# BELENUS

## Lowering Costs by Improving Efficiencies in Biomass Fueled Boilers: New Materials and Coatings to Reduce Corrosion

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# Deliverable: D3.7

## Final results of the erosion tests

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| Dissemination level | | |
|---|---|---|
| PU | Public | X |
| PP | Restricted to other programme participants (including the Commission Services) | |
| RE | Restricted to a group specified by the consortium (including the Commission Services) | |
| CO | Confidential, only for members of the consortium (including the Commission Services) | |

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## Executive Summary

This deliverable, D3.7, shows the final results of the erosion tests performed by INTA. For this test, a total of 11 coatings developed by the consortium partners INTA, Kanthal (formerly SMT) and TEandM and 2 bulk materials developed by Kanthal have been studied.

# Table of Contents

# 1. Introduction

The erosion tests have been carried out in two rounds, the results of first one are shown in Deliverable 3.6 "Intermediate results of the erosion tests" from 2022. The tests were performed on different coatings developed by the three coating developers: INTA, Kanthal and TEandM. A total of 14 coatings and 2 bulk materials were tested: 7 coatings from INTA, 3 coatings and 2 bulk materials from Kanthal and 4 coatings from TEandM. The coatings were deposited on SVM12. The coated samples have already been tested in the first round. For the second round, slurry coatings were excluded because they did not perform well in the first one. Additionally, two samples of uncoated SVM12 were also tested as reference.

Erosion tests were performed at INTA under very aggressive conditions using the equipment shown in the Figure 1. The test conditions of the second round have changed, being slightly less aggressive but for a longer time. The test was carried out under the following conditions:

- Erodent agent: Corundum F220 (Particle size: 53–75 µm)
- Erodent discharge pressure: 2,5 bar
- Test Temperature: Ambient temperature
- Impact angle: 45º
- Distance: 22 cm
- Sample size: 30x20mm (Thickness: 5 mm)
- Sample description: Uncoated and coated SVM12 and 2 bulk newly developed materials.
- Exposure time: 5, 10, 15 and 20 min

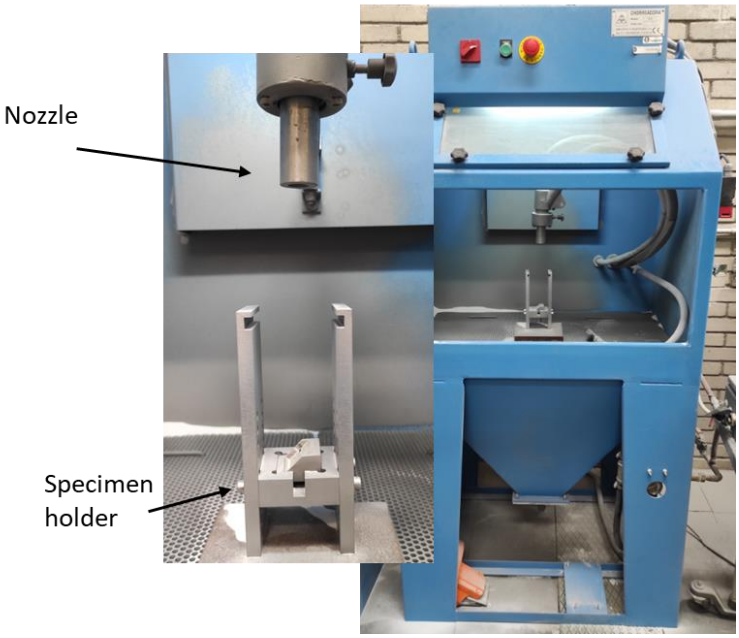



*Figure 1. Erosion equipment*

This deliverable shows the erosion mass loss results after 5 min, 10 min, 15 min and 20 min of exposure as well as the macroscopic images of the specimens after the different exposure times.

# 2. Coatings tested

The coatings selected for the erosion tests are listed below. All coatings were described in Deliverable 2.1 "Microstructural Characterization of as-Deposited coatings" from November 2019 and Deliverable 2.2 "Microstructural Characterization of Best Performing Coatings" from January 2021.

