PHMSA
Pipeline and Hazardous Materials Safety Administration

Pipeline Transportation: Hydrogen and Emerging Fuels R&D Public Meeting and Forum, Nov. 30-Dec. 2, 2021 (Virtual)

Corrosion of Pipelines: from Machine Learning-Guided Damage Detection to Prevention/Mitigation

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Acknowledgment

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Outline

1. Background

2. Proposed Concept

3. Case Study

4. Summary

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1. Background

- **Corrosion of oil/gas metallic pipelines**

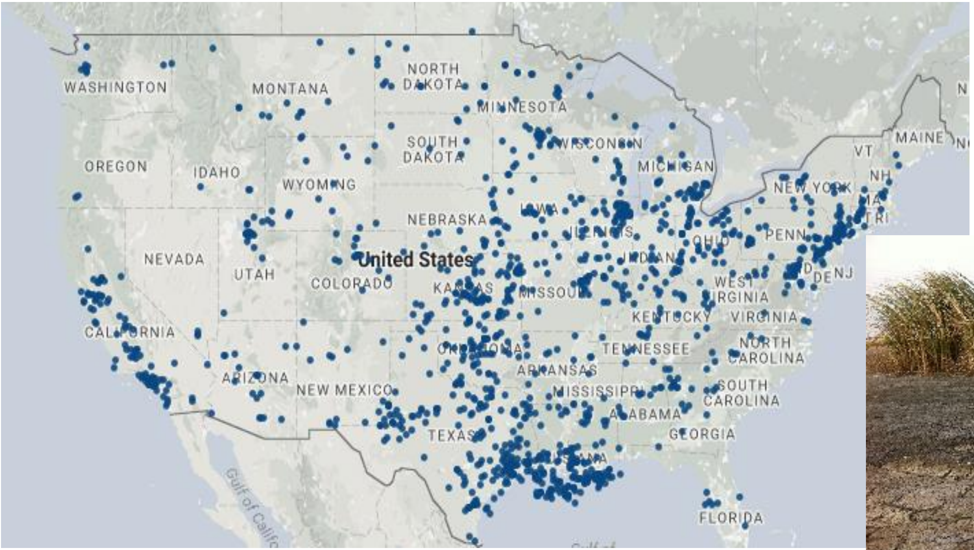

Fig. a Pipeline incidents in the United State[1]

Fig. b Pipeline spill[2]

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[1]. Photos from http://projects.propublica.org/pipelines/

[2] http://www.occupy.com/article/20000-barrels-spilled-north-dakota-pipeline-rupture?qt-article_tabs=2

1. Background

○ Corrosion of oil/gas metallic pipelines

Fig. 1 Internal corrosion: a) localized pits[1], b) fouling[2] and c) wear/erosion[3]

Table 1. Pipeline accidents in recent years at North Dakota (Pan et al., 2017[4]).

Accident	Location	Year	Loss
Pipeline spill	Tioga	2014	One gas pipeline exploded and burned
Pipeline spill	Tioga	2013	**865,000 gallons (one of the largest to happen onshore in U.S. history)**
Pipeline spill	Sargent County	2011	Spilling 400 barrels of crude oil
Pipeline spill	Neche	2010	Releasing 3,784 barrels of crude oil
Pipeline spill	Mantador	2004	Residents were evacuated, and a rail line was shut down
Pipeline spill	Barnes County	2003	Releasing 9,000 barrels of propane
Pipeline ruptured	Bottineau	2001	1.1 million US gallons (4,200 m^3) of gasoline burned
Pipeline spill	Harwood	2001	Spilling 40 barrels of fuel oil

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[1]. Photos from http://www.flickriver.com/photos/59127492@N07/5416927808/
[2]. Photos from http://www.icorr.org/news/180/index.phtml
[3]. Photos from https://sites.google.com/site/metropolitanforensics/root-causes-andcontributing-factors-of-gas-and-liquid-pipeline-failures
[4]. Pan, H.; Ge, R.; Xingyu, W.; Jinhui, W.; Na, G.; Zhibin, L. Embedded Wireless Passive Sensor Networks for Health Monitoring of Welded Joints in Onshore Metallic Pipelines. In *ASCE 2017 Pipelines*; 2017.

