
# Final European Metal AM MSc Guideline

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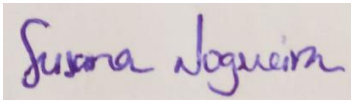
| Susana Nogueira<br>EWF |  | 23/09/20 |
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# Foreword

The Final Metal AM MSc Curriculum is an innovative Curriculum developed by ADMIRE Partners that can be adapted at any European University with a Metal Additive Manufacturing program.

The advantages of this Curriculum for all project stakeholders are highlighted in D5.6 under the chapter: Final European Metal AM MSc Curriculum.

In this document the brand-new Curriculum developed by ADMIRE Partners is illustrated in detail.

This document shall be used to assist European Universities in the development of their own Curriculum totally aligned with the Final Metal AM MSc Curriculum, accordingly to the rules and procedures kept for the ADMIRE Network of Universities under the supervision of the International AM Qualification System.

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# 1 Introduction

The Final Metal AM MSc Curriculum was developed with the objective to comply with several inputs and adversities found by ADMIRE project stakeholders (students, universities, industry, standardization bodies).

For a full overview of the advantages and to understand what brought ADMIRE Partners to develop this final Curriculum please check D5.6.

This document is divided into 2 sections. The first section is related to the Final updated Metal AM MSc Curriculum, directed to the professional profiles of the Metal AM Coordinator and the Metal AM Engineer. The second section is related to an example of the practical application of this Curriculum in one of the ADMIRE Partners' Universities (Cranfield University).

Attached in the annexes of this document there is also a detailed analysis on the comparison between the Final Curriculum and the one implemented in Cranfield University, ensuring in this way an alignment between the project developed Curriculums.

# 2 Section I - Final Metal AM MSc Curriculum

In this chapter the 4 different Guidelines that englobe the Final Metal AM MSc Curriculum are illustrated. The Curriculum is directed to 4 distinct professional profiles, namely:

- Metal AM Coordinator (EQF Lvl 6)
- Metal AM Process Engineer PBF-LB (EQF Lvl 7)
- Metal AM Process Engineer DED-Arc (EQF Lvl 7)
- Metal AM Process Engineer DED-LB (EQF Lvl 7)

Hereinafter each one of the sub-chapter highlight the Educational Guidelines for the Curriculum of each one of the afore mentioned professional profiles.

## Metal AM Coordinator

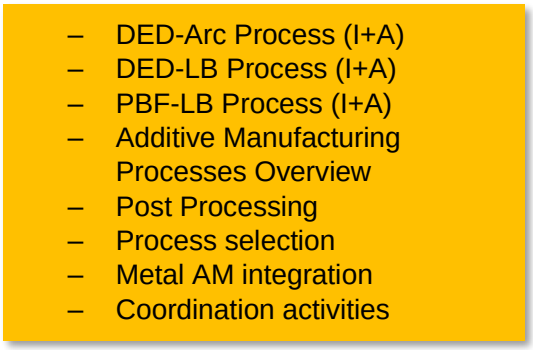


*Figure 1 Metal AM Coordinator Competence Units*

## ENGINEERS

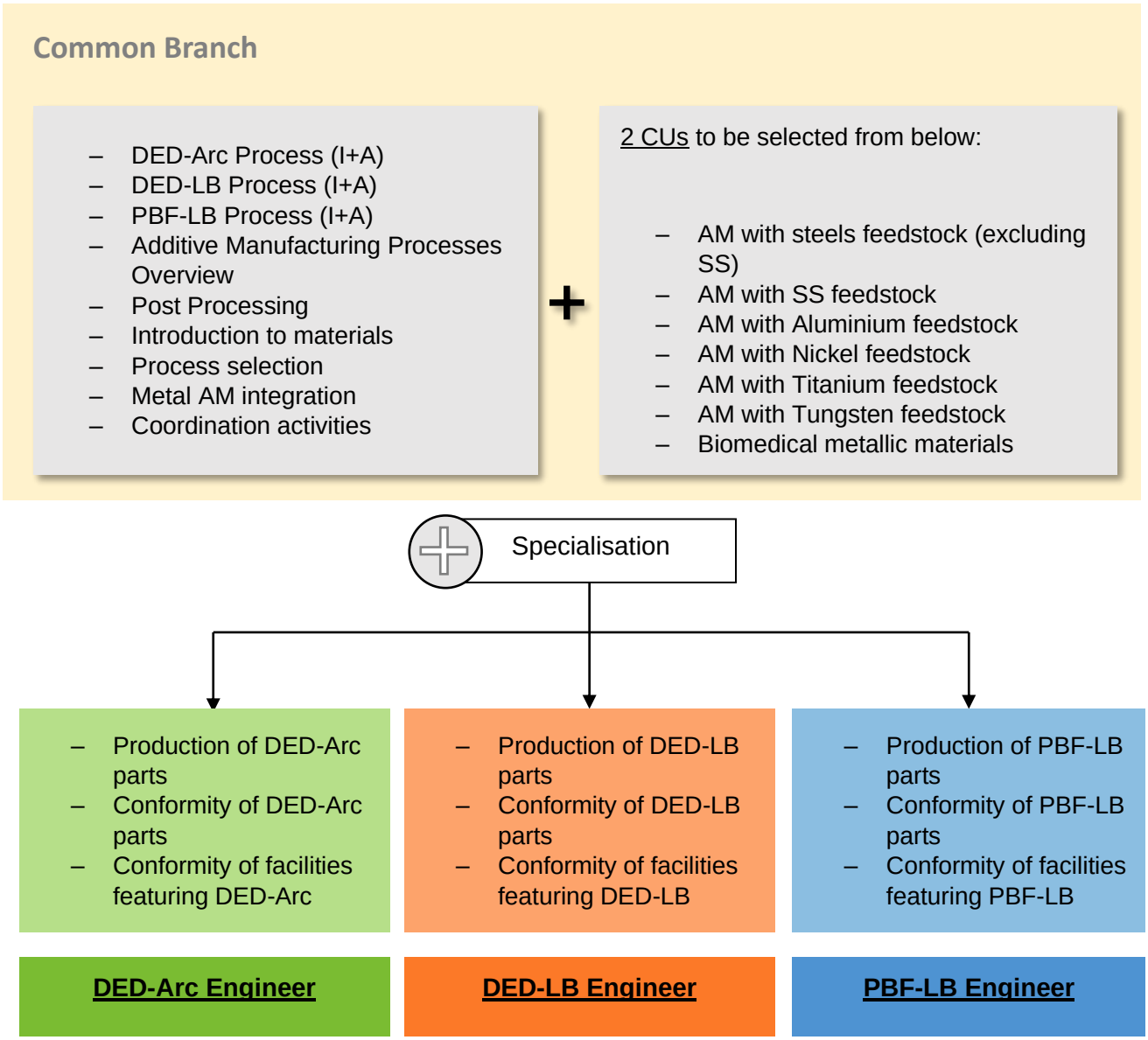


*Figure 2 Metal AM Engineer Competence Units*

# 3 Metal AM Coordinator

## 3.1 Preface

The present document consists in European/International Metal AM Coordinator Guideline, developed in ADMIRE project.