## 2.1. INTA coatings

In Deliverable 3.6 "Intermediate results of the erosion tests" from 2022 it was shown that the slurry coatings did not perform well against erosion under the chosen test conditions, therefore they did not continue in the longer term test. Table 1 shows the coatings selected by INTA for the erosion test.

*Table 1. List of coatings selected by INTA for erosion tests.*

| Coatings selected by INTA | |
|---|---|
| **ihNiCr+Al** | HVOF |
| **ihHHS+Al** | HVOF |
| **ihNiCr+sAl** | Hybrid |
| **ihHHS+sAl** | Hybrid |

Figure 2. Macroscopic images of INTA specimens.

shows a macroscopic image of the different INTA coated specimens before the erosion test.

ihNiCr+Al ihHHS+Al ihNiCr+sAl ihHHS+sAl

*Figure 2. Macroscopic images of INTA specimens.*

## 2.2. Kanthal coatings

Table 2 shows the coatings selected by Kanthal for the erosion test before the erosion test.

*Table 2. List of coatings selected by Kanthal for erosion tests.*

| Coatings selected by Kanthal | |
|---|---|
| **sbFeCrAl1** | Bulk |
| **sbAPMT** | Bulk |
| **swFeCrAl1** | Overlay welded |
| **swAPMT** | Overlay welded |
| **swA625** | Overlay welded |

*Figure 3. Macroscopic images of Kanthal specimens.*

shows images of the Kanthal bulk materials and coated specimens.

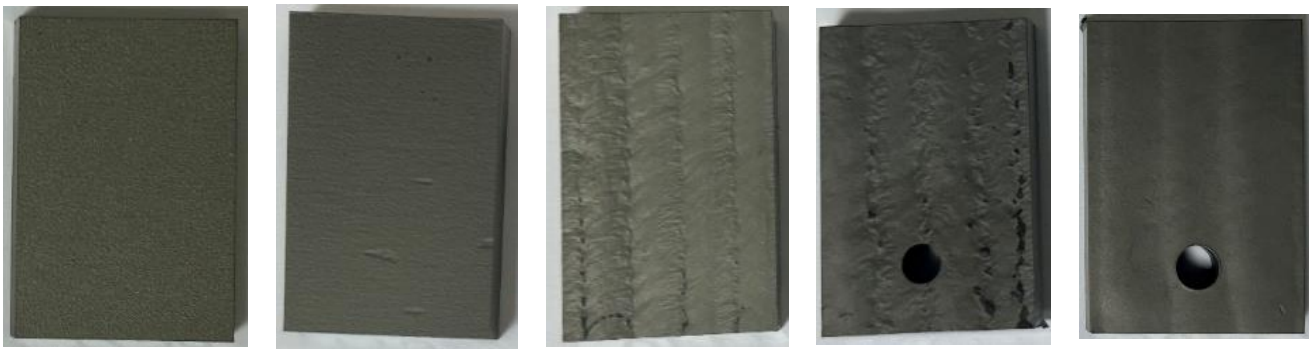



*Figure 3. Macroscopic images of Kanthal specimens.*

## 2.3. TEandM coatings

Table 3 shows the coatings selected by TEandM for the erosion test.

*Table 3. List of coatings selected by TEandM for erosion tests.*

| Coatings selected by TEandM | |
|---|---|
| **thFeCr** | HVOF |
| **thCoMoCr** | HVOF |
| **tlFeCr** | Laser cladding |
| **tlA625** | Laser cladding |

*Figure 4. Macroscopic images of TEandM specimens.*

shows a macroscopic image of the TEandM coated specimens before the erosion test.