1. Background

- **Challenges:**
  - **Detection**: Sensing and assessing corrosion-induced damage (early-stage, data process of collected data with high variances, e.g., noise interference for signals)
  - **Prevention/Mitigation**: Conventional coating systems (low-damage tolerance, inaccessible for repair)

2. Proposed Concept

- **Solutions:**

Failure Mechanism

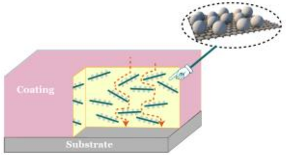
Removal of corrosive agents

Corrosion of pipeline systems

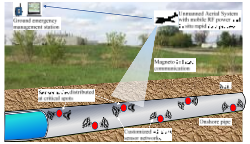
Mitigation and Protection

Monitoring and Diagnosis

New nanocomposite coatings

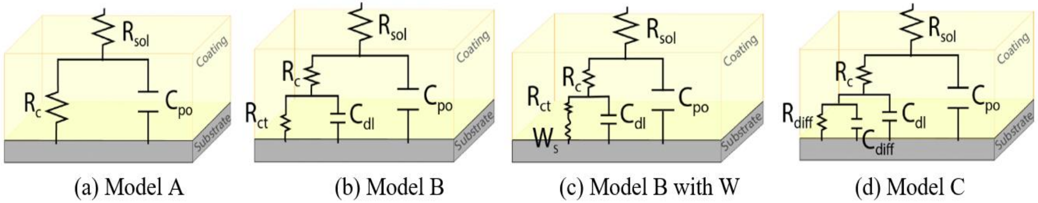


Machine-learning guided damage detection

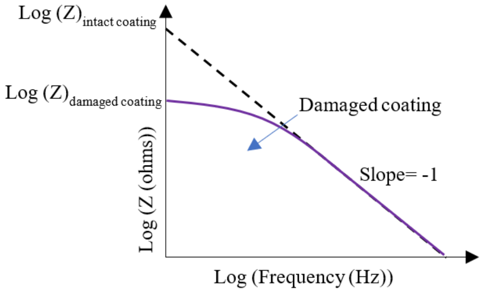


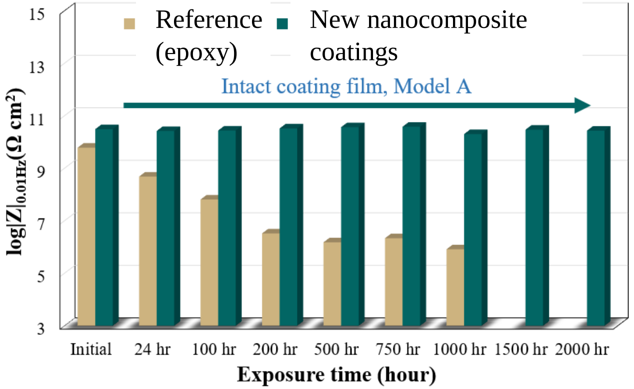
3. Case study— *New nanocomposite coatings*

- **Performance in terms of corrosion resistance:**

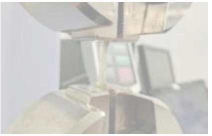


Equivalent electrical circuit models at four stages: (a)-(d)



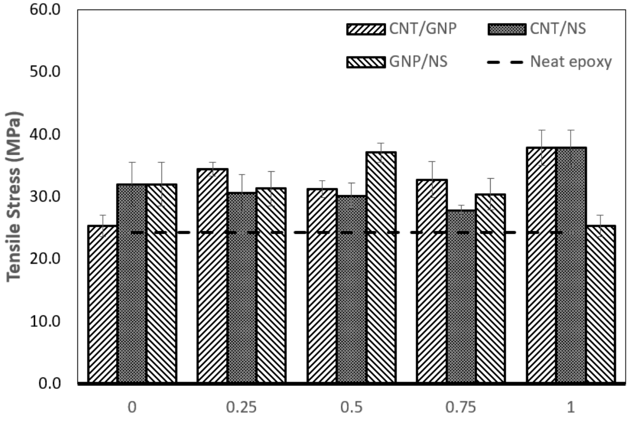


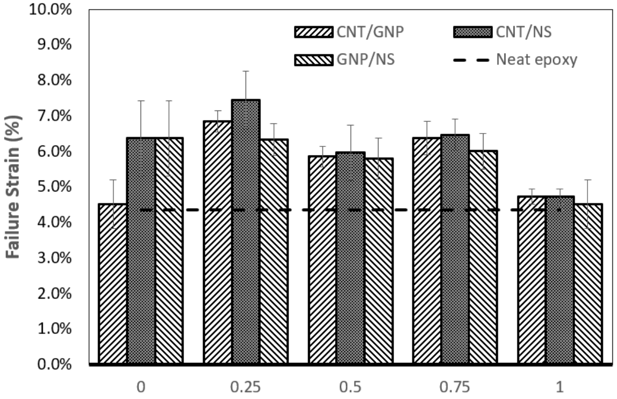
3. Case study— *New nanocomposite coatings*