This guideline for the European education, training, examination and qualification of additive manufacturing personnel has been prepared, evaluated and formulated by the International Additive Manufacturing Qualification Council (IAMQC). Contains general information for the public and organizations that implement this qualification.

Copies of this document can be downloaded from ADMIRE website: www.admire.eu or requested to the IAMQS Authorized Nominated Bodies for Metal Additive Manufacturing (AM ANBs) or EWF Management Team.

## 3.2 Metal AM Coordinator Introduction

This guideline covers the minimum requirements for education and training, which have been agreed upon by all the International AM Qualification System members, in terms of Learning Outcomes (Knowledge and Skills) and the recommended contact (teaching) hours to be devoted to achieving them. It will be revised periodically by the International AM Qualification Council (IAMQC) to take into account changes to reflect the "state of the art".

Students successfully completing examinations will be expected to be capable of applying the achieved learning outcomes at a level consistent with the qualification diploma level.

The modular course contents are given in the following structure (overview):

| **COMPETENCE UNITS** | **E/I MAMC** | |
|---|---|---|
| | **Recommended Contact Hours*** | **Expected Workload**** |
| CU 00: Additive manufacturing Process Overview | 7 | 14 |
| CU 01: DED-Arc Process | 42 | 84 |
| CU 08: DED-LB Process | 35 | 70 |
| CU 15: PBF-LB Process | 35 | 70 |
| CU 25: Post Processing | 14 | 28 |
| CU 34: Process Selection | 28 | 56 |
| CU 35: Metal AM Integration | 21 | 42 |
| CU 36: Coordination Activities | 7 | 14 |
| **TOTAL** | **189** | **378** |

* Contact Hours are the minimum recommended teaching hours for the Standard Routes. A contact hour shall contain at least 50 minutes of direct teaching time.

** Workload is calculated in hours, corresponds to an estimation of the time students typically need to complete all learning activities required to achieve the defined learning outcomes in formal learning environments plus the necessary time for individual study.

Within the International AM Qualification System´s qualifications, there are two types of Competence Units:

- Cross-cutting Competence Unit - A competence unit whose learning outcomes are not directly linked with one job function since the knowledge and skills achieved will be mobilized in several job functions and activities.
- Functional Competence Unit - A competence unit whose learning outcomes are directly linked with at least one job function and in which the knowledge and skills achieved will be mobilized in specific job functions and related activities.

The expected learning outcomes are described in two ways: generic outcome descriptors organized in knowledge, skills, autonomy and responsibility; and in detail for each competence unit, organized in job functions and related activities, knowledge and skills corresponding to a specific proficiency level within International AM Qualification System´s Framework levels (see Appendix I).

On each Competence Unit, objectives and scope are defined for a specific depth of knowledge and skills.

Recommended contact hours are distributed between theoretical (A), assigned projects/exercises (B), practical work-shop training(C), as showed in the following example:

## 3.3 Professional Profile

Metal AM Coordinators are the professionals with the specific knowledge, skills, autonomy and responsibility to assess the technical adequacy of AM processes to part requirements. His/her's main tasks are to:

| ***Qualification: Example 1*** | |
|---|---|
| **CONTACT HOURS** | **X= (SUM A:C)** |
| **Subject Contents** | A + B + C |

- Evaluate manufacturing suitability for customers' requests defining which processes are fit for the request, based on the application, material, design and cost of the part.
- Coordinate the work with the AM Team

## 3.4 Routes to Qualification

Two distinct routes to gaining the qualifications described in this document have been agreed.

1. The Standard Route
2. Blended Learning Route

### 3.4.1 The Standard Route

The Standard Route requires successful completion of IAMQS approved courses which are designed to meet all the requirements in this Guideline. This is the route recommended by IAMQS as offering the fastest, most comprehensive manner in which the detailed knowledge may be covered.

### 3.4.2 Blended Learning Route

The Cross-Cutting Competence Units (theoretical knowledge and skills) may be taught using Distance Learning Programs under the control of the AM ANB and all the Functional Competence Units (practical knowledge and skills) must be taught at the Authorized Training Bodies for Metal Additive Manufacturing (AM ATB) facilities.

## 3.5 General Access Conditions

The defined access conditions approved by IAMQS Technical Working Groups Area of competence "Implementation and Authorisation" of the IAMQS are given in detail for all countries participating in the IAMQS system.

The access conditions to Metal AM Coordinators admission are the following:

- Engineering degree in Mechanical, Materials, Aeronautic or similar.

## 3.6 Special Requirements

### 3.6.1 Standard Route

Applicants shall satisfy the access conditions, to be accepted for the attendance of a training course conducted by an IAMQS Member Organization.

There will be written, oral and practical examinations (where applicable) for the award of the applicable International AM Diploma.

It is not obligatory to follow exactly the order of the Competence Units given in this guideline and choice in the arrangement of the detailed knowledge is permitted, with the exception that **the first Competence Unit to be provided must be CU 00: Additive manufacturing Process Overview.**

Complementary to the Competence Units that are required for the purpose of the European/International Metal Additive Manufacturing Engineering Expert Diploma issuing, a set of optional Competence Units that can also be of added value for the student and can be implemented by the AM ATB as a supporting training and education offer.

For these optional Competence Units, separate Records of Achievement will be issued after examination approval. Whenever these optional Competence Units are considered mandatory for a certain IAMQS Qualification, they can be recognized for the purpose of such Qualification Diploma.

The examination of any Competence Unit for the purpose of being validated individually, not included in a Qualification course, shall be completed within a period of 1 year from the starting day of the Competence Unit.

If the Competence Unit “A” is done as a part of a qualification course, the examination shall be completed within a period of 4 years from the date of the completion of the first Competence Unit from the qualification where Competence Unit “A” is integrated in. Failure in the examination shall require re-examination.