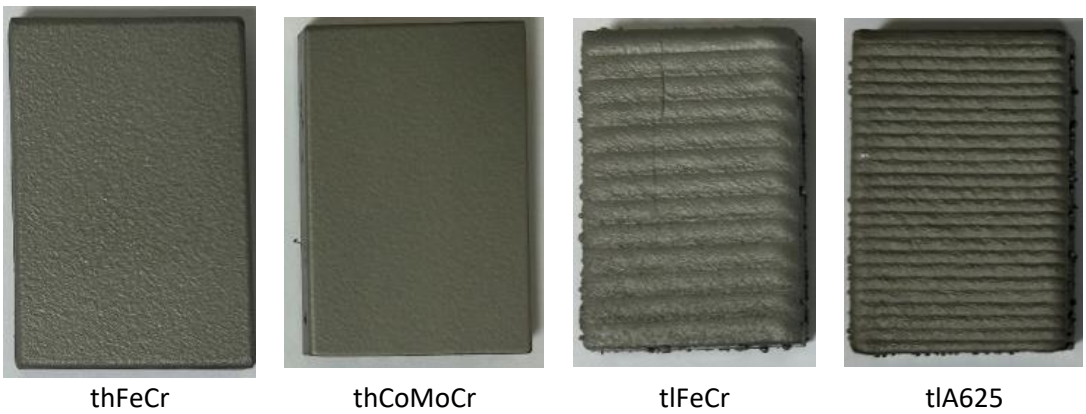



*Figure 4. Macroscopic images of TEandM specimens.*

# 3. Erosion test results

The results obtained for the coatings, bulk materials and reference material after the erosion test at different times are shown below.

## 3.1. Gravimetric Data

Figure 6 and Table 5 gather the erosion mass loss of the samples exposed to the second round of erosion testing for 5, 10, 15 and 20 min.

Most of the coatings have similar behavior, with slight differences in weight loss up to 20 minutes of exposure, in most cases with higher mass loss than the substrate (SVM12). The coatings based on FeCr have the lowest weigh loss, being the best performing coatings. The coating with the highest mass loss is the thCoMoCr as in the first run. In the intermediate results, it was indicated that in the hybrid coatings (ihHHS+isAl and ihNiCr+sAl) the slurry layer was removed and in this test the behavior was the same (ihHHS+Al and ihNiCr+Al). The ihNiCrAl coating performed worse than in first run in which it exhibited better behavior.

