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MADE-3D

Multi-Material Design using 3D Printing

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= Deliverable D3.1 =

Baseline Powder

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VALIDATION

Reviewers	Name	Validation date
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Executive Summary

Description of the baseline powders procured and delivered in compliance with the requirements set in Task 3.1 of Work Package 3 of the MADE-3D project. Basic information and relevant properties of the metal powders are included in the present report.

1. Introduction

The Deliverable 3.1: Baseline powder collects and reports the relevant information on metal powders required for the printing activities enlisted in Task 3.1 of Work Package 3 (WP3) of MADE-3D project. Based on the specific technological needs of the project partners leading the 3D printing activities, tailor-made powder batches were provided.

An overview of the different reference materials and quantities was extracted from the Description of Action (DoA) Part A and reported in Table 1.

***Table 1**: List of baseline materials and quantities required for first print runs conducted in Task 3.1.*

Material	Quantity [kg]	3D printing technology / Owner of Use Case
Ti64	80	DED / Skyrora
Inconel 718	130	DED / Skyrora
FeSi-2.9	100	PBF-LB / Safran
316L	100	PBF-LB / Safran
AlSi10Mg	50	PBF-LB / AVL
CuCrZr	100	PBF-LB / AVL

2. Relevant information and characteristics of baseline powder

The metal alloys identified as base materials for the multi-material 3D printing within the MADE-3D project were the following:

- titanium alloy Ti-6Al-4V (Ti64),
- nickel alloy Inconel 718,
- low-silicon iron alloy FeSi2.9,
- stainless steel 316L,
- aluminum alloy AlSi10Mg,
- copper alloy CuCrZr.

It is worth to underline that commercial powders of the alloys listed above were procured from external providers. The supply of benchmark materials was deemed to accelerate the experimental campaigns planned for the first part of the project, namely the optimization of process parameters for the two additive manufacturing technologies exploited for the production of demonstrators, and separation of used powders.

Titanium and nickel-based alloys were selected for the printing tests related to the Use Case owned by Skyrora, for aerospace applications. Skyrora procured the metal powders of the two alloys internally, based on the acceptance criteria of their multi-material directed energy deposition (DED) machine. Regarding the iron-based alloys, the soft magnetic material FeSi2.9 and non-magnetic stainless steel were procured by University of Paderborn (UPB). A first batch of around 70kg for each of the two materials was dedicated to first build jobs and separation tests of the used powders, whereas the remaining powders will be procured in a second phase to complete the feedstock for the Use Case owned by Safran for automotive applications.

Aluminum and copper-based alloys, on the other hand, were selected as benchmark materials for the Use Cases owned by AVL for automotive applications and procured from an external source by f3nice. These powders needed to be sieved by f3nice and IGCV in order to obtain the most suitable particle size distribution (PSD) for multi-material powder bed fusion (PBF) process and subsequent separation of the aluminum and copper-based used powders. A full-size batch of 100kg of copper alloy powders was delivered to IGCV for sieving. A smaller batch of 10kg of the aluminum alloy powders was initially sieved by f3nice and delivered to IGCV, for first printing and separation tests, whereas additional 50kg were procured by f3nice and stored to be sieved at a later stage, based on the output of the first tests conducted by IGCV.

For a better understanding of the additional steps which followed the procurement of the powders, it is worth mentioning that multi-material additive manufacturing introduces additional specifications for the powder feedstock. Besides the chemical composition, which will be investigated and tuned as a result of the R&D activities within the MADE-3D project, the PSD of the powders had to be taken into account. With a view to separating different materials at the end of the printing to be reused for increased sustainability of the manufacturing process, it was necessary to deviate from commercial powder specifications. This was particularly important for the PBF process with aluminum and copper-based materials, which required non-overlapping of PSD for the metal particles, which were not achieved by conventional powder providers.

2.1. Titanium and nickel-based alloys

The powders procured by Skyrora were analyzed by Centre Suisse D'electronique et de Microtechnique (CSEM), to assess their quality before testing in the DED machine. Representative images of the powders of Ti64 and Inconel 718 were obtained by means of Scanning Electron Microscopy (SEM) and are reported in Figure 1 and Figure 2.

