

# Coatings for phase change heat exchange

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## Why phase change heat exchange?

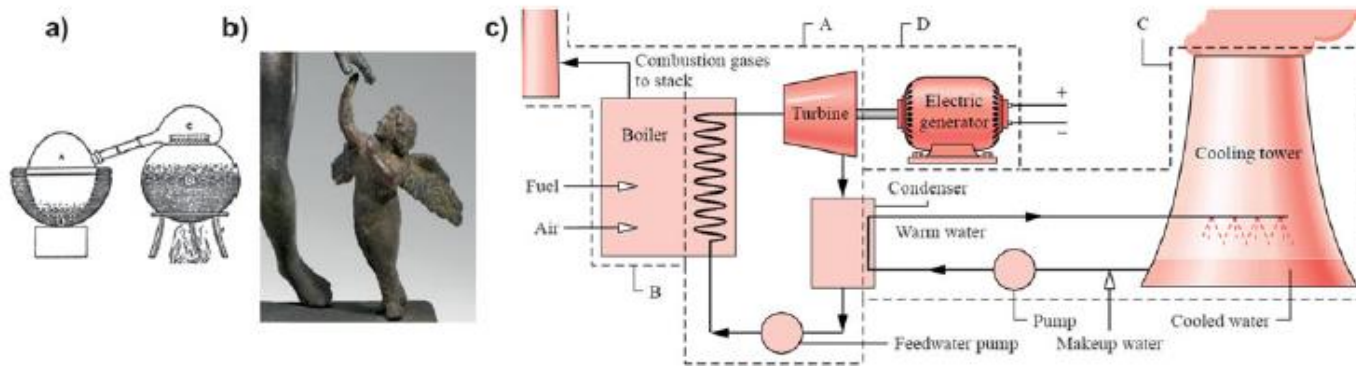
Phase change is essential for energy applications, because **latent heat is much larger than sensible heat.**

### Example:

For water, and for 1 g:

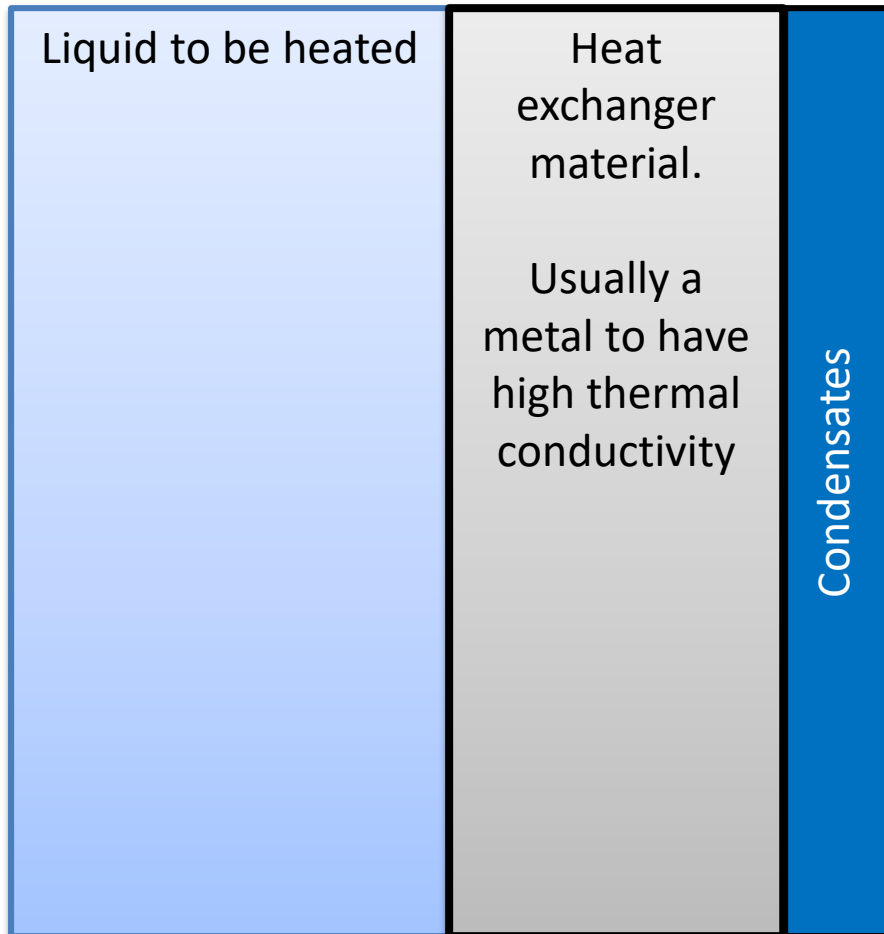
Latent heat to boil = 2260 J

Heat required to increase the temperature by 5 K = 21 J



**Figure 1.** Human beings have relied on phase change heat transfer from Antiquity to now, to satisfy needs such as (a) alcohol production by distillation<sup>1</sup> (ca. 600 BCE, India), (b) metal casting for military or artistic purposes (Eros with Aphrodite, bronze, ca. 100 BCE), and (c) boiling and condensation for mechanical power, since the industrial revolution of the 19th century.<sup>4</sup> Figures (a, b, c) reprinted with respective permissions of ASME, by courtesy of the Getty's Open Content Program, and with the permission of the Taylor and Francis Group.