## 3.7 Qualification Outcome Descriptors

| QUALIFICATION | IAMQS LEVEL | KNOWLEDGE | SKILLS | AUTONOMY AND RESPONSIBILITY |
|---|---|---|---|---|
| **E/I MAMC** | **ADVANCED** | Advanced knowledge and critical understanding of the theory, principles and applicability of metal additive manufacturing processes. | Advanced problem-solving skills including critical evaluation, allowing to choose the proper technical and economical solutions, when applying metal additive manufacturing processes, in complex and unpredictable conditions | Manage the selection of metal additive manufacturing processes in a highly complex context.<br>Act autonomously in decision making and of the metal additive manufacturing personnel's tasks |

## 3.8 Mandatory Competence Units Learning Outcomes

### 3.8.1 Competence Unit 00: Additive Manufacturing Processes Overview

| **CU00: Additive Manufacturing Processes Overview**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Directed energy deposition | 1 |
| Powder bed fusion | 1 |
| Vat photopolymerization | 1 |
| Material jetting | 1 |
| Binder jetting | 1 |
| Material extrusion | 1 |
| Sheet lamination | 1 |
| **Total** | 7 |
| **WORKLOAD** | **14** |

| **Learning Outcomes – CU00: Additive Manufacturing Processes Pverview** | |
|---|---|
| **KNOWLEDGE** | Factual and broad knowledge of theory, principles and applicability of:<br>– Directed energy deposition<br>– Powder bed fusion<br>– Vat photopolymerization<br>– Material jetting<br>– Binder jetting<br>– Material extrusion<br>– Sheet lamination |
| **SKILLS** | Distinguish parts produced by different AM processes<br>Recognise the advantages and limitations of AM processes from a manufacturing process chain point of view<br>Identify the applicability of different AM processes, according to the characteristics of each process |

### 3.8.2 Competence Unit 01: DED Arc Process

| CU 01 DED-Arc Process | RECOMENDED CONTACT HOURS | |
|---|---|---|
| LEVEL | INDEPENDENT (I) (applied to Operators and Engineers) | ADVANCED (A) (applied only for Enginners) |
| DED-Arc System (Hardware & Software) | 5 | 0 |
| DED-Arc Physical Principles, Processes and Parameters | 5 | 0 |
| DED-Arc Build platform, feedstock and other consumables | 3 | 0 |
| Post processing operations | 1 | 0 |
| DED-Arc Processes | 0 | 14 |
| DED-Arc Build platform, feedstock and other consumables | 0 | 5 |
| DED-Arc Equipment and accessories | 0 | 3 |
| DED-Arc Manufacturing strategy | 0 | 6 |
| **Subtotal Per Level** | **14** | **28** |
| **Cumulated Subtotal** | **14** | **42** |
| | | **WORKLOAD** |
| **PER LEVEL** | 14 | 42 |
| **CUMULATED** | **28** | **84** |

| LEARNING OUTCOMES – CU 01: DED-Arc Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only for Enginners)** |
| **KNOWLEDGE** | Factual and broad of:<br>– DED-Arc systems<br>– Arc physics<br>– Processable materials with DED-Arc<br>– Processing atmosphere requirements with DED-Arc<br>– Sensors and process controls with DED-Arc | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>— DED-Arc equipment, accessories, including build platform, feedstock and other consumables<br>— DED-Arc process parameters and variables, including post processing operations |

| LEARNING OUTCOMES – CU 01: DED-Arc Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only for Enginners)** |
| **SKILLS** | Describe the DED-Arc systems, including the components and their functions<br>Distinguish different types of feedstock<br>Associate the interaction of the process heat source with the feedstock<br>Recognise the DED-Arc parameters and the influence of their adjustment on the as built part (e.g. deformation)<br>Recognise the characteristics of the DED-Arc build platform, feedstock and other consumables<br>Identify the problems associated with inadequate preparation and set-up of the build platform, handling and storage of feedstock and application of the gases used in DED-Arc | Assess the possibility of manufacturing a specific part with DED-Arc based on the characteristics and limitations of the process<br>Relate the influence of the process parameters, build platform, feedstock and other consumables with the properties of the as built part.<br>Implement different methodologies related with to process parameters and deposition strategies for reducing distortion of as built parts<br>Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them.<br>Select specific materials for different applications to meet part requirements.<br>Identify specific metallurgical aspects of DED-Arc parts<br>Define DED-Arc parameters for manufacturing specific parts<br>Adjust process parameters, manufacturing strategy and set up to prevent part defects and process related issues |

### 3.8.3 Competence Unit 08: DED-LB Process

| CU 08: DED-LB Process | RECOMENDED CONTACT HOURS | |
|---|---|---|
| LEVEL | INDEPENDENT (I) (applied to Operators and Engineers) | ADVANCED (A) (applied only for Enginners) |
| DED-LB System (Hardware & Software) | 5 | 0 |
| DED-LB Physical Principles | 2 | 0 |
| DED-LB Parameters | 3 | 0 |
| Build platform, feedstock and other consumables | 3 | 0 |
| Post processing operations | 1 | 0 |
| DED-LB Processes | 0 | 7 |
| DED-LB Build platform, feedstock and other consumables | 0 | 5 |
| DED-LB Equipment and accessories | 0 | 2 |
| DED-LB Manufacturing strategy | 0 | 7 |
| **Subtotal Per Level** | **14** | **21** |
| **Cumulated Subtotal** | **14** | **35** |
| | | **WORKLOAD** |
| **PER LEVEL** | 14 | 35 |
| **CUMULATED** | **28** | **70** |

| LEARNING OUTCOMES – CU 08: DED-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only for Enginners)** |
| **KNOWLEDGE** | Factual and broad of:<br>– DED-LB systems<br>– Laser Characteristics<br>– Build platform<br>– Powder/wire<br>– Gases<br>– Processable materials with DED-LB | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– DED-LB equipment, accessories, including build platform, feedstock and other consumables<br>– DED-LB process parameters and variables, including post processing operation |

| LEARNING OUTCOMES – CU 08: DED-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only for Enginners)** |
| **SKILLS** | Describe the DED-LB systems, including the com-ponents and their functions<br><br>Distinguish different types of feedstock<br><br>Associate the interaction of the process heat source with the feedstock<br><br>Recognise the DED-LB parameters and the influence of their adjustment on the as built part (e.g. deformation)<br><br>Recognise the characteristics of the DED-LB build platform, feedstock and other consumables<br><br>Identify the problems associated with inadequate prepa-ration and set-up of the build platform, handling and storage of feedstock and application of the gases used in DED-LB<br><br>Recognise the basic principles of 3D CAD systems and machine control software | Explain how the DED-LB process works<br><br>Explain the influence of modifying process parameters on the as built part<br><br>Discuss the influence of build platform, feedstock and other consumables characteristics on part manufacturing<br><br>Identify areas that will need thermal compensation<br><br>Identify the cause of defects and propose methods for their mitigation<br><br>Discuss the adequacy of selected equipment and accessories on the part manufacturing<br><br>Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them<br><br>Select specific materials for different applications to meet part requirements<br><br>Identify specific metallurgical aspects of DED-LB parts<br><br>Identify the variables used to define the DED-LB manufacturing strategy |