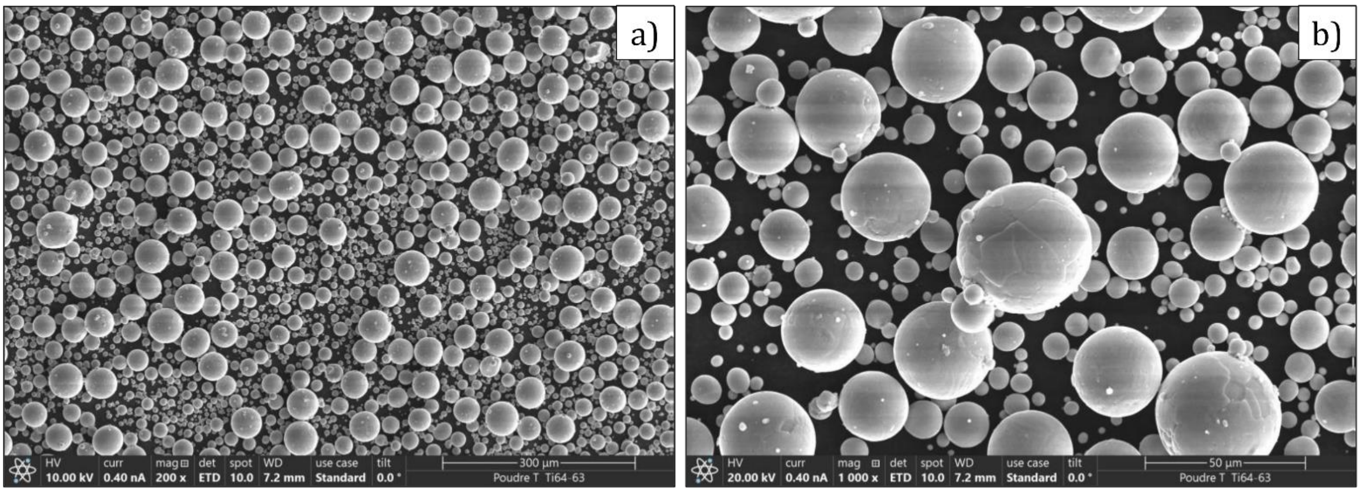

Figure 1: *SEM top view images of Ti64 powders at a) lower and b) higher magnification.*

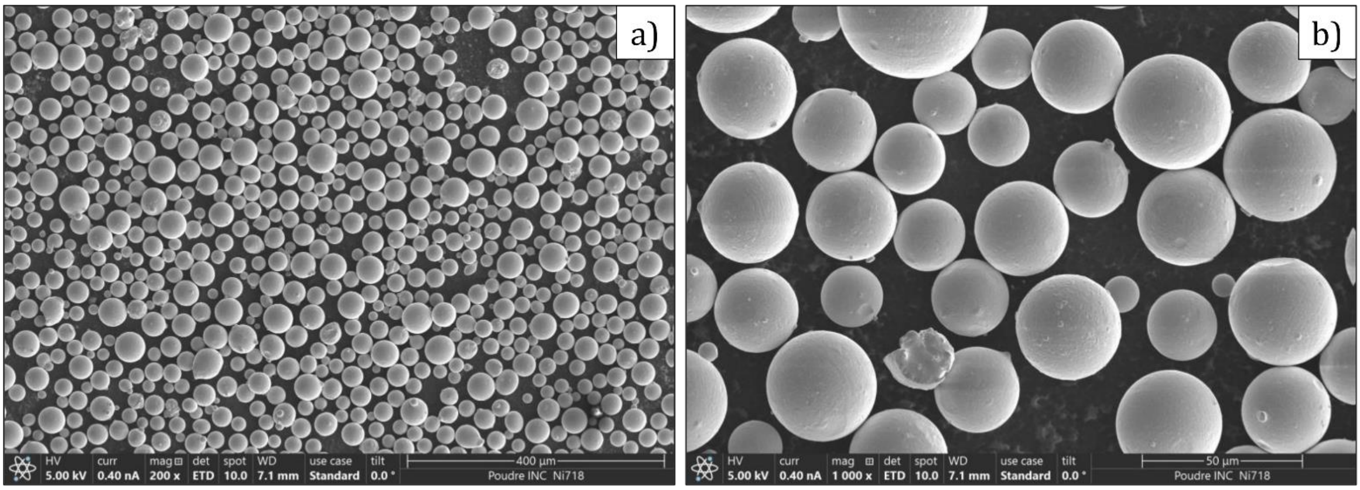

Figure 2: *SEM top view images of Inconel 718 powders at a) lower and b) higher magnification.*