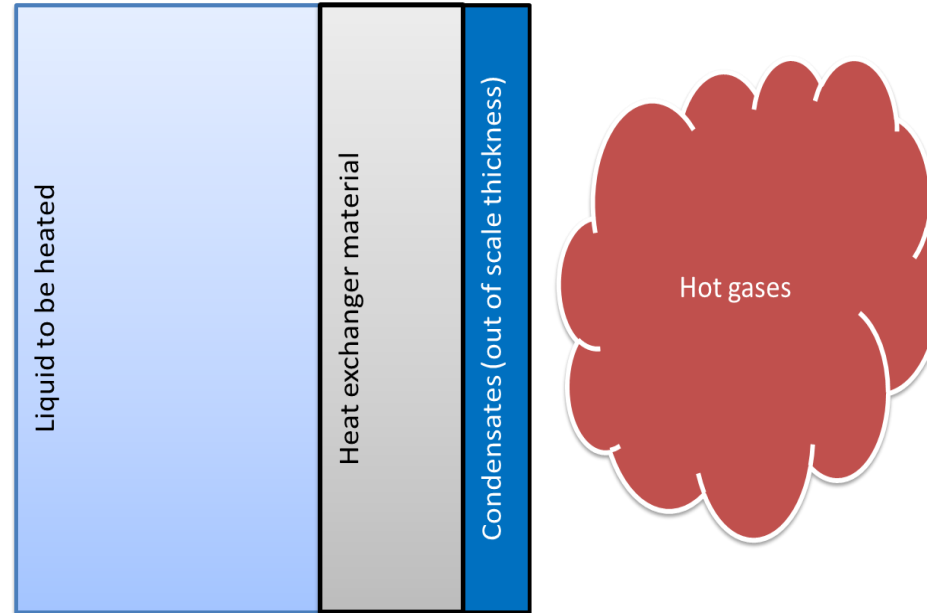
# \_Phase change heat exchange



(Relative dimensions are not in same scale)



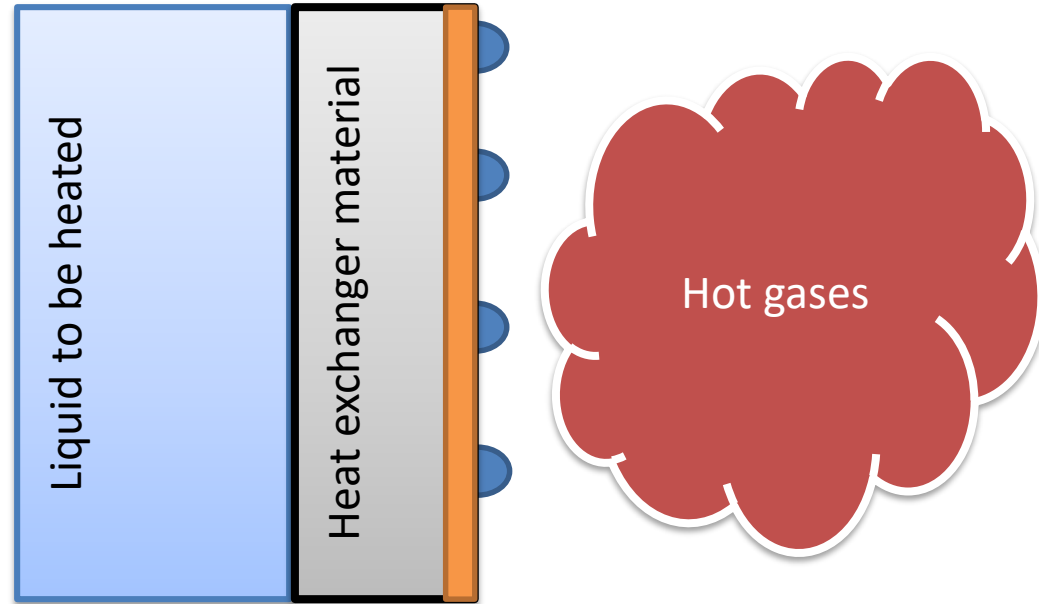
# \_Phase change heat exchange-Need for coatings