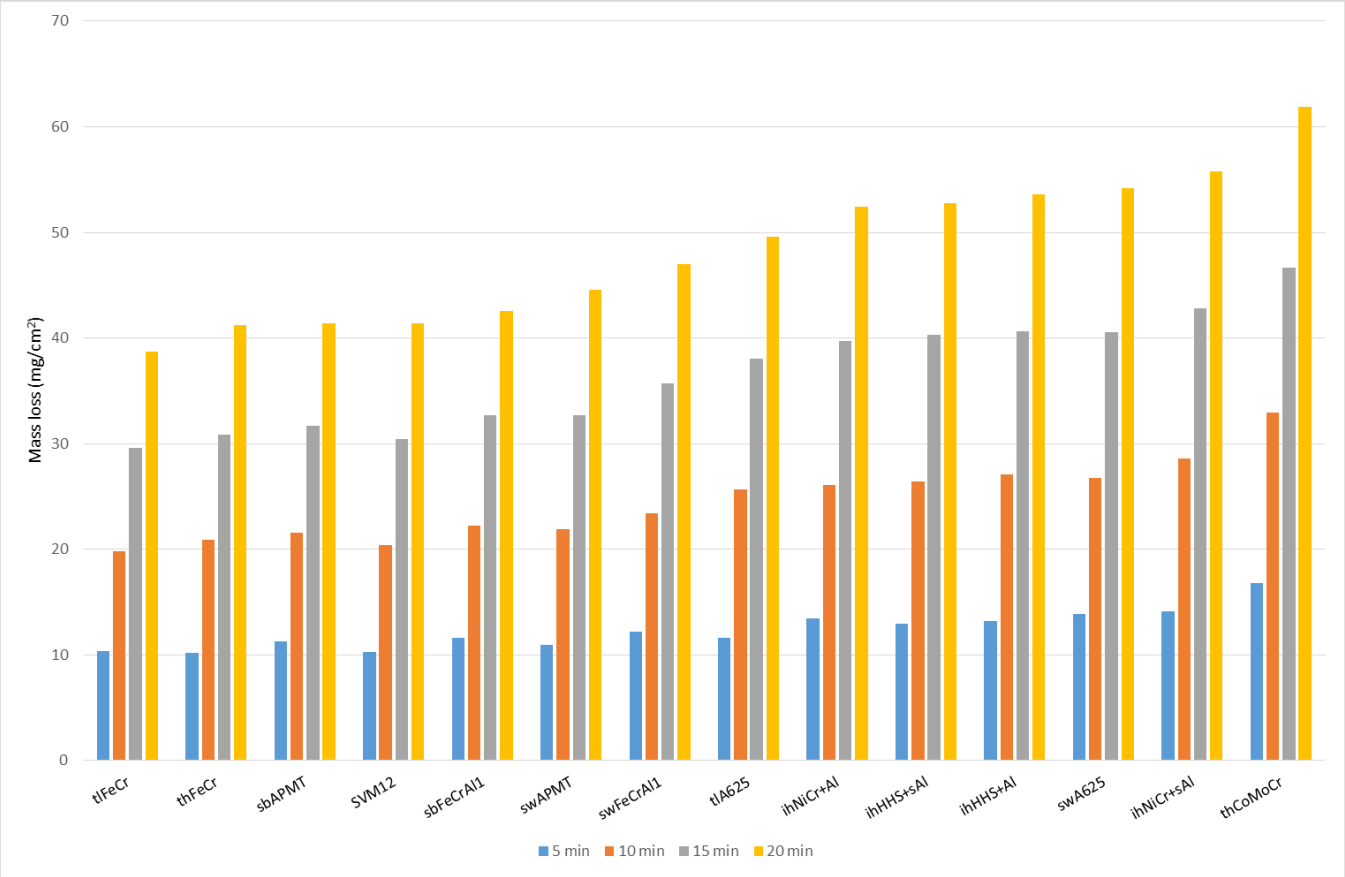



*Figure 5. Specimen mass change after erosion test.*

*Table 4. Specimen mass change after erosion test.*

| | Erosion rate (mg/cm²·min) | | | |
|---|---|---|---|---|
| **Reference** | **5 min** | **10 min** | **15 min** | **20 min** |
| **SVM12** | 2.05 | 2.04 | 2.03 | 2.07 |
| **Coating** | **5 min** | **10 min** | **15 min** | **20 min** |

| | | | | | |
|---|---|---|---|---|---|
| **ihNiCr+Al** | **HVOF** | 2.68 | 2.61 | 2.65 | 2.62 |
| **ihHHS+Al** | **HVOF** | 2.64 | 2.71 | 2.71 | 2.68 |
| **ihNiCr+sAl** | **Hybrid** | 2.26 | 2.16 | 2.11 | 2.07 |
| **ihHHS+sAl** | **Hybrid** | 2.83 | 2.86 | 2.85 | 2.79 |
| **sbFeCrAl1** | **Bulk** | 2.33 | 2.23 | 2.18 | 2.13 |
| **sbAPMT** | **Bulk** | 2.26 | 2.16 | 2.11 | 2.07 |
| **swFeCrAl1** | **Overlay welded** | 2.43 | 2.34 | 2.38 | 2.35 |
| **swAPMT** | **Overlay welded** | 2.19 | 2.19 | 2.18 | 2.23 |
| **swA625** | **Overlay welded** | 2.78 | 2.67 | 2.70 | 2.71 |
| **thFeCr** | **HVOF** | 2.03 | 2.09 | 2.06 | 2.06 |
| **thCoMoCr** | **HVOF** | 3.36 | 3.30 | 3.11 | 3.09 |
| **tlFeCr** | **Laser cladding** | 2.08 | 1.98 | 1.97 | 1.94 |
| **tlA625** | **Laser cladding** | 2.33 | 2.56 | 2.53 | 2.48 |

## 3.2. SVM12

| 0 min | 5 min | 10 min |
|---|---|---|
|  |  |  |

| 15 min | 20 min |
|---|---|
|  |  |

Figure 1 shows samples of SVM12 along the erosion test.

| SVM12 |
|---|

| Macroscopic images | | |
|---|---|---|
| 0 min | 5 min | 10 min |
|  |  |  |
| 15 min | 20 min | |
|  |  | |

*Figure 1. Macroscopic images of SVM12 specimens after erosion test.*

## 3.3. INTA coatings

- <u>HVOF coatings</u>

Figure 2 shows the images of the HVOF coatings after the erosion test.