2.2. Iron-based alloys

The PSD of FeSi2.9 and 316L powders procured by UPB was analysed by UPB by means of laser diffraction, to confirm the compatibility of the iron alloys with the requirements of the PBF machine. Representative indicators of the measured PSD, namely the 10th, 50th and 90th percentiles of the size distributions, are reported in Table 2. Since the envisaged separation strategy of these iron-based alloys would be independent form PSD, the conventional size distributions of commercial powders were acceptable for the printing and separation tests.

Table 2*: relevant percentiles for the PSD of FeSi2.9 and 316L powders assessed by means of laser diffraction.*

Material	D_{10} [µm]	D_{50} [µm]	D_{90} [µm]
FeSi-2.9	24,1	37,4	58,2
316L	19,5	30,2	46,5

Additionally, the allocation of powders for initial tests pertaining to separation of the two alloys from the used powders after the PBF printing process and first build jobs are reported in Table 3.

Table 3*: List of quantities of FeSi2.9 and 316L powders used for the first experimental campaigns of the optimization of PBF and separation processes.*

Material	Quantity [kg]	Purpose of use
FeSi-2.9	9	Initial tests
FeSi-2.9	45	Powder separation tests
316L	45	Powder separation tests
FeSi-2.9	25	First PBF build jobs
316L	25	First PBF build jobs

2.1. Aluminum and copper-based alloys

As already specified at the beginning of Section 2, the specifications for multi-material PBF process on aluminum and copper-based alloys prompted the need to rework the powders by means of additional sieving procedures. Hence, to share the effort of the procedures IGCV took care of the CuCrZr powders, whereas f3nice managed the AlSi10Mg ones. The D_{10}, D_{50} and D_{90} values for the PSD of the two metal alloys in the as-received conditions are reported in Table 4, as per certificates of acceptance by powder provider.

***Table 4**: relevant percentiles for the PSD of AlSi10Mg and CuCrZr powders assessed by means of laser diffraction by the provider of the powders.*

Material	D_{10} [µm]	D_{50} [µm]	D_{90} [µm]
AlSi10Mg	49,3	61,5	72,1
CuCrZr	15,7	30,5	45,3

Aluminum and copper-based powders are deemed to be recycled through a separation strategy based on size distributions. To this end, it was fundamental to widen the gap between the D_{10} value of the first alloy powders and the D_{90} of the second. Specifically, the target value for D_{10} of AlSi10Mg was fixed at 56 µm, whereas the D_{90} of CuCrZr was set at 45µm. Consequently, the AlSi10Mg powders were sieved with an ultrasonic sieving equipment and metal meshes with nominal opening size of 53 µm and 56 µm, whereas the CuCrZr powders were sieved with a similar equipment and metal meshes with nominal opening size of 36 µm. Lastly, the modified PSD were measured by IGCV by means of laser diffraction and the resulting percentile values are listed in Table 5. Representative images of the powders of CuCrZr and AlSi10Mg were obtained by means of SEM and are reported in Figure 3 and Figure 4.

***Table 5**: relevant percentiles for the PSD of AlSi10Mg and CuCrZr powders assessed by means of laser diffraction after sieving operations.*

Material	D_{10} [µm]	D_{50} [µm]	D_{90} [µm]
AlSi10Mg	53	68,0	86,9
CuCrZr	11,4	19,4	32,3