## What is the problem here?

1. Condensates might be corrosive, if hot gases contain  $\text{SO}_x$ , Cl, etc.
2. Filmwise condensates introduce additional thermal resistance.
3. Condensates that are not being easily self-removed from the surface prohibit additional condensates to perform thermal exchange

# \_Phase change heat exchange-Ultimate goal



## Why do we need a coating?

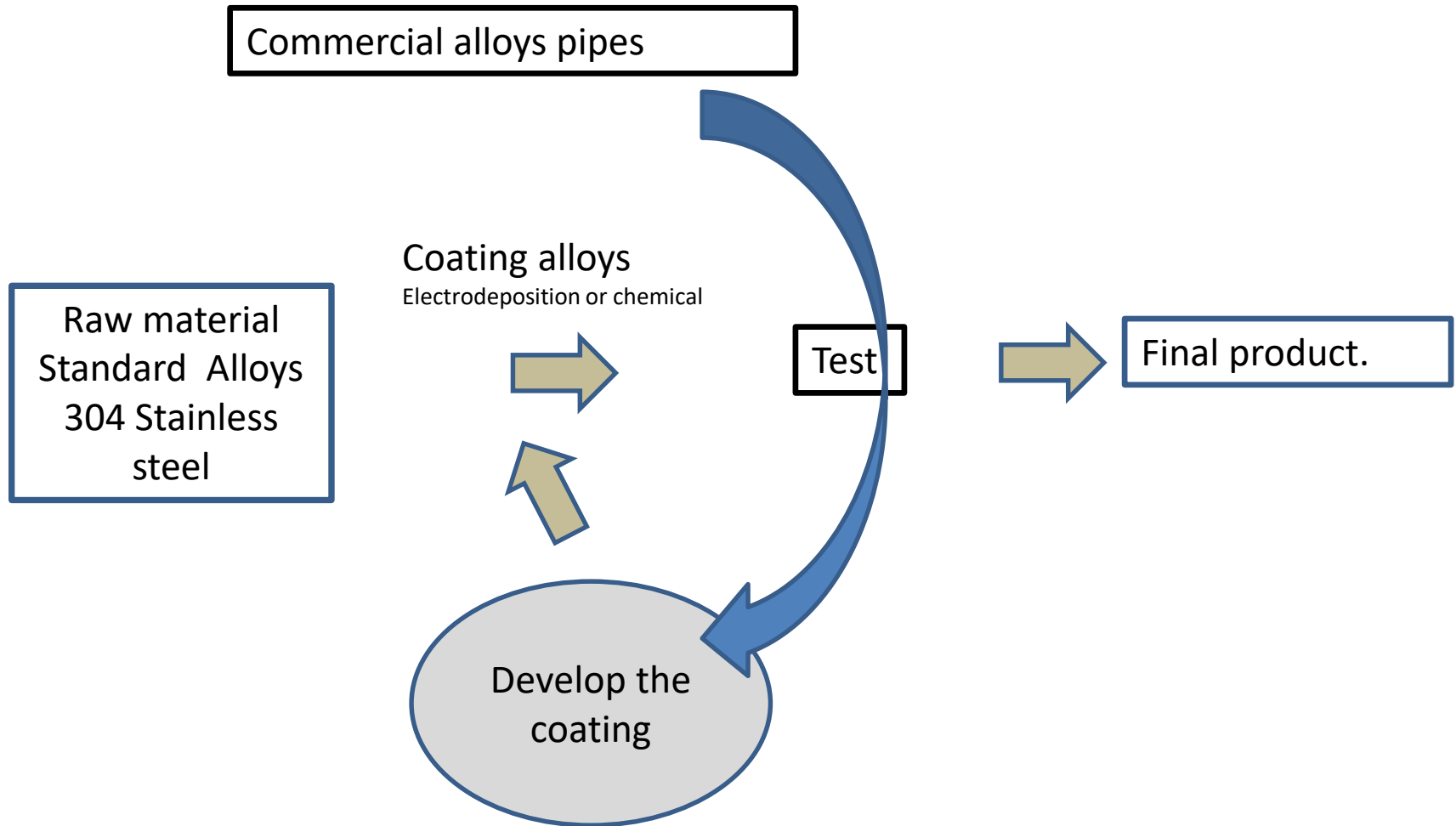
1. Corrosion protection: Condensates might be corrosive if hot gases contain  $\text{SO}_x$ , Cl, etc.
2. To enhance dropwise condensation over filmwise condensation: Filmwise condensates introduce additional thermal resistance.
3. Ease removal of condensates: Condensates shall be easily self-removed from the surface to allow for additional thermal exchange.

