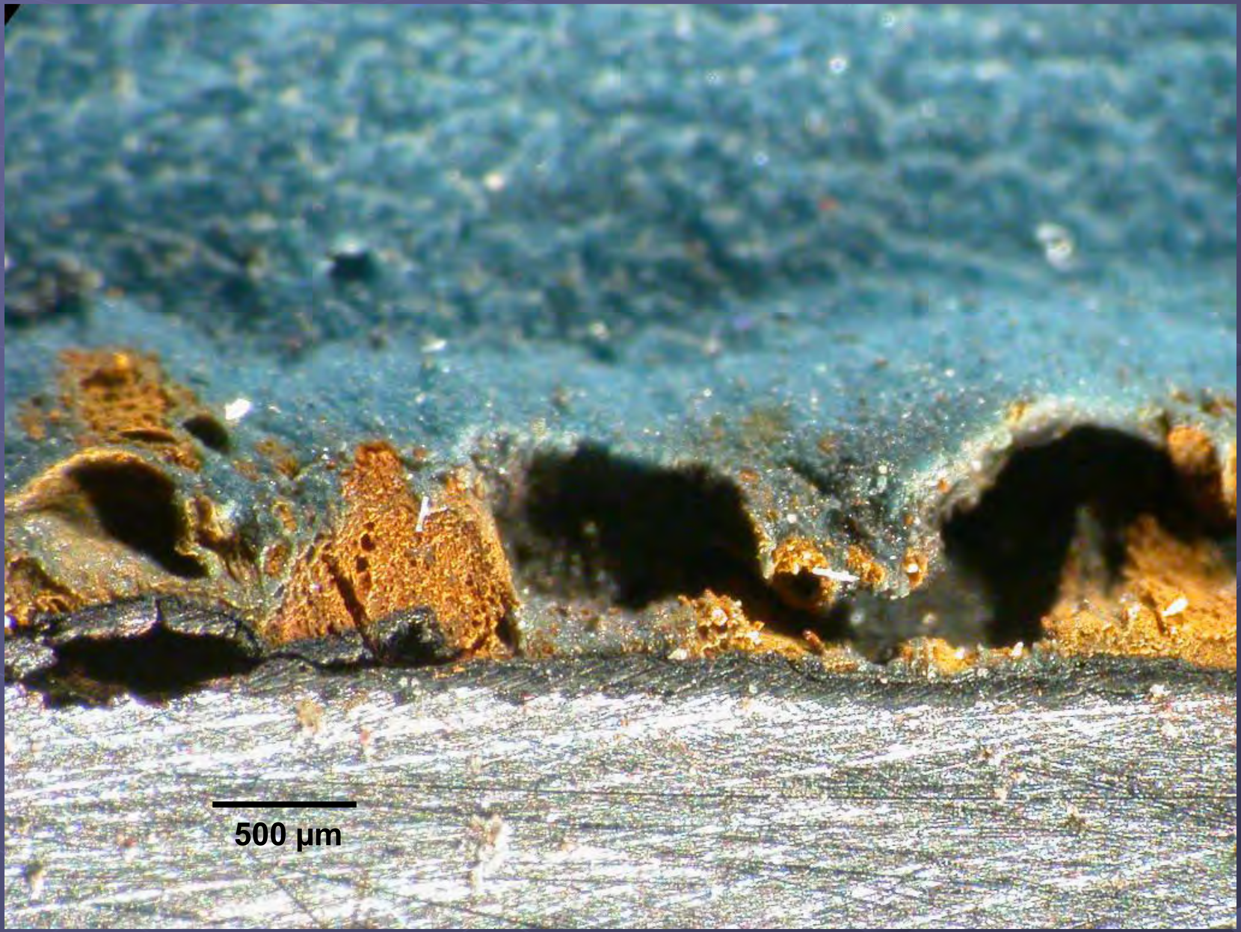
delaminated surface



delaminated surface

Laboratory Evaluation

Microscopic pictures of rubber steel interface



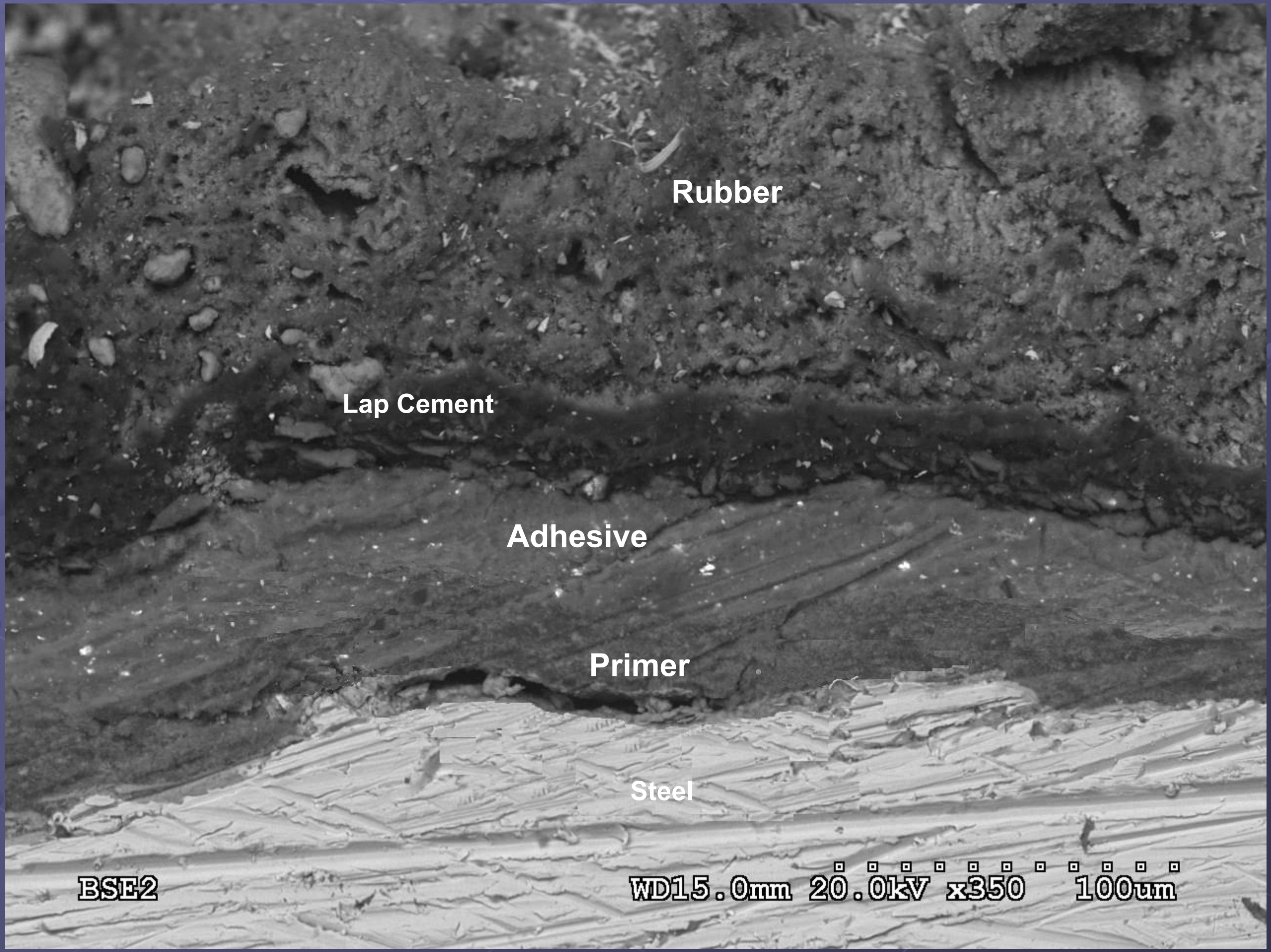
cross-section

Laboratory Evaluation

Microscopic pictures of rubber steel interface