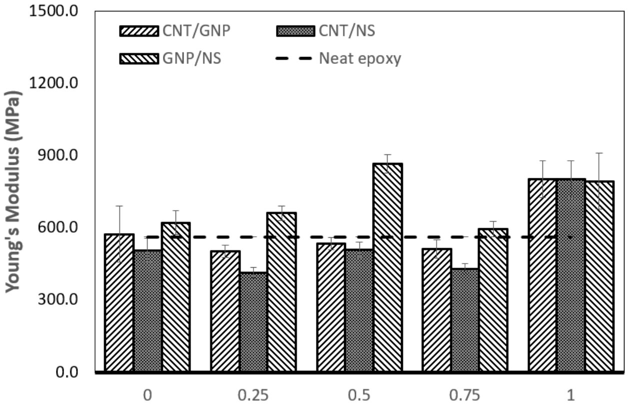


○ Performance in terms of mechanical-tensile:

- Tensile strength
- Ultimate strain
- Young's modulus







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3. Case study— *New nanocomposite coatings*

○ Performance in terms of mechanical-abrasion resistance:

- Mass loss after abrasion
- SEM image of abraded surface

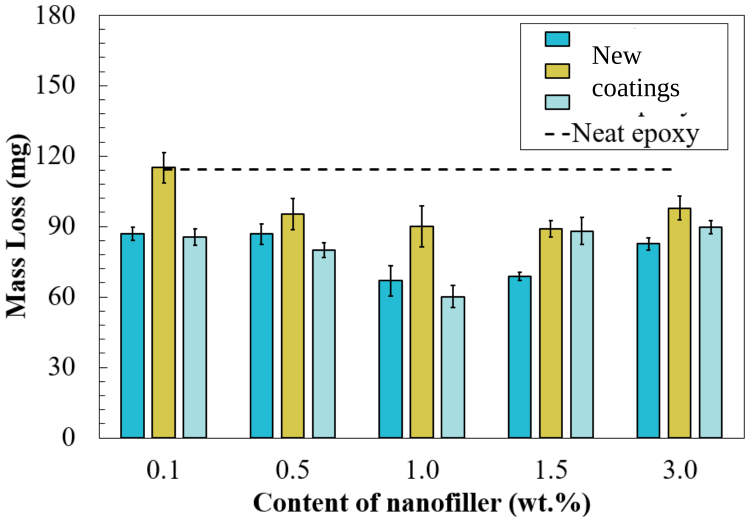

Fig. a Mass loss of nanocomposites