The coating shall also exhibit high thermal conductivity

## Two approaches were followed and are presented hereafter

1. Coatings with formulations close to conventional alloys with desirable properties. Here we will present the Alloy 59-coating, which provides exceptional corrosion protection against  $\text{H}_2\text{SO}_4$  and  $\text{HCl}$
2. Coatings with robust hydrophobic properties with very good corrosion protection against  $\text{H}_2\text{SO}_4$  and functional wetting phenomena

# Development of innovative coatings within I-ThERM



## Testing



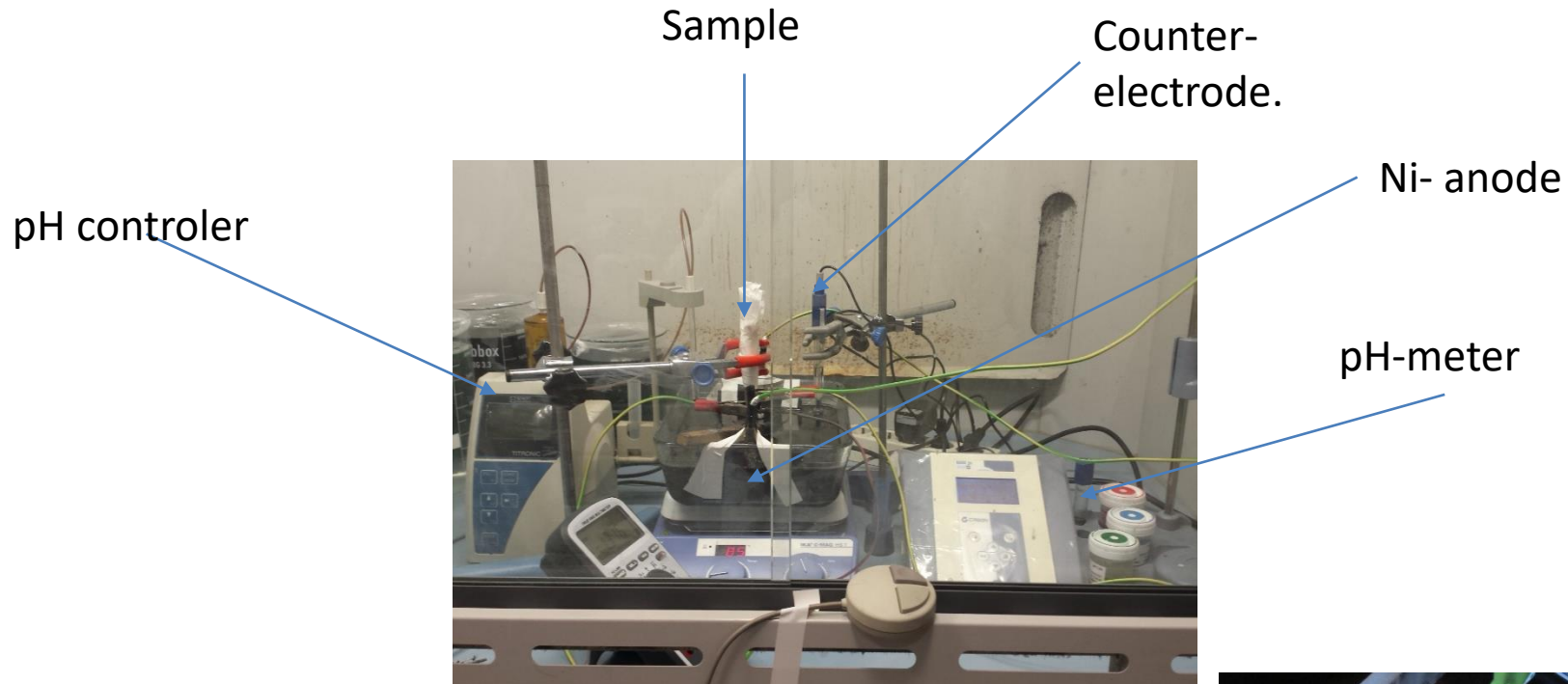
**Figure 1.** Experimental Setup for fast quality assessment of coatings