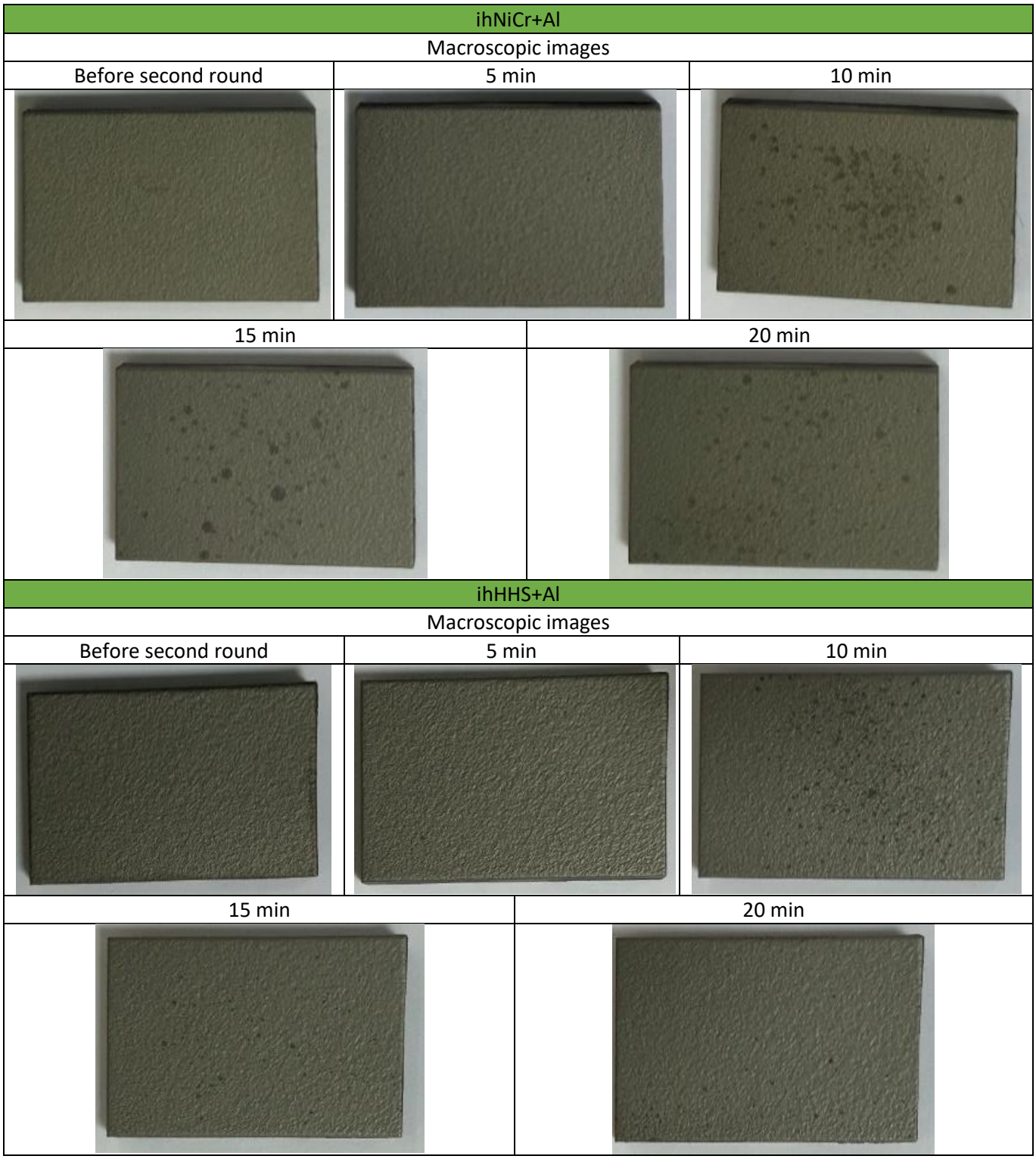



*Figure 2. Images of INTA HVOF coated specimens after erosion test.*

- <u>Hybrid coatings</u>

Figure 3 shows the images of the hybrid coatings after the erosion test. In the first round, in the ihHHS+sAl coating, the slurry coating deposited on the HVOF coating has disappeared, remaining only the HVOF coating. Cracks appear on the ihHHS+sAl coating and a part of the coatings detaches as the test time increases. This cracks are localizated in the upper zone.