### 3.8.4 Competence Unit 15: PBF-LB Process

| CU 15: PBF-LB Process | RECOMENDED CONTACT HOURS | |
|---|---|---|
| LEVEL | INDEPENDENT (I) (applied to Operators and Engineers) | ADVANCED (A) (applied only to Enginners) |
| PBF-LB Process Principles | 2 | 0 |
| PBF-LB System – Hardware and Software | 4 | 0 |
| PBF-LB Parameters | 3 | 0 |
| PBF-LB Feedstock | 2 | 0 |
| PBF-LB Consumables | 2 | 0 |
| Post Processing | 1 | 0 |
| PBF-LB Processes | 0 | 7 |
| PBF-LB Build substrate, feedstock and other consumables | 0 | 5 |
| PBF-LB Equipment and accessories | 0 | 2 |
| PBF-LB Manufacturing strategy | 0 | 7 |
| **Subtotal Per Level** | **14** | **21** |
| **Cumulated Subtotal** | **14** | **35** |
| | | **WORKLOAD** |
| **PER LEVEL** | 14 | 35 |
| **CUMULATED** | **28** | **70** |

| LEARNING OUTCOMES – CU 15: PBF-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only for Enginners)** |
| **KNOWLEDGE** | Factual and broad knowledge of:<br>– PBF-LB systems<br>– Laser characteristics<br>– Build platform<br>– Powder<br>– Gases<br>– Processable materials with PBF-LB | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– PBF-LB equipment, accessories, including build platform, feedstock and other consumables<br>– PBF-LB process parameters and variables, including post processing operation |

| LEARNING OUTCOMES – CU 15: PBF-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only for Enginners)** |
| **SKILLS** | Describe the PBF-LB systems, including the components and their functions<br>Recognise the characteristics of the PBF-LB build platform, feedstock and other consumables<br>Recognise the PBF-LB parameters and the influence of their adjustment on the as built part<br>Recognise the interaction of the process heat source with the feedstock<br>Identify the problems associated with inadequate preparation and setup of the build platform, handling and storage of feedstock and application of the gases used in PBF-LB | Explain how the PBF-LB process works<br>Explain the influence of modifying process parameters on the as built part<br>Discuss the influence of build platform, feedstock and other consumables characteristics on part manufacturing<br>Identify areas that will need thermal compensation<br>Identify the cause of defects and propose methods for their mitigation<br>Discuss the adequacy of selected equipment and accessories on the part manufacturing<br>Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them<br>Select specific materials for different applications to meet part requirements<br>Identify specific metallurgical aspects of PBF-LB parts<br>Identify the variables used to define the PBF-LB manufacturing strategy |

### 3.8.5 Competence Unit 25: Post Processing

| **CU 25: Post Processing**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| General considerations | 2 |
| Thermal treatment | 4 |
| Plastic deformation methods | 2 |
| Subtractive manufacturing | 2 |
| Finishing operations | 2 |
| Practical application | 2 |
| **Total** | 14 |
| **WORKLOAD** | **28** |

| **Learning Outcomes – CU 25: Post Processing** | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Post processing methods (heat treatment, cold work methods, subtractive manufacturing, finishing operations) |
| **SKILLS** | Discuss methods to reduce distortion, using different post processes, for a variety of part geometries and AM processes.<br>Explain the applicable post processing methods to several AM processes as built parts<br>Describe the effect of different heat treatments on microstructure, mechanical properties, residual stress and defects<br>Explain the requirements that the as built part needs to have/comply according to each post process |

## 3.8.6 Competence Unit 34: Process selection

| CU 34: Process Selection<br>SUBJECT TITLE | CONTACT HOURS |
|---|---|
| Economics and productivity | 7 |
| AM Job analysis | 21 |
| **Total** | 28 |
| **WORKLOAD** | **56** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Process selection** | **6 ADVANCED** | Evaluate, for a specific part, which AM processes can be used for its production | Analysing manufacturing suitability of a client's specific requests<br>Proposing AM processes based on part design (in the conceptual design phase, together with the Design Engineer), materials, other manufacturing operations, required properties and applications<br>Ensuring liaison with other technical areas (design, materials, etc.) to guarantee manufacturability of AM parts<br>Using cost models to establish comparisons between different AM processes/materials and other required processes considering the full manufacturing chain<br>Estimating manufacturing times according to each process | **28** | **56** |

| Learning Outcomes – CU 34: Process selection | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Technical adequacy of AM processes to part requirements<br>– Costing and manufacturing time assessment |
| **SKILLS** | Relate supply chain strategies to their effects on the performance of a manufacturing organisation<br>Define the objectives, principles, terminology and systems of management accounting, including costing<br>Elaborate quotations for clients, calculating the cost of a product made by AM, including labour costs, overhead costs, and consumable costs.<br>Compare AM production costs to traditional manufacturing costs determining the return on investment.<br>Estimate manufacturing duration based on the process and part designs specifications<br>Recommend AM processes for specific applications based on job requirements analysis |

### 3.8.7 Competence Unit 35: Metal AM integration

| CU 35: Metal AM integration<br>SUBJECT TITLE | CONTACT HOURS |
|---|---|
| Production Management | 7 |
| AM Commercial Integration | 3,5 |
| Case studies | 10,5 |
| **Total** | 21 |
| **WORKLOAD** | **42** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Metal AM integration** | **6 ADVANCED** | Support the continuous technical and commercial integration of Metal AM in an industrial environment | Providing inputs for the design of production management procedures, based on the advantages and limitations of Metal AM processes | **21** | **42** |
| | | | Providing feedback to the management concerning Metal AM costs (e.g. collected from the production by the specialized engineers) | | |
| | | | Promoting AM capability to relevant stakeholders within the company, for its range of products | | |

| Learning Outcomes – CU 35: Metal AM integration | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– AM processes adoption on a company's business model<br>– Technical and commercial implementation plans for AM production |
| **SKILLS** | Analyse all the manufacturing processes existing in the company comparing AM with other manufacturing processes<br>Design AM cells including selection of AM machine and methods to manipulate the part, fixturing and sensing of the part, equipment for loading and unloading.<br>Design a factory layout that incorporates all required manufacturing operations<br>Provide inputs for a factory layout design that incorporates all required manufacturing operations<br>Recommend procedures for integration of AM processes within the company's manufacturing chain<br>Discuss the commercial aspects related to the integration of AM fostering the involvement of internal and external stakeholders in the adoption of AM |

### 3.8.8 Competence Unit 36: Coordination activities

| CU 36: Coordination activities<br>SUBJECT TITLE | CONTACT HOURS |
|---|---|
| Communications and coordination | 3 |
| Documentation | 4 |
| **Total** | 7 |
| **WORKLOAD** | **14** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Coordination activities** | **6 ADVANCED** | Coordinate the work with the AM team | Ensuring the link with external suppliers, as well as management, staff and other company departments | **7** | **14** |
| | | | Managing documentation related with the AM process | | |

| Learning Outcomes – CU 36: Coordination activities | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Communications and coordination procedures<br>– Document handling and control |
| **SKILLS** | Manage communications across all actors involved in the AM manufacturing chain<br>Establish procedures for information control and traceability<br>Control all the information generated within a given AM |

# 4 Metal AM DED-Arc Process Engineer

## 4.1 Preface

The present document consists in European/International Metal AM Process Engineer DED-Arc Guideline, developed in ADMIRE project.