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## lab-. ELECTRODEPOSITION



- Stainless steel 304
- Stainless steel 316
- Carbon steel

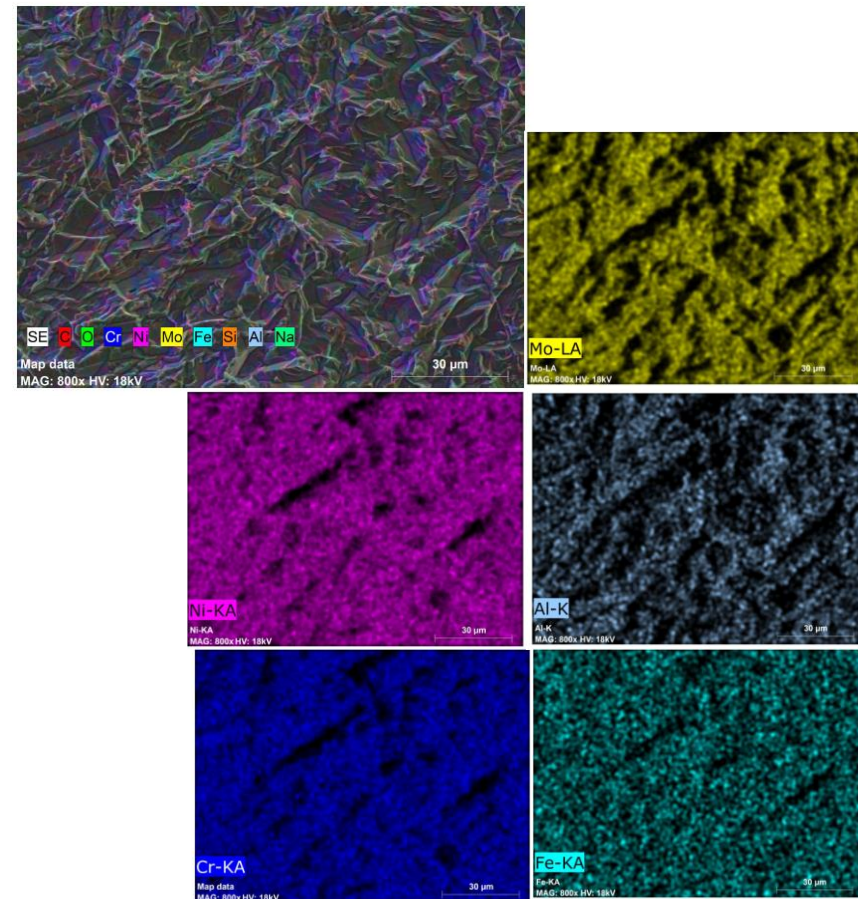
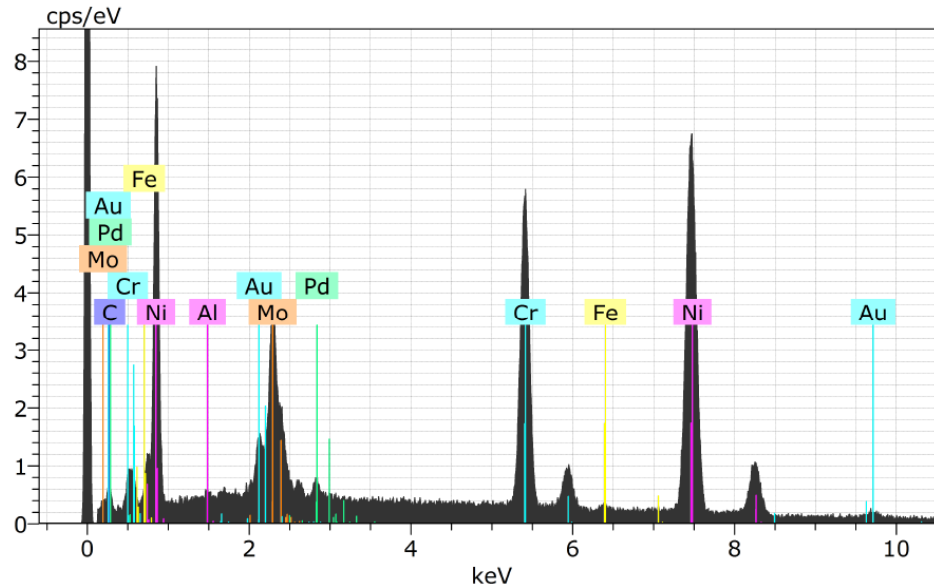


## ELECTRODEPOSITION – pilot plant.

50-70 liters.



The formation of the Alloy59-like phase has been confirmed with Scanning Electron Microscopy and EDX (element mapping)



Element	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (3 Sigma) [wt.%]
Carbon	6	K-series	0.00	0.00	0.00	0.00
Chromium	24	K-series	19.43	20.62	24.79	1.71
Nickel	28	K-series	55.80	59.22	63.08	4.78
Molybdenum	42	L-series	13.18	13.99	9.12	1.52
Palladium	46	L-series	1.14	1.21	0.71	0.22
Gold	79	L-series	4.09	4.34	1.38	0.72
Iron	26	K-series	0.42	0.44	0.50	0.15
Aluminium	13	K-series	0.17	0.18	0.43	0.12
Total:			94.23	100.00	100.00	



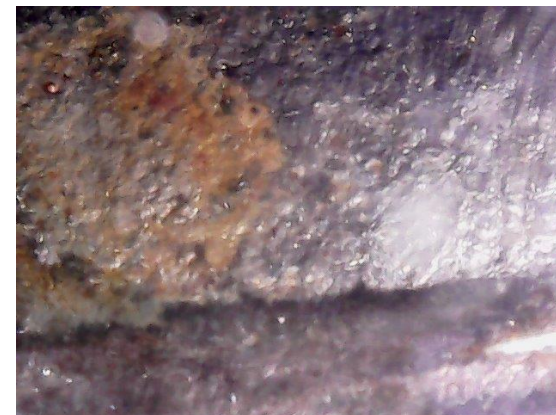
# Development of innovative coatings within I-ThERM