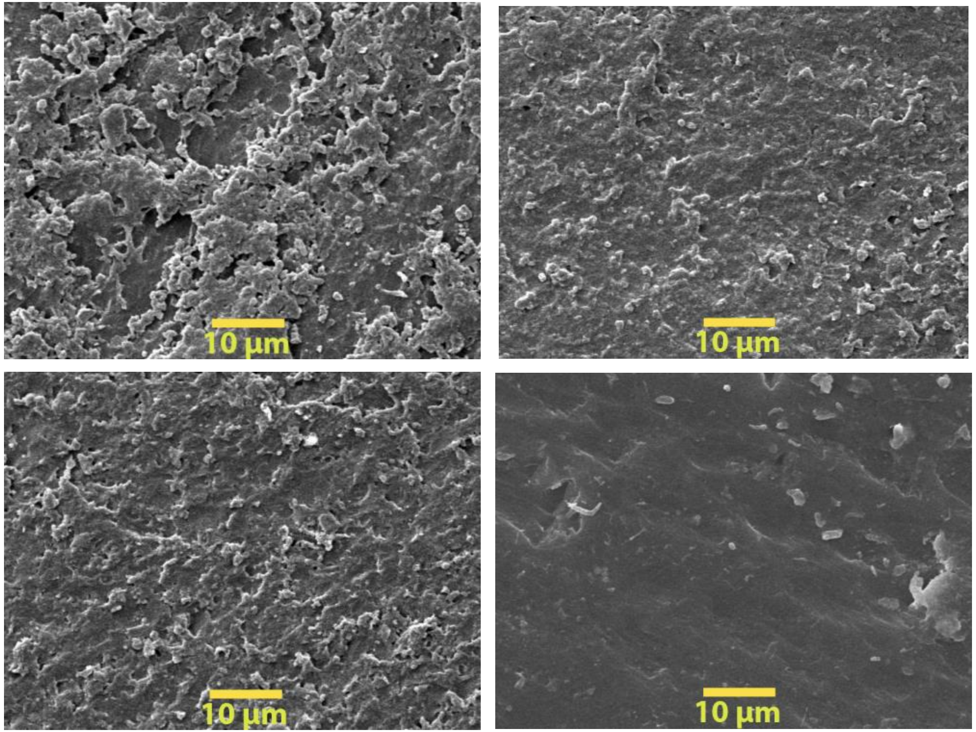

Fig. b SEM image of abraded surface

3. Case study— *New nanocomposite coatings*

- **Performance in terms of wettability:**

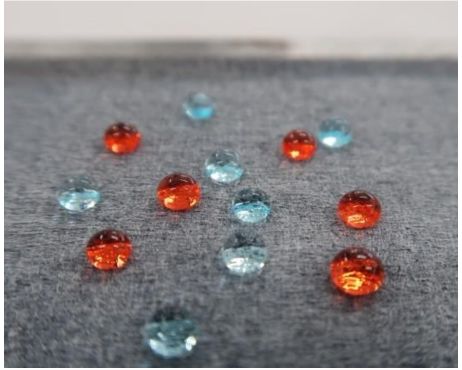

Fig. a Picture of water (blue) and hexadecane (red) on new coating

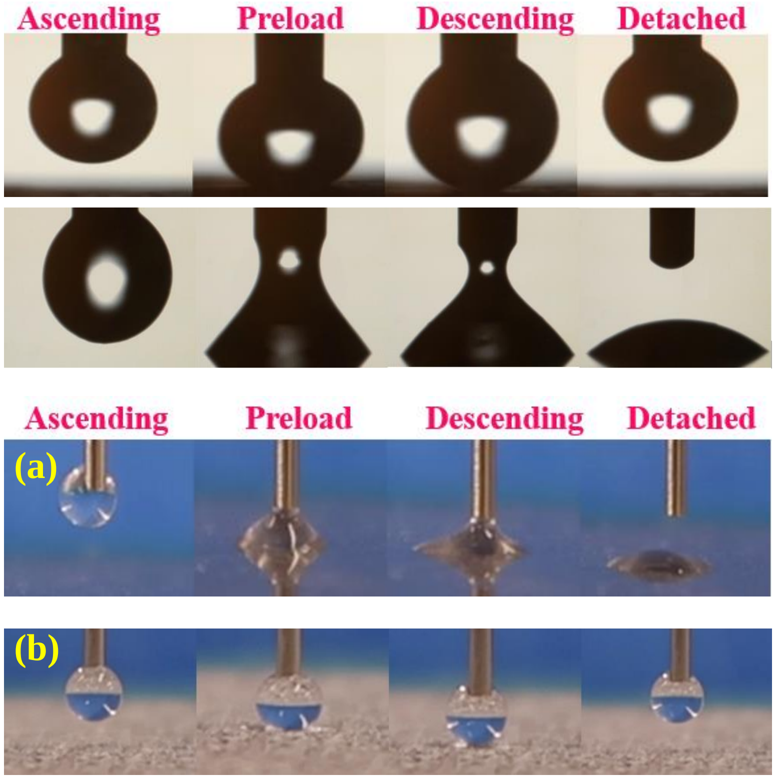

Fig. b Water droplet ascending and descending of (a) neat epoxy, (b) high-performance coating