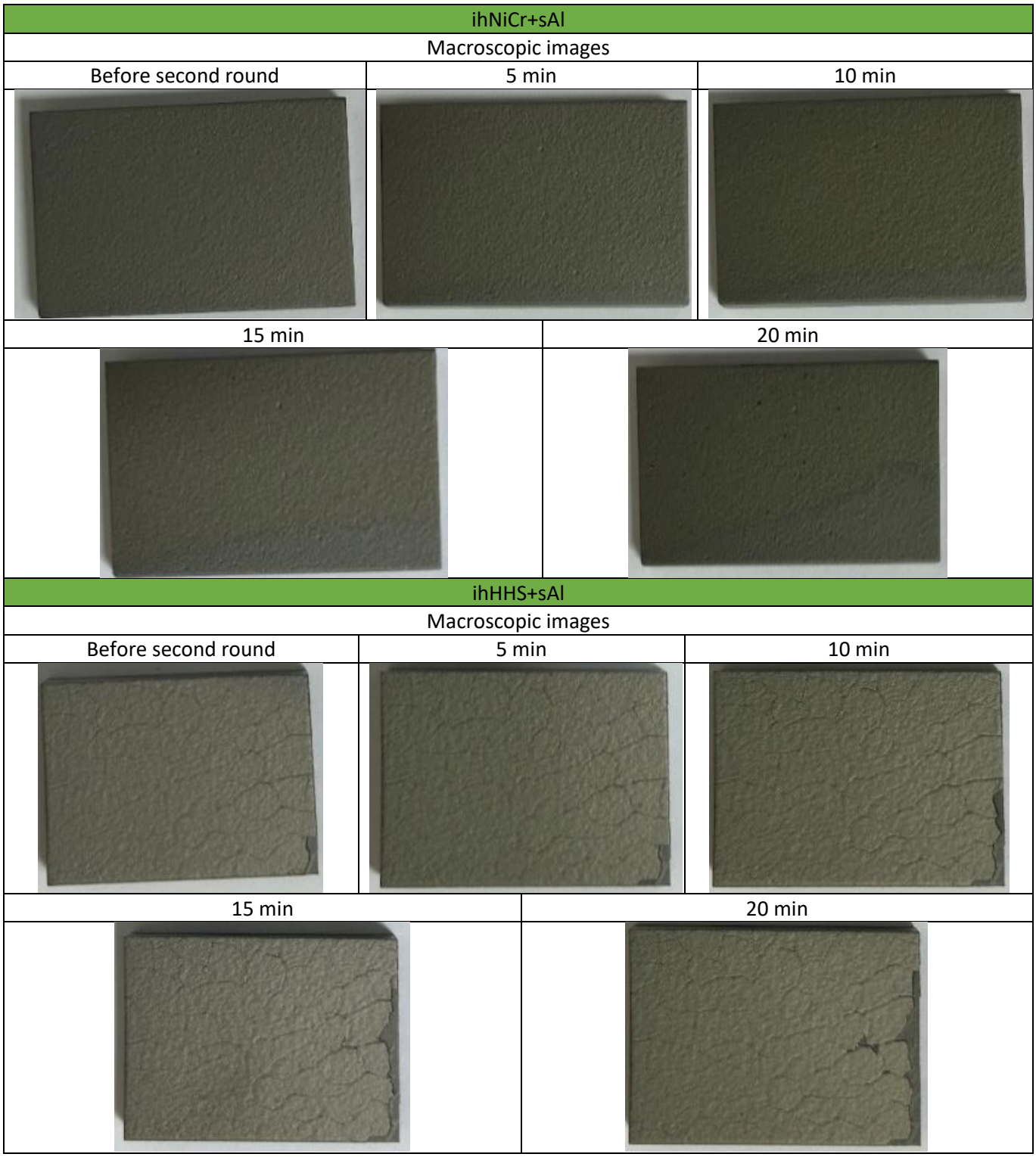
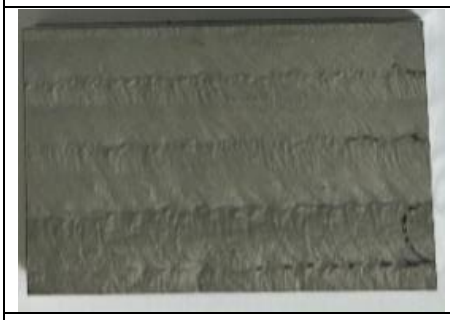
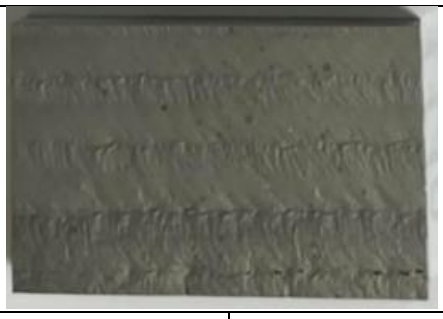