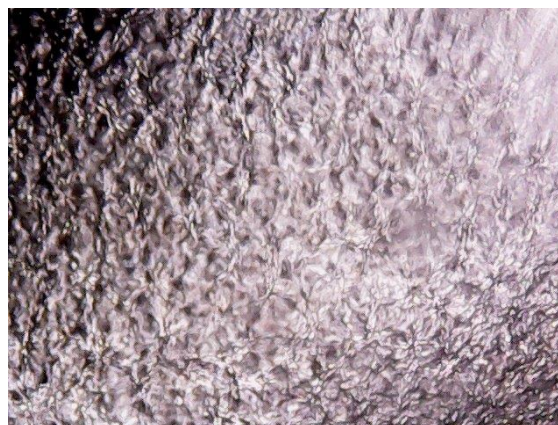
**Reference**



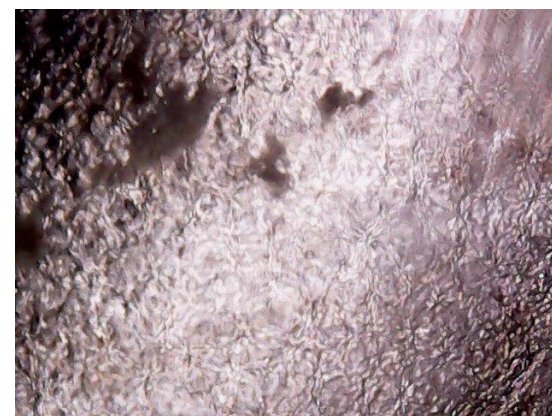
**HCl 10%**



**HCl 33%**



**H<sub>2</sub>SO<sub>4</sub> 10%**

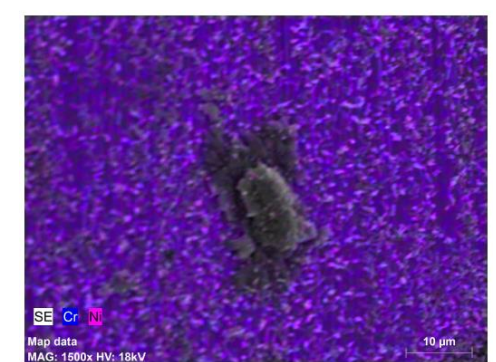
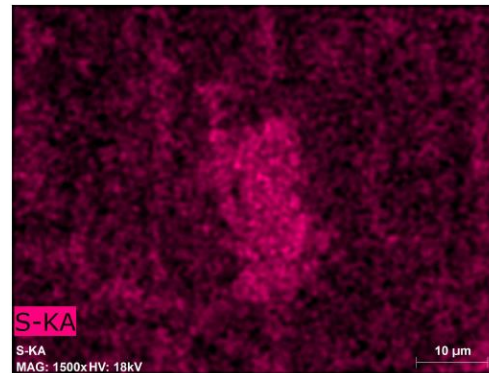
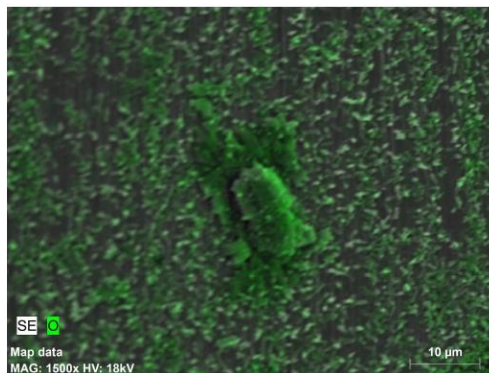
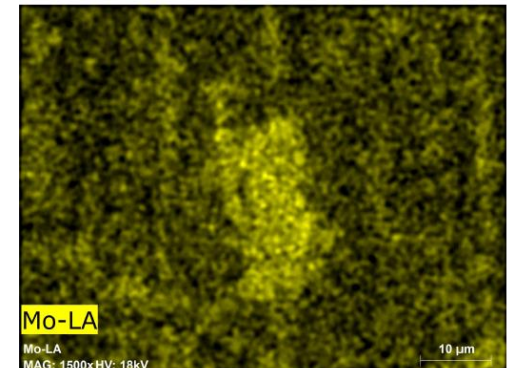
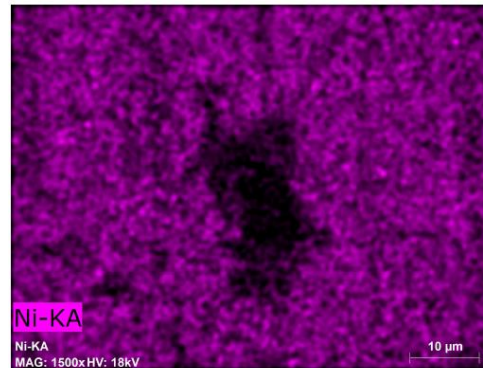