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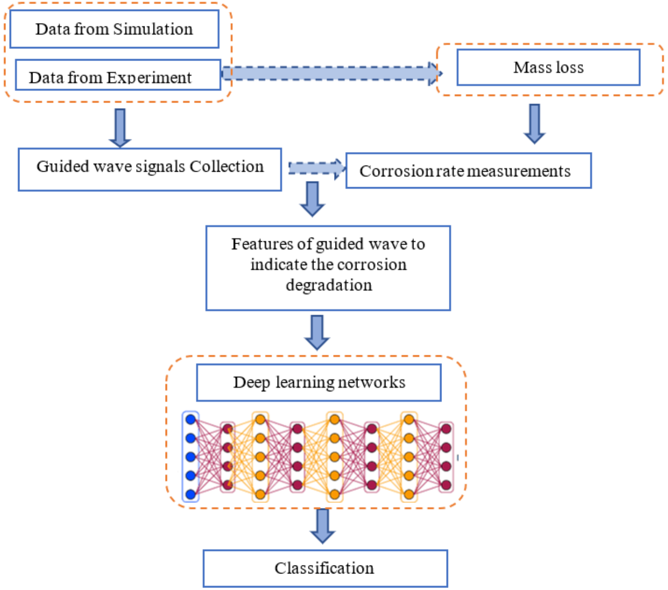
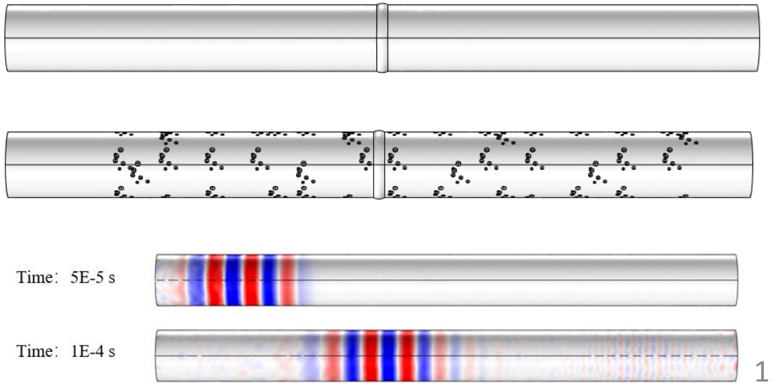
*Note: the information has patent protection in the United States.

3. Case study— *Machine-learning guided damage detection*

- **Machine learning guided damage detection:**





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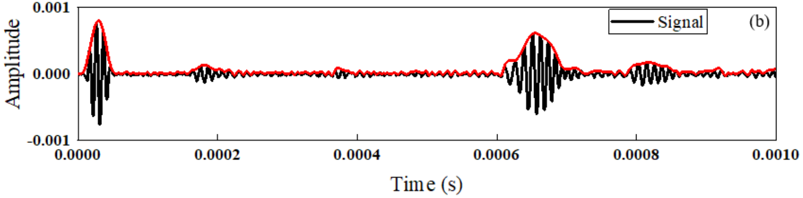
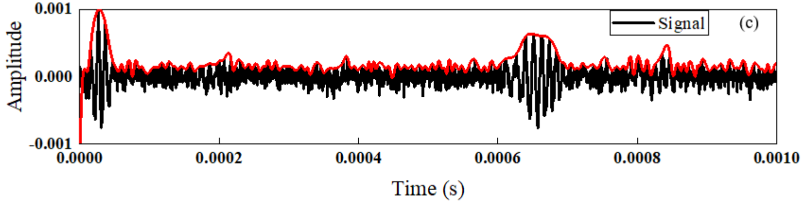
3. Case study— *Machine-learning guided damage detection*