This guideline for the European education, training, examination and qualification of additive manufacturing personnel has been prepared, evaluated and formulated by the International Additive Manufacturing Qualification Council (IAMQC). Contains general information for the public and organizations that implement this qualification.

Copies of this document can be downloaded from ADMIRE website: www.admire.eu or requested to Authorized Nominated Bodies for Metal Additive Manufacturing (AM ANBs) or EWF Management Team.

## 4.2 Metal AM DED-Arc Process Engineer Introduction

This guideline covers the minimum requirements for education and training, which have been agreed upon by all International AM Qualification System (IAMQS) members, in terms of Learning Outcomes (Knowledge and Skills) and the recommended contact (teaching) hours to be devoted to achieving them. It will be revised periodically by International AM Qualification Council to take into account changes to reflect the "state of the art".

Students successfully completing examinations will be expected to be capable of applying the achieved learning outcomes at a level consistent with the qualification diploma level.

The modular course contents are given in the following structure (overview):

| COMPETENCE UNITS | I/IE DED-Arc | |
|---|---|---|
| | Recommended Contact Hours* | Expected Workload** |
| CU 00: Additive manufacturing Process Overview | 7 | 14 |
| CU 01: DED-Arc Process | 42 | 84 |
| CU 08: DED-LB Process | 35 | 70 |
| CU 15: PBF-LB Process | 35 | 70 |
| CU 25: Post Processing | 14 | 28 |
| CU 34: Process selection | 28 | 56 |
| CU 35: Metal AM integration | 21 | 42 |
| CU 36: Coordination activities | 7 | 14 |
| CU 37: Production of DED-Arc parts | 28 | 56 |
| CU 38: Conformity of DED-Arc parts | 42 | 84 |
| CU 39: Conformity of facilities featuring DED-Arc | 7 | 28 |
| **TOTAL** | **266** | **532** |
| **Optional CUs** | | |
| CU 26: Introduction to materials | 14 | 28 |
| **TOTAL** | **280** | **560** |
| **Materials CUs*** ** | | |
| CU 27: AM with steels feedstock (excluding Stainless Steel) | 21 | 42 |
| CU 28: AM with Stainless Steel feedstock | 14 | 28 |
| CU 29: AM with Aluminium feedstock | 7 | 14 |
| CU 30: AM with Nickel feedstock | 7 | 14 |
| CU 31: AM with Titanium feedstock | 14 | 28 |
| CU 32: AM with Tungsten feedstock | 3,5 | 7 |

| | | |
|---|---|---|
| CU 33: Biomedical metallic materials | 7 | 14 |

* Contact Hours are the minimum recommended teaching hours for the Standard Routes. A contact hour shall contain at least 50 minutes of direct teaching time.

** Workload is calculated in hours, corresponds to an estimation of the time students typically need to complete all learning activities required to achieve the defined learning outcomes in formal learning environments plus the necessary time for individual study.

***A minimum of 2 CUs shall be selected from the list **Materials CUs** in order to successfully complete the qualification

Within the International AM Qualification System´s qualifications, there are two types of Competence Units:

- Cross-cutting Competence Unit - A competence unit whose learning outcomes are not directly linked with one job function since the knowledge and skills achieved will be mobilized in several job functions and activities.
- Functional Competence Unit - A competence unit whose learning outcomes are directly linked with at least one job function and in which the knowledge and skills achieved will be mobilized in specific job functions and related activities.

The expected learning outcomes are described in two ways: generic outcome descriptors organized in knowledge, skills, autonomy and responsibility; and in detail for each competence unit, organized in job functions and related activities, knowledge and skills corresponding to a specific proficiency level within International AM Qualification System´s Framework levels (see Appendix I).

On each Competence Unit, objectives and scope are defined for a specific depth of knowledge and skills.

Recommended contact hours are distributed between theoretical (A), assigned projects/exercises (B), practical work-shop training(C), as showed in the following example:

| ***Qualification: E*xample 1** | |
|---|---|
| **CONTACT HOURS** | **X= (SUM A:C)** |
| **Subject Contents** | A + B + C |

## 4.3 Professional Profile

Metal AM Coordinators are the professionals with the specific knowledge, skills, autonomy and responsibility to assess the technical adequacy of AM processes to part requirements. His/her's main tasks are to:

- Evaluate manufacturing suitability for customers' requests defining which processes are fit for the request, based on the application, material, design and cost of the part.
- Coordinate the work with the AM Team

## 4.4 Routes to Qualification

Two distinct routes to gaining the qualifications described in this document have been agreed.

3. The Standard Route
4. Blended Learning Route

### 4.4.1 The Standard Route

The Standard Route requires successful completion of IAMQS approved courses which are designed to meet all the requirements in this Guideline. This is the route recommended by IAMQS as offering the fastest, most comprehensive manner in which the detailed knowledge may be covered.

### 4.4.2 Blended Learning Route

The Cross-Cutting Competence Units (theoretical knowledge and skills) may be taught using Distance Learning Programs under the control of the AM ANB and all the Functional Competence Units (practical knowledge and skills) must be taught at the Authorized Training Bodies for Metal Additive Manufacturing (AM ATB) facilities.

## 4.5 General Access Conditions

The defined access conditions approved by IAMQS Technical Working Groups Area of competence "Implementation and Authorisation" of the IAMQS are given in detail for all countries participating in the IAMQS system.

The access conditions to Metal AM Coordinators admission are the following:

- Engineering degree in Mechanical, Materials, Aeronautic or similar.

## 4.6 Special Requirements

### 4.6.1 Standard Route

Applicants shall satisfy the access conditions, to be accepted for the attendance of a training course conducted by an IAMQS Member Organization.

There will be written, oral and practical examinations (where applicable) for the award of the applicable International AM Diploma.