delaminated surface

Laboratory Evaluation
SEM Image of Steel-Rubber Interface



Laboratory Evaluation

EDX Analysis of material layers in the steel-rubber interface

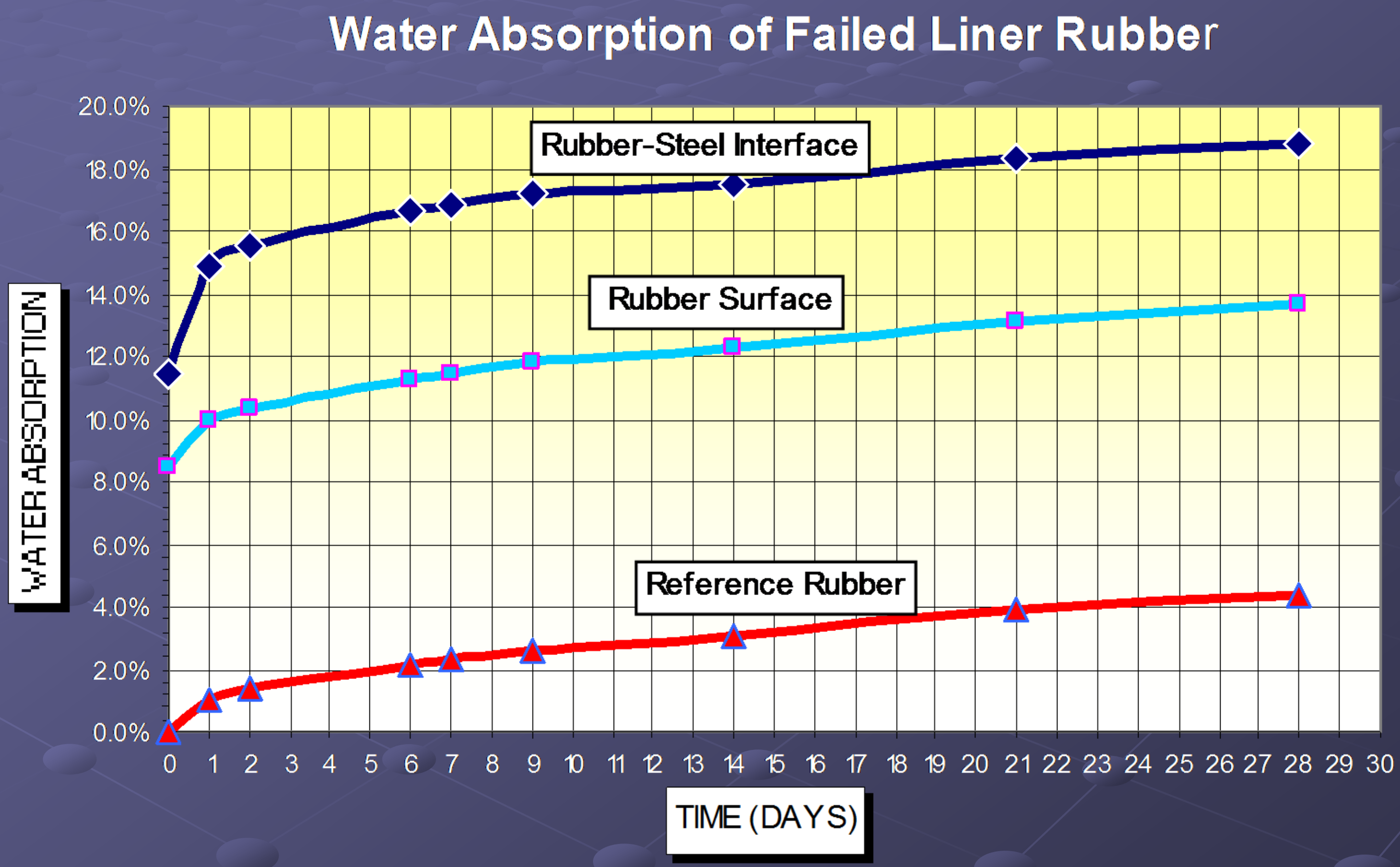
Elements	Concentration %				
	Steel	Primer	Adhesive	Lap cement	Rubber
Carbon	10.2	45	60.2	82.0	80.1
Oxygen	ND	21	6.8	10.3	12.9
Sulphur	ND	0.3	1.0	0.9	0.9
Chlorine	ND	**10.0**	**20.9**	0.8	ND
Titanium	ND	**10.7**	0.2	ND	0.5
Iron	89	7.8	7.2	5.8	2.2
Bromine	ND	NA	**3.1**	ND	ND
Manganese	**0.7**	NA	ND	ND	ND