- **Machine learning guided damage detection:**

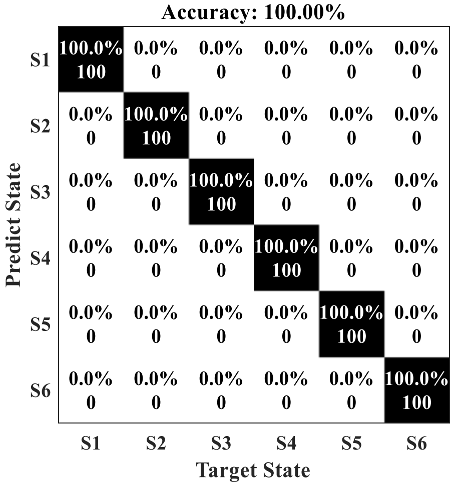
-Noise interference



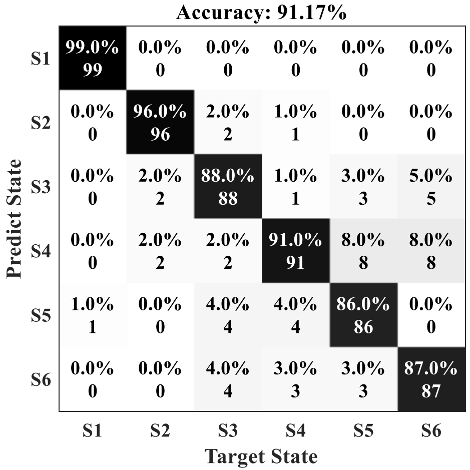
(a) SNR=100 dB



(b) SNR=80 dB



(a) SNR=100 dB

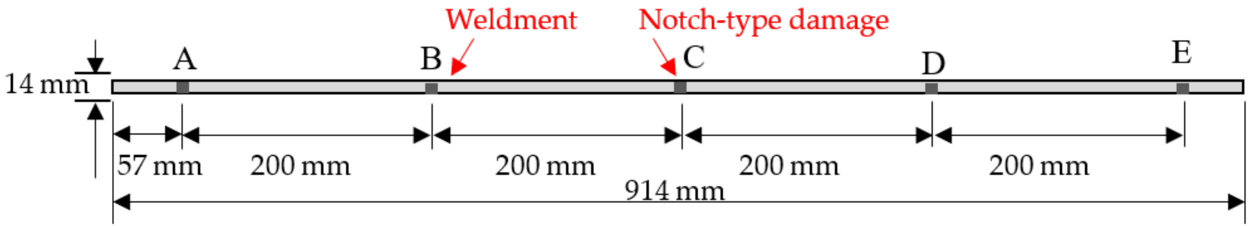


(b) SNR=80 dB

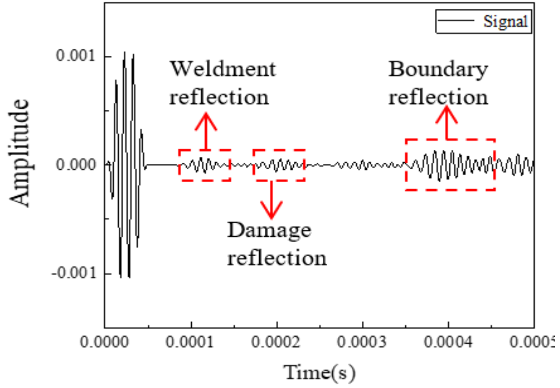
3. Case study— *Machine-learning guided damage detection*

○ Machine learning guided damage detection:

-Material discontinuity



(a) Plate with a butt welded joint at point B and a 6-mm long notch-type damage at point C.



(b) Signal collected from point A

Table 1, Comparison of accuracy in two cases

Noise level	120 *dB*	110 *dB*	100 *dB*	90 *dB*	80 *dB*
Without weldment	100.00%	100.00%	100.00%	100.00%	56.4%
With weldment	100.00%	100.00%	80.00%	73.10%	65.71%

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3. Case study— *Machine-learning guided damage detection*

- **Machine learning guided damage detection:**

-Shallow learning

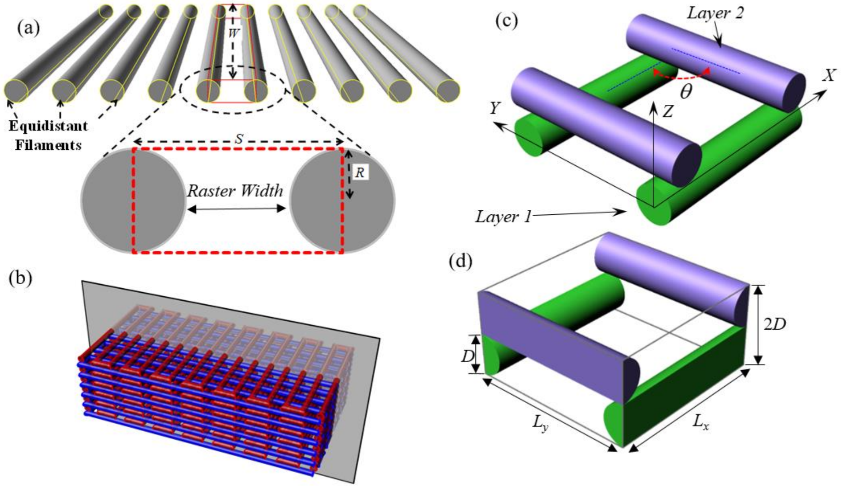
Method		Classification by physics-based			Classification by SVM		
					No feature selection		Feature selection
Features		Amp	Frq	RMS	Physics based Features	All Features	Selected features
Noise level	120dB	100.00%	100.00%	100.00%	100.00%	100.00%	**100.00%**
	110dB	97.71%	100.00%	98.86%	98.86%	98.86%	**100.00%**
	100dB	81.14%	86.29%	84.00%	92.00%	84.00%	**95.43%**
	90dB	44.00%	64.00%	72.00%	80.00%	72.00%	**86.29%**
	80dB	19.43%	34.86%	39.43%	53.71%	39.43%	**56.00%**