It is not obligatory to follow exactly the order of the Competence Units given in this guideline and choice in the arrangement of the detailed knowledge is permitted, with the exception that **the first Competence Unit to be provided must be CU 00: Additive manufacturing Process Overview.**

Complementary to the Competence Units that are required for the purpose of the European/International Metal Additive Manufacturing Engineering Expert Diploma issuing, a set of optional Competence Units that can also be of added value for the student and can be implemented by the AM ATB as a supporting training and education offer.

For these optional Competence Units, separate Records of Achievement will be issued after examination approval. Whenever these optional Competence Units are considered mandatory for a certain IAMQS Qualification, they can be recognized for the purpose of such Qualification Diploma.

The examination of any Competence Unit for the purpose of being validated individually, not included in a Qualification course, shall be completed within a period of 1 year from the starting day of the Competence Unit.

If the Competence Unit “A” is done as a part of a qualification course, the examination shall be completed within a period of 4 years from the date of the completion of the first Competence Unit from the qualification where Competence Unit “A” is integrated in. Failure in the examination shall require re-examination.

## 4.7 Qualification Outcome Descriptors

| QUALIFICATION | IAMQS LEVEL | KNOWLEDGE | SKILLS | AUTONOMY AND RESPONSIBILITY |
|---|---|---|---|---|
| **E/I MAMC** | **ADVANCED** | Advanced knowledge and critical understanding of the theory, principles and applicability of metal additive manufacturing processes. | Advanced problem-solving skills including critical evaluation, allowing to choose the proper technical and economical solutions, when applying metal additive manufacturing processes, in complex and unpredictable conditions | Manage the selection of metal additive manufacturing processes in a highly complex context.<br>Act autonomously in decision making and of the metal additive manufacturing personnel's tasks |

## 4.8 Mandatory Competence Units Learning Outcomes

### 4.8.1 Competence Unit 00: Additive Manufacturing Processes Overview

| **CU 00: Additive Manufacturing Processes Overview**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Directed energy deposition | 1 |
| Powder bed fusion | 1 |
| Vat photopolymerization | 1 |
| Material jetting | 1 |
| Binder jetting | 1 |
| Material extrusion | 1 |
| Sheet lamination | 1 |
| **Total** | 7 |
| **WORKLOAD** | **14** |

| **Learning Outcomes – CU00: Additive Manufacturing Processes Overview**Erro! A origem da referência não foi encontrada. | |
|---|---|
| **KNOWLEDGE** | Factual and broad knowledge of theory, principles and applicability of:<br>– Directed energy deposition<br>– Powder bed fusion<br>– Vat photopolymerization<br>– Material jetting<br>– Binder jetting<br>– Material extrusion<br>– Sheet lamination |
| **SKILLS** | Distinguish parts produced by different AM processes<br>Recognise the advantages and limitations of AM processes from a manufacturing process chain point of view<br>Identify the applicability of different AM processes, according to the characteristics of each process |

### 4.8.2 Competence Unit 01: DED-Arc Process

| CU 01 DED-Arc Process | RECOMENDED CONTACT HOURS | |
|---|---|---|
| LEVEL | INDEPENDENT (I) (applied to Operators and Engineers) | ADVANCED (A) (applied only to Enginners) |
| DED-Arc System (Hardware & Software) | 5 | 0 |
| DED-Arc Physical Principles, Processes and Parameters | 5 | 0 |
| DED-Arc Build platform, feedstock and other consumables | 3 | 0 |
| Post processing operations | 1 | 0 |
| DED-Arc Processes | 0 | 14 |
| DED-Arc Build platform, feedstock and other consumables | 0 | 5 |
| DED-Arc Equipment and accessories | 0 | 3 |
| DED-Arc Manufacturing strategy | 0 | 6 |
| **Subtotal Per Level** | **14** | **28** |
| **Cumulated Subtotal** | **14** | **42** |
| | | **WORKLOAD** |
| **PER LEVEL** | 14 | 42 |
| **CUMULATED** | **28** | **84** |

| LEARNING OUTCOMES – CU 01: DED-Arc Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only to Enginners)** |
| **KNOWLEDGE** | Factual and broad of:<br>– DED-Arc systems<br>– Arc physics<br>– Processable materials with DED-Arc<br>– Processing atmosphere requirements with DED-Arc<br>– Sensors and process controls with DED-Arc | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– DED-Arc equipment, accessories, including build platform, feedstock and other consumables<br>– DED-Arc process parameters and variables, including post processing operations |

| LEARNING OUTCOMES – CU 01: DED-Arc Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only to Enginners)** |
| **SKILLS** | Describe the DED-Arc systems, including the components and their functions<br><br>Distinguish different types of feedstock<br><br>Associate the interaction of the process heat source with the feedstock<br><br>Recognise the DED-Arc parameters and the influence of their adjustment on the as built part (e.g. deformation)<br><br>Recognise the characteristics of the DED-Arc build platform, feedstock and other consumables<br><br>Identify the problems associated with inadequate preparation and set-up of the build platform, handling and storage of feedstock and application of the gases used in DED-Arc | Assess the possibility of manufacturing a specific part with DED-Arc based on the characteristics and limitations of the process<br><br>Relate the influence of the process parameters, build platform, feedstock and other consumables with the properties of the as built part.<br><br>Implement different methodologies related with to process parameters and deposition strategies for reducing distortion of as built parts<br><br>Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them.<br><br>Select specific materials for different applications to meet part requirements.<br><br>Identify specific metallurgical aspects of DED-Arc parts<br><br>Define DED-Arc parameters for manufacturing specific parts<br><br>Adjust process parameters, manufacturing strategy and set up to prevent part defects and process related issues |

### 4.8.3 Competence Unit 08: DED-LB Process

| CU 08: DED-LB Process | RECOMENDED CONTACT HOURS | |
|---|---|---|
| LEVEL | INDEPENDENT (I) (applied to Operators and Engineers) | ADVANCED (A) (applied only to Enginners) |
| DED-LB System (Hardware & Software) | 5 | 0 |
| DED-LB Physical Principles | 2 | 0 |
| DED-LB Parameters | 3 | 0 |
| Build platform, feedstock and other consumables | 3 | 0 |
| Post processing operations | 1 | 0 |
| DED-LB Processes | 0 | 7 |
| DED-LB Build platform, feedstock and other consumables | 0 | 5 |
| DED-LB Equipment and accessories | 0 | 2 |
| DED-LB Manufacturing strategy | 0 | 7 |
| **Subtotal Per Level** | **14** | **21** |
| **Cumulated Subtotal** | **14** | **35** |
| | | **WORKLOAD** |
| **PER LEVEL** | 14 | 35 |
| **CUMULATED** | **28** | **70** |