**H<sub>2</sub>SO<sub>4</sub> 40%**



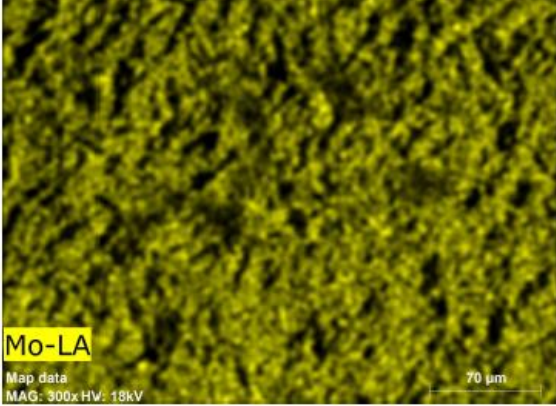
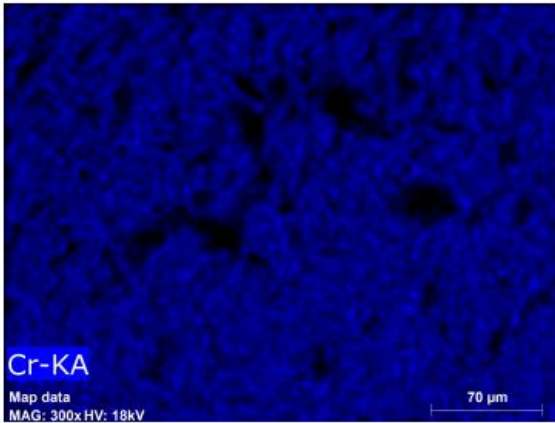
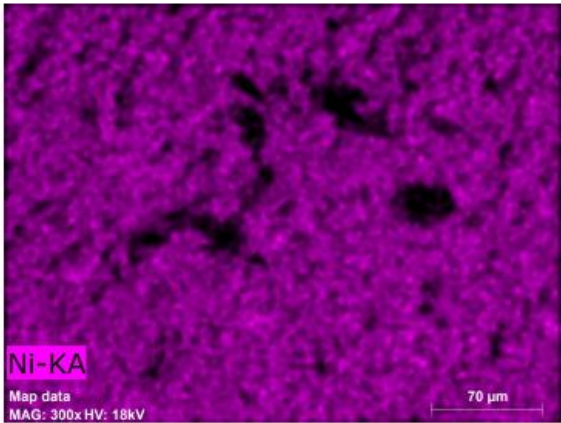
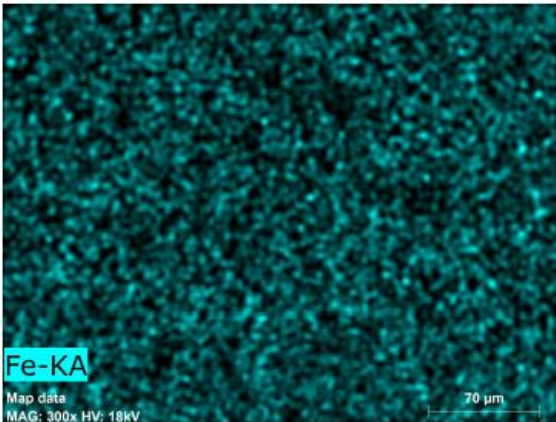
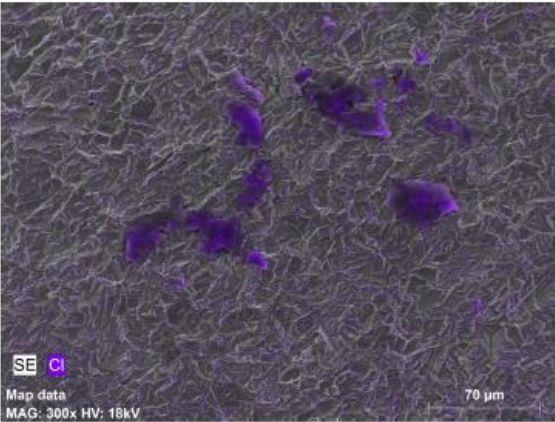
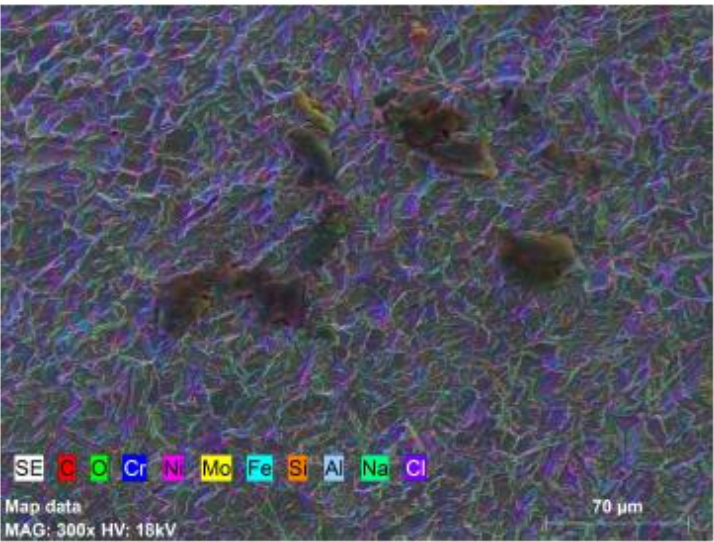
# Development of innovative coatings within I-ThERM