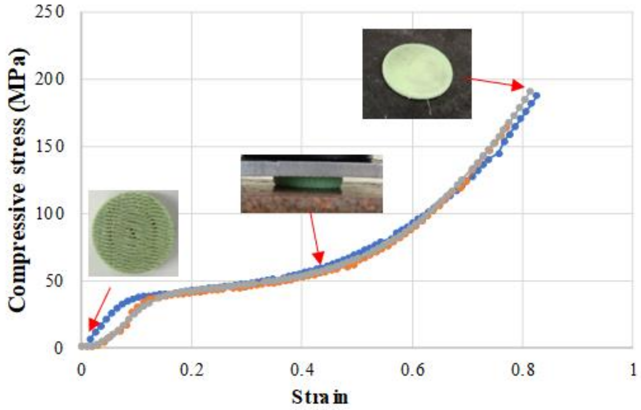
-Deep learning

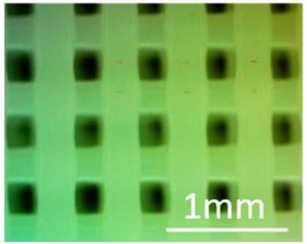
	100 dB	90 dB	80 dB	70 dB	60 dB
SVM_WT	98.5%	84.1%	57.3%	31.4%	26.5%
SVM_PH	**100%**	91.1%	64.9%	42.2%	26.5%
SVM_ALL	**100%**	**100%**	**100%**	84.00%	46.4%
SVM_FS	**100%**	**100%**	98.4%	77.9%	49.9%
CNN	**100%**	**100%**	**100%**	88.75%	62.5%
Resnet	**100%**	**100%**	**100%**	**93.19%**	**67.69%**

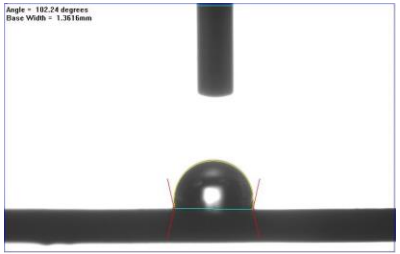
3. Case study— *Removal of corrosive agents*

- **3D printing lattices for water/oil separation:**









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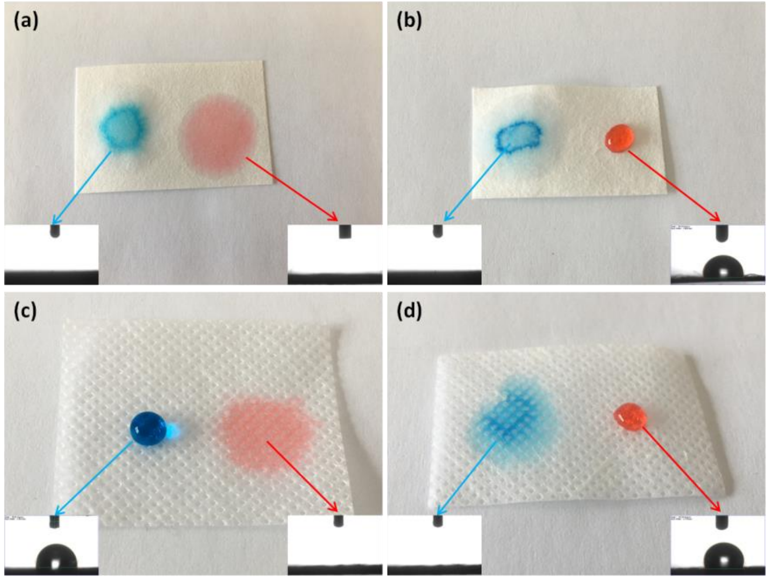
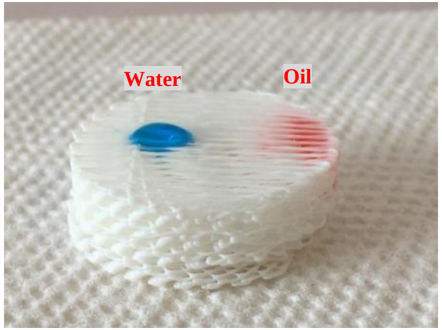
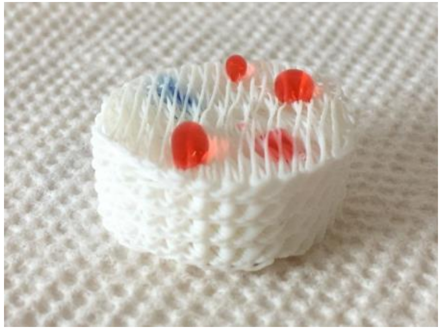
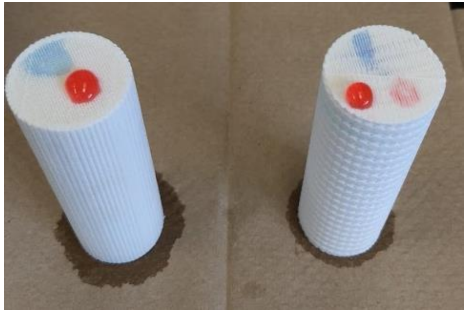
3. Case study— *Removal of corrosive agents*