| LEARNING OUTCOMES – CU 08: DED-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only for Enginners)** |
| **KNOWLEDGE** | Factual and broad of:<br>– DED-LB systems<br>– Laser Characteristics<br>– Build platform<br>– Powder/wire<br>– Gases<br>– Processable materials with DED-LB | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– DED-LB equipment, accessories, including build platform, feedstock and other consumables<br>– DED-LB process parameters and variables, including post processing operation |

| LEARNING OUTCOMES – CU 08: DED-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only for Enginners)** |
| **SKILLS** | Describe the DED-LB systems, including the com-ponents and their functions<br><br>Distinguish different types of feedstock<br><br>Associate the interaction of the process heat source with the feedstock<br><br>Recognise the DED-LB parameters and the influence of their adjustment on the as built part (e.g. deformation)<br><br>Recognise the characteristics of the DED-LB build platform, feedstock and other consumables<br><br>Identify the problems associated with inadequate prepa-ration and set-up of the build platform, handling and storage of feedstock and application of the gases used in DED-LB<br><br>Recognise the basic principles of 3D CAD systems and machine control software | Explain how the DED-LB process works<br><br>Explain the influence of modifying process parameters on the as built part<br><br>Discuss the influence of build platform, feedstock and other consumables characteristics on part manufacturing<br><br>Identify areas that will need thermal compensation<br><br>Identify the cause of defects and propose methods for their mitigation<br><br>Discuss the adequacy of selected equipment and accessories on the part manufacturing<br><br>Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them<br><br>Select specific materials for different applications to meet part requirements<br><br>Identify specific metallurgical aspects of DED-LB parts<br><br>Identify the variables used to define the DED-LB manufacturing strategy |

### 4.8.4 Competence Unit 15: PBF-LB Process

| CU 15: PBF-LB Process | RECOMENDED CONTACT HOURS | |
|---|---|---|
| LEVEL | INDEPENDENT (I) (applied to Operators and Engineers) | ADVANCED (A) (applied only to Enginners) |
| PBF-LB Process Principles | 2 | 0 |
| PBF-LB System – Hardware and Software | 4 | 0 |
| PBF-LB Parameters | 3 | 0 |
| PBF-LB Feedstock | 2 | 0 |
| PBF-LB Consumables | 2 | 0 |
| Post Processing | 1 | 0 |
| PBF-LB Processes | 0 | 7 |
| PBF-LB Build substrate, feedstock and other consumables | 0 | 5 |
| PBF-LB Equipment and accessories | 0 | 2 |
| PBF-LB Manufacturing strategy | 0 | 7 |
| **Subtotal Per Level** | **14** | **21** |
| **Cumulated Subtotal** | **14** | **35** |
| | | **WORKLOAD** |
| **PER LEVEL** | 14 | 35 |
| **CUMULATED** | **28** | **70** |

| LEARNING OUTCOMES – CU 15: PBF-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only for Enginners)** |
| **KNOWLEDGE** | Factual and broad knowledge of:<br>– PBF-LB systems<br>– Laser characteristics<br>– Build platform<br>– Powder<br>– Gases<br>– Processable materials with PBF-LB | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– PBF-LB equipment, accessories, including build platform, feedstock and other consumables<br>– PBF-LB process parameters and variables, including post processing operation |

| LEARNING OUTCOMES – CU 15: PBF-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only for Enginners)** |
| **SKILLS** | Describe the PBF-LB systems, including the components and their functions<br>Recognise the characteristics of the PBF-LB build platform, feedstock and other consumables<br>Recognise the PBF-LB parameters and the influence of their adjustment on the as built part<br>Recognise the interaction of the process heat source with the feedstock<br>Identify the problems associated with inadequate preparation and setup of the build platform, handling and storage of feedstock and application of the gases used in PBF-LB | Explain how the PBF-LB process works<br>Explain the influence of modifying process parameters on the as built part<br>Discuss the influence of build platform, feedstock and other consumables characteristics on part manufacturing<br>Identify areas that will need thermal compensation<br>Identify the cause of defects and propose methods for their mitigation<br>Discuss the adequacy of selected equipment and accessories on the part manufacturing<br>Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them<br>Select specific materials for different applications to meet part requirements<br>Identify specific metallurgical aspects of PBF-LB parts<br>Identify the variables used to define the PBF-LB manufacturing strategy |

### 4.8.5 Competence Unit 25: Post Processing

| Erro! A origem da referência não foi encontrada.**CU 25: Post Processing**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| General considerations | 2 |
| Thermal treatment | 4 |
| Plastic deformation methods | 2 |
| Subtractive manufacturing | 2 |
| Finishing operations | 2 |
| Practical application | 2 |
| **Total** | 14 |
| **WORKLOAD** | **28** |

| **Learning Outcomes – CU 25: Post Processing** | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Post processing methods (heat treatment, cold work methods, subtractive manufacturing, finishing operations) |
| **SKILLS** | Discuss methods to reduce distortion, using different post processes, for a variety of part geometries and AM processes.<br>Explain the applicable post processing methods to several AM processes as built parts<br>Describe the effect of different heat treatments on microstructure, mechanical properties, residual stress and defects<br>Explain the requirements that the as built part needs to have/comply according to each post process |

### 4.8.6 Competence Unit 26: Introduction to materials

| **CU 26: Introduction to materials**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Structure and properties of metals and alloys | 3 |
| Solidification and Phase Diagrams | 3 |
| Solid state transformations and TTT diagrams | 4 |
| Failure mechanisms: fracture, fatigue, creep | 4 |
| **Total** | 14 |
| **WORKLOAD** | **28** |

| **Learning Outcomes – CU 26: Introduction to materials** | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Structure and properties of metals and alloys;<br>– Solidification and solid-state transformations<br>– Microstructures<br>– Degradation and Failure |
| **SKILLS** | Describe the structures of pure metals and alloys.<br>Explain, in detail, the principles of transformation and conditions of structure under which it occurs.<br>Interpret in detail the phase diagrams information and apply phase diagrams to define microstructures, mechanical properties and alloys.<br>Realise the mechanical properties of metallic materials according to their structures.<br>Describe the differences between elastic, plastic, cold and hot deformation that can occur in metals.<br>Explain the advantages and disadvantages of metals recrystallization, work hardening and strain ageing.<br>Interpret crystalline lattice distortion from given alloying elements and subsequent structural changes.<br>Compare the mechanisms of precipitation, types of precipitates and their location within the microstructure.<br>Explain the effect of loading conditions and temperature on the mechanical properties of metallic materials.<br>Explain in detail the differences between cracks and fractures comparing the mechanisms of different types of failures.<br>Assess types of failures. |