A59 40% H<sub>2</sub>SO<sub>4</sub> 48 h



# Development of innovative coatings within I-ThERM

A59 33% HCl 48 h





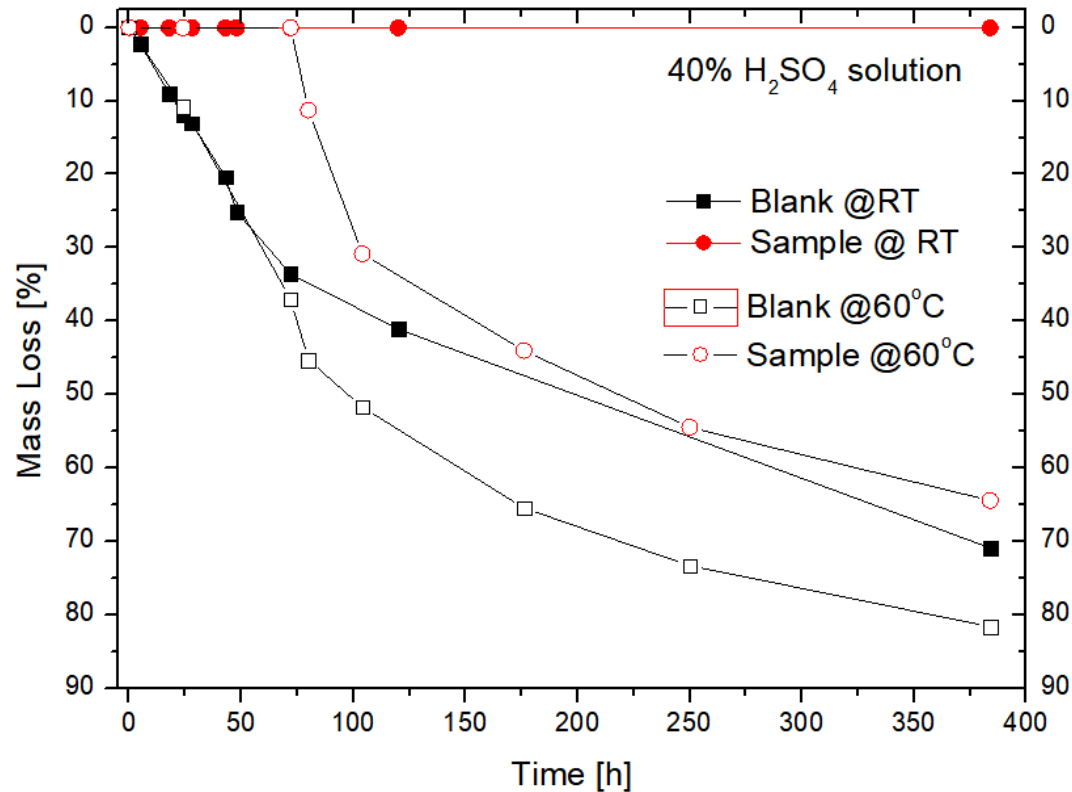
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# Development of innovative coatings within I-ThERM

- ✓ All dry process
- ✓ Easy to implement
- ✓ Hydrophobic coating
- ✓ No problem with adhesion
- ✓ High thermal conductivity
- ✓ Very good protection against  $\text{H}_2\text{SO}_4$

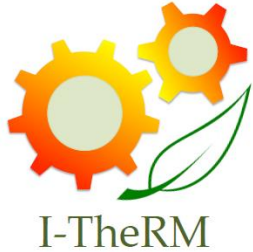


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Fully immersed sample at  $\text{H}_2\text{SO}_4$  @ RT



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\_Thank you

*Thank you for your attention*