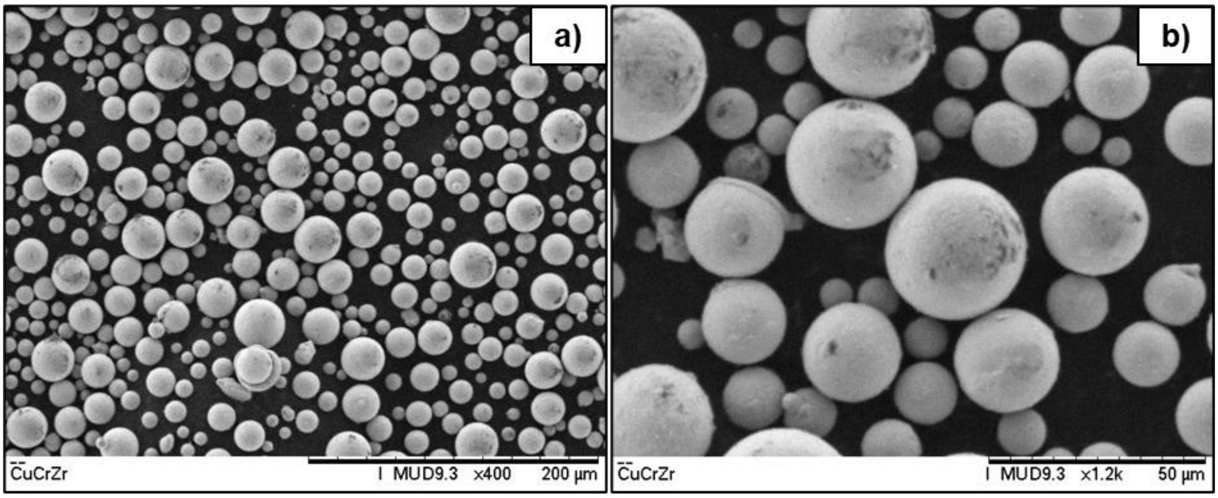

***Figure 3:** SEM top view images of CuCrZr powders at a) lower and b) higher magnification.*

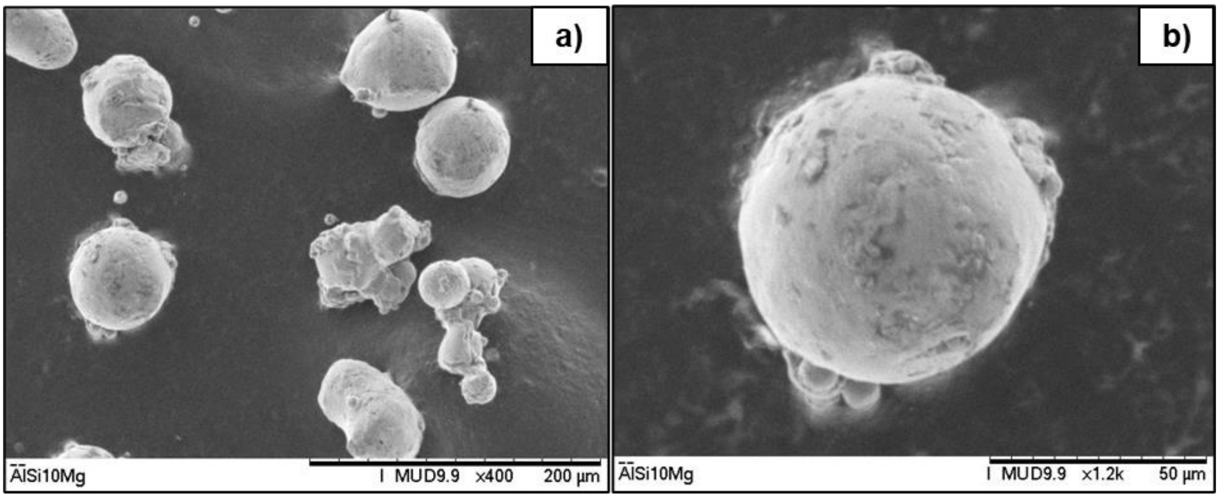

Figure 4: *SEM top view images of AlSi10Mg powders at a) lower and b) higher magnification.*

3. Conclusions and Outlook

Baseline powders were provided as benchmark materials to run the first phases of optimization concerning both the multi-material additive manufacturing processes and the recycling of mixed powders collected after the 3D printing activities. The use of off-the shelf products proved to be overall fruitful, although it resulted in additional effort for the aluminum-copper alloys combination, since the request for out-of-standard size distributions was either rejected by external providers or unnecessarily expensive. Consequently, the evaluation of results of additional sieving procedures deployed to match the requirements of the PBF process constitutes an ongoing activity which will be carried out in the first months of the second year of MADE-3D project.

4. Dissemination Level

This deliverable is public.