### 4.8.7 Competence Unit 27: AM with Steels feedstock (excluding Stainless Steel)

| **CU27: AM with Steels feedstock (excluding Stainless Steel)**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Characteristics and classification of Low alloy Carbon Steels | 3 |
| Characteristics and classification of Cr-Mo steels | 2 |
| Characteristics and classification of Maraging steels | 1,5 |
| Characteristics and classification of High strength steels | 1,5 |
| Behaviour in AM – General considerations | 2 |
| Behaviour in AM of Low alloy Carbon Steels | 2 |
| Behaviour in AM of Cr-Mo steels | 2 |
| Behaviour in AM of Maraging steels | 2 |
| Behaviour in AM of High strength steels | 2 |
| Cracking phenomena in parts processed by AM | 3 |
| **Total** | 21 |
| **WORKLOAD** | **42** |

| **Learning Outcomes –CU 27:AM with Steels feedstock (excluding Stainless Steel)** | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Different types of Steels as feedstock for producing AM parts, namely: carbon steels, Cr-Mo, maraging and high strength steels |
| **SKILLS** | Describe the theory, principles and applicability of steels:<br>– Describe processability with AM, including obtained properties and their relation with process parameters<br>– Describe main causes of cracking and how to avoid<br>– Identify possible imperfections, including metallurgical imperfections, and how to avoid<br>– Select types of heat treatments when necessary<br>For the following types of steels: low alloy, Cr-Mo, maraging and high strength steels:<br>– Explain in detail the effects of micro-alloying, relating grain refinement to mechanical properties.<br>– Discuss the AM conditions for a certain part taking into account the material ability for AM<br>– Discuss carbon equivalent (CE), t 8/5 concept and preheating temperature<br>– Discuss hardenability and maximum cooling rate<br>– Identify the type of heat treatments requirements for a certain part, inferring the heat treatment conditions (depending of the shape and size of the part, the application and the code). |

### 4.8.8 Competence Unit 28: AM with Stainless Steel feedstock

| **CU 28: AM with Stainless Steel feedstock**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Characteristics and classification of Stainless Steels – general considerations | 2 |
| Characteristics and classification of Austenitic Stainless Steels | 1 |
| Characteristics and classification of Martensitic Ferritic Stainless Steels | 1 |
| Characteristics and classification of Duplex Stainless Steels | 1 |
| Characteristics and classification of Precipitation hardened SS | 1 |
| Behaviour in AM of Austenitic Stainless Steels | 2 |
| Behaviour in AM of Martensitic Ferritic Stainless Steels | 2 |
| Behaviour in AM of Duplex Stainless Steels | 1 |
| Behaviour in AM of Precipitation hardened Stainless Steels | 1 |
| Cracking phenomena in Stainless Steel parts processed by AM | 2 |
| **Total** | 14 |
| **WORKLOAD** | **28** |

| **Learning Outcomes – CU 28:AM with Stainless Steel feedstock** Erro! A origem da referência não foi encontrada. | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Different types of Stainless Steels as feedstock for producing AM parts, namely: Austenitic, Ferritic, Martensitic, Duplex and Precipitation hardened |
| **SKILLS** | Identify stainless steels type: austenitic, ferritic, martensitic, precipitation hardened, duplex and its ability to be processed by AM in all processes with different feedstock<br>Identify main problems for each Stainless Steel when AM processed by different AM processes and feedstock<br>Identify the material processability with AM, the type of heat source and feedstock<br>Discuss and predict how to prevent major cracking phenomena<br>Decide the type of post treatment required for a certain part (according to the type of stainless steel, the shape and size of the part, the application and any relevant documentation) |

### 4.8.9 Competence Unit 29: AM with Aluminium feedstock

| **CU 29: AM with Aluminium feedstock**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Characteristics and classification of Aluminium and its alloys | 2 |
| Aluminium and aluminium alloys and their behaviour in AM | 3 |
| Cracking phenomena in parts processed by AM | 2 |
| **Total** | 7 |
| **WORKLOAD** | **10** |

| **Learning Outcomes – CU 29: AM with Aluminium feedstock** | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Aluminium alloys and their processability with AM<br>– Main causes of cracking and how to avoid<br>– Types and objectives of heat treatment techniques |
| **SKILLS** | For the following metal and alloys – Aluminium:<br>– Interpret the processability with AM for each alloy with different AM processes and feedstock<br>– Discuss the applications, recommending processing parameters and shielding gases to achieve quality requirements for a specific part<br>– Distinguish heat treatable and non-heat treatable alloys and problems in AM<br>– Recommend methods to avoid cracking phenomena and solid-state micro fissures, providing alternatives where necessary. |

## 4.8.10 Competence Unit 30: AM with Nickel feedstock

| **CU30: AM with Nickel feedstock**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Characteristics and classification of Nickel and its alloys | 2 |
| Nickel and nickel alloys and their behaviour in AM | 3 |
| Cracking phenomena in parts processed by AM | 2 |
| **Total** | 7 |
| **WORKLOAD** | **14** |

| **Learning Outcomes – CU 30: AM with Nickel feedstock** | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Nickel processability with AM<br>– Main causes of cracking and how to avoid<br>– Types and goals of heat treatment techniques |
| **SKILLS** | For the following metal and alloys – Nickel:<br>– Interpret the processability with AM for each alloy with different AM processes and feedstock<br>– Discuss the applications, recommending processing parameters and shielding gases to achieve quality requirements for a specific part<br>– Recommend methods to avoid cracking phenomena and solid-state micro fissures, providing alternatives where necessary. |

### 4.8.11 Competence Unit 31: AM with Titanium feedstock

| CU31: AM with Titanium feedstock | CONTACT HOURS |
|---|---|
| **SUBJECT TITLE** | |
| Characteristics and classification of Titanium and its alloys | 4 |
| 3Titanium and titanium alloys and their behaviour in AM | 6 |
| Cracking phenomena in parts processed by AM | 4 |
| **Total** | 14 |
| **WORKLOAD** | **28** |

| Learning Outcomes – CU31: AM with Titanium feedstock | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Titanium processability with AM<br>– Main causes of cracking and how to avoid<br>– Types and goals of heat treatment techniques |
| SKILLS | Describe in detail the theory, principles and applicability of:<br>– Titanium processability with AM<br>– Main causes of cracking and how to avoid<br>– Heat treatments- types and techniques<br><br>For the following metal and its alloys – Titanium:<br>– Interpret the processability with AM<br>– Discuss the applications, recommending heat input, shielding gases to achieve quality requirements for a specific part<br>– Recommend methods to avoid cracking phenomena and solid-state micro cracks, providing alternatives where necessary. |

## 4.8.12 Competence Unit 32: AM with Tungsten feedstock

| **