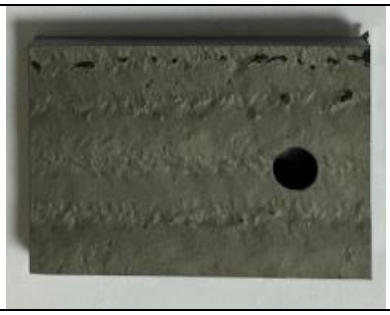
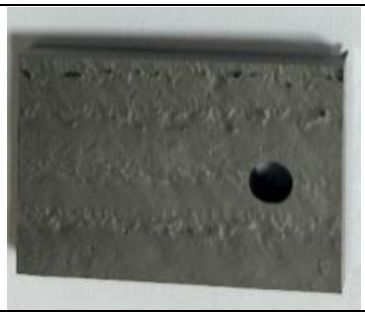

*Figure 3. Images of INTA hybrid coated specimens after erosion test.*

## 3.4. Kanthal coatings

- Overlay welding

Figure 4 shows the images of the overlay welding coatings after erosion test.

| swFeCrAl1 | | |
|---|---|---|
| Macroscopic images | | |
| Before second round | 5 min | 10 min |
|  |  |  |
| 15 min | 20 min | |
|  |  | |

| swAPMT | | |
|---|---|---|
| Macroscopic images | | |
| Before second round | 5 min | 10 min |
|  |  |  |
| 15 min | 20 min | |
|  |  | |

| swA625 | | |
|---|---|---|
| Macroscopic images | | |
| Before second round | 5 min | 10 min |
|  |  |  |
| 15 min | 20 min | |
|  |  | |

*Figure 4. Images of Kanthal overlay welding coated specimens after erosion test.*

- <u>Bulk materials</u>

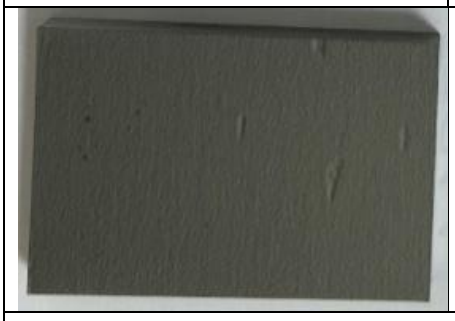
| Before second round | 5 min | 10 min |
|---|---|---|
|  |  |  |
| 15 min | 20 min | |
|  |  | |

Figure 5 shows the images of the bulk materials after 5, 10, 15 and 20 min of erosion exposure.

| sbFeCrAl1 |
|---|

| Macroscopic images | | |
|---|---|---|
| Before second round | 5 min | 10 min |
|  |  |  |
| 15 min | 20 min | |
|  |  | |

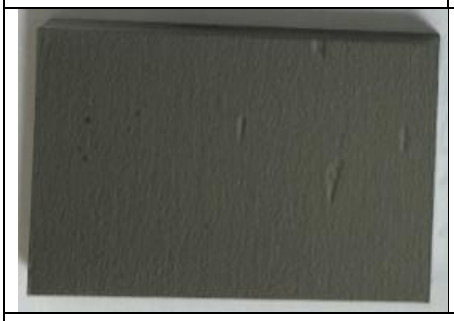
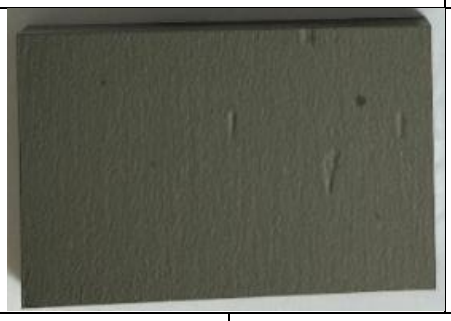
| sbAPMT | | |
|---|---|---|
| Macroscopic images | | |
| Before second round | 5 min | 10 min |
|  |  |  |
| 15 min | 20 min | |
|  |  | |