Laboratory Evaluation

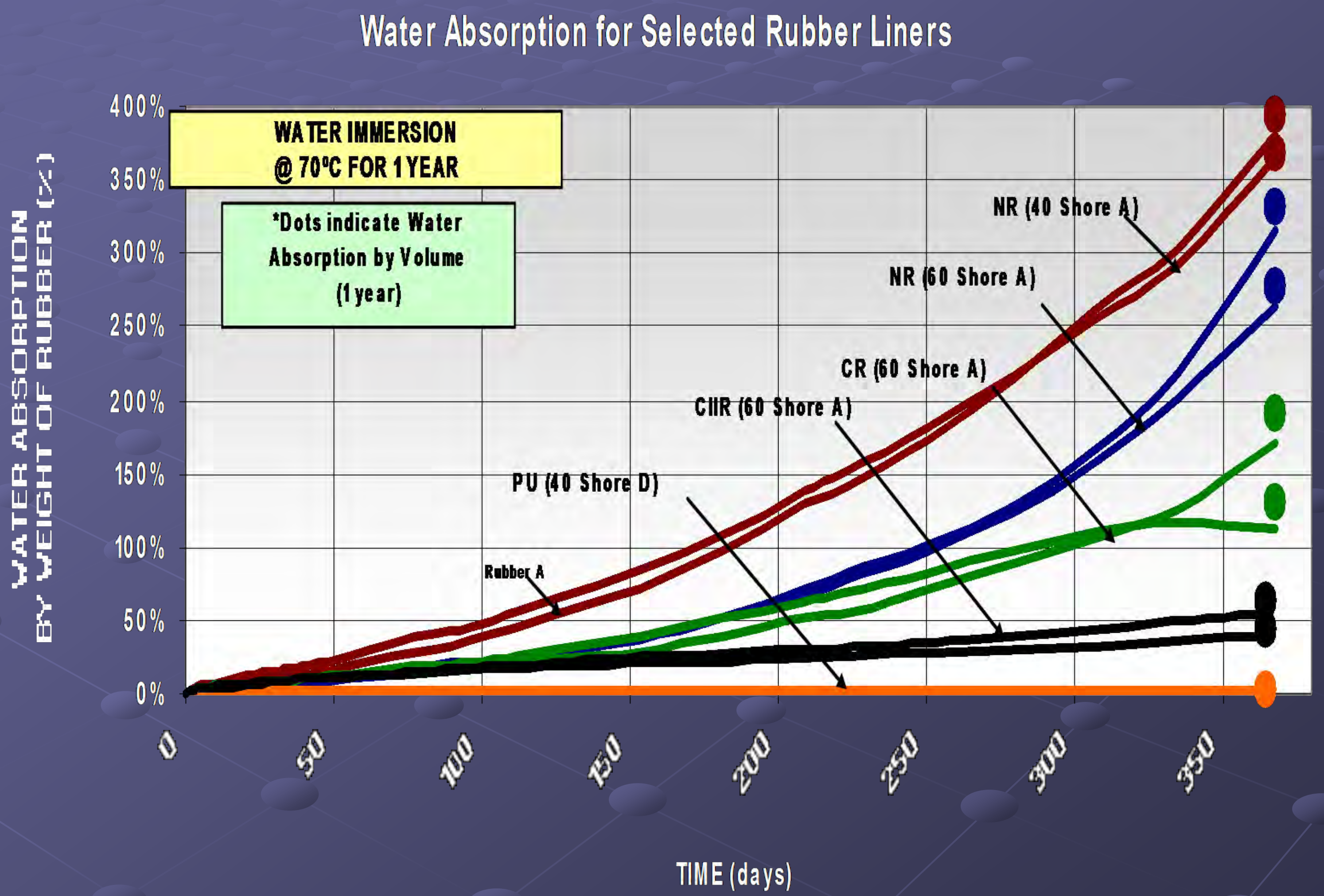
Water contaminants from boiling of adhesive and primer films

Elements	Concentration mg/l	
	Primer	Adhesive
Calcium	2.5	7.4
Copper	<0.1	<0.1
Iron	<0.1	0.8
Manganese	<0.01	0.02
Potassium	2.1	1.8
Sodium	17	112
Magnesium	<0.2	16
Chloride	**202**	**1159**
Bromide	1	**532**
Organic acids	3	3
pH	**5.5**	**2.0**

Laboratory Evaluation



Laboratory Evaluation



Comments and Conclusions

- The majority of rubbers used for bonding with metals frequently show very high water absorption in prolonged contact with water, particularly if this contact occurs at elevated temperatures.
- Water absorbed by rubber may directly affect the rubber-metal interface or may undergo condensation in the vicinity of the metal interface due to the “cold wall effect” particularly when voids are present.
- A significant quantity of water, which may be present in the rubber bonded with metal, could accelerate metal corrosion directly or indirectly.
- Some adhesives may react with water in the metal-rubber interface and corrosive compounds may be created, including hydrochloric and hydrobromic acids. This may be an issue when elevated service temperatures are expected.

Comments and Conclusions - 2

- Steel corrosion products may migrate into the rubber and accelerate rubber aging, particularly during elevated temperatures in service. This process is suspected to generate formic and acetic acids further accelerating the corrosion process.
- Most of the standard testing procedures for evaluation of bonding rubbers to metal do not take into consideration long term water absorption by rubbers.
- Further work on environmentally friendly and user friendly rubber to steel adhesives is required, particularly when elevated temperature service is expected in an aggressive environment.

Acknowledgments

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