- **3D printing lattices for water/oil separation:**









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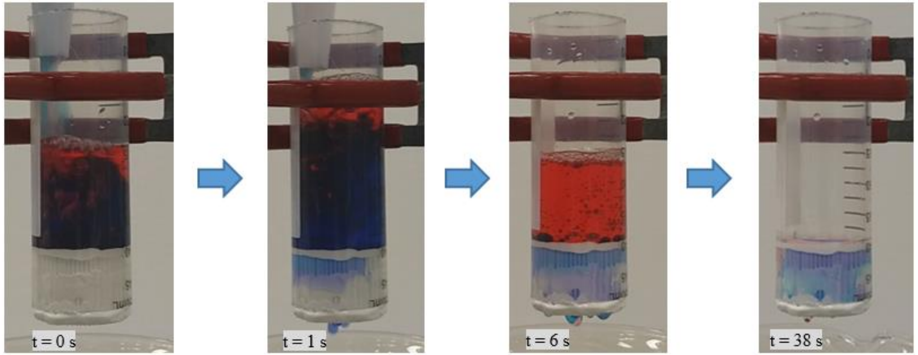
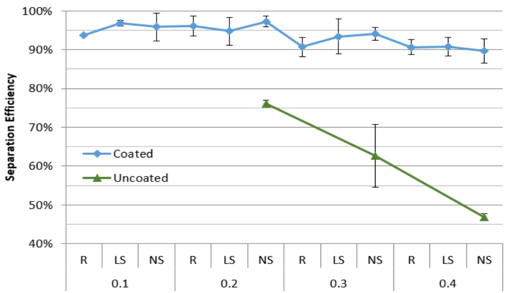
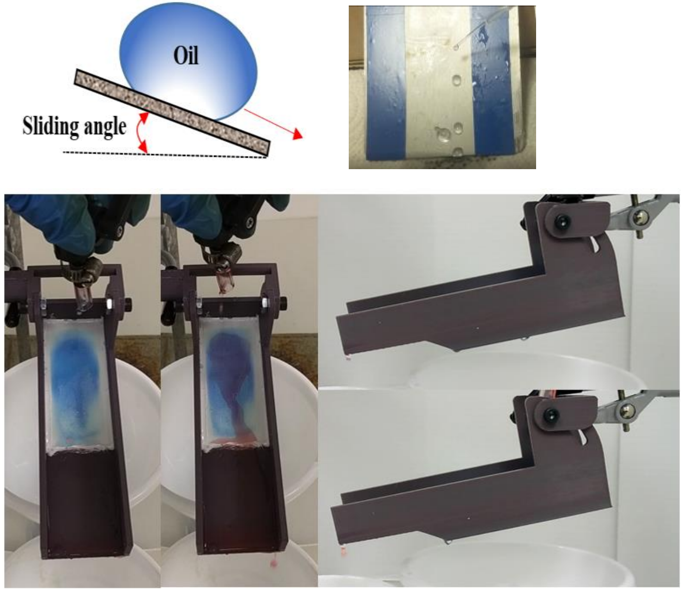


0.2-mm 3D printing LS type lattices





Sliding angle

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4. Summary

- The projects aimed to address corrosion issues experienced in pipelines from different perspectives.

- The proposed nanocomposite coatings with high damage tolerance as well as superior corrosion resistance as one solution for pipeline corrosion control and prevention

- The proposed machine learning guided framework for early-stage corrosion-induced damage detection for pipelines

- The proposed approach for removal of corrosive agents (e.g., water) for pipeline corrosion prevention

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