*Figure 5. Images of Kanthal bulk material specimens after erosion test.*

## 3.5. TEandM coatings

- <u>HVOF coatings</u>

Figure 4 shows the images of the HVOF coatings after erosion test.

| thFeCr |
|---|

| Macroscopic images | | |
|---|---|---|
| Before second round | 5 min | 10 min |
|  |  |  |
| 15 min | 20 min | |
|  |  | |

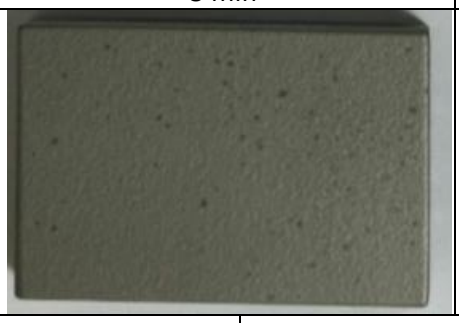
| thCoMoCr | | |
|---|---|---|
| Macroscopic images | | |
| Before second round | 5 min | 10 min |
|  |  |  |
| 15 min | 20 min | |
|  |  | |

*Figure 6. Images of TEandM HVOF coated specimens after erosion test.*

- <u>Laser cladding</u>

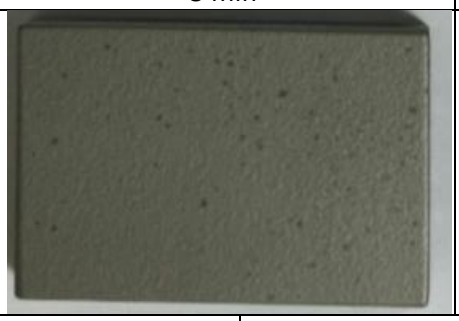
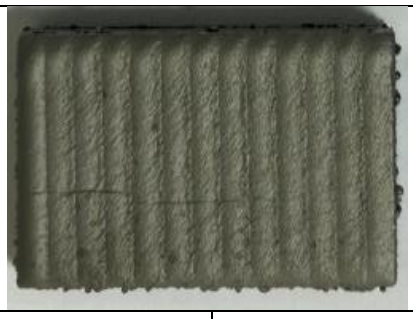
| Before second round | 5 min | 10 min |
|---|---|---|
|  |  |  |
| 15 min | 20 min | |
|  |  | |

Figure 6 shows the images of the laser cladding coatings after the erosion test.

| tlFeCr | | |
|---|---|---|
| Macroscopic images | | |
| Before second round | 5 min | 10 min |
|  |  |  |
| 15 min | 20 min | |
|  |  | |

| tlA625 |
|---|

| Macroscopic images | | |
|---|---|---|
| Before second round | 5 min | 10 min |
|  |  |  |
| 15 min | 20 min | |
|  |  | |

*Figure 7. Images of TEandM laser cladding coated specimens after erosion test.*

## 4. Conclusions

Most of the coatings selected for the final test perform similary in the erosion test up to 20 minutes of exposure and do not significantly improve the erosion resitance of uncoated SVM12. However it most be taken into consideration that the behavior of the oxidized SVM 12 is much worse as demonstrated in Deriverable 3.6. In most cases, no significant changes in the surface of the coatings have been observed. The hybrid coatings that contain a top slurry aluminized layer have the same behavior than HVOF coatings because this slurry layer has removed on the first round test test.

According to the gravimetric results, the best performing coatings were the FeCr based coatings (thFeCr and tlFeCr) and the bulk APMT.

# 5. Degree of Progress

The deliverable D3.7 is completed.

# 6. Dissemination Level

The dissemination level of the deliverable D3.7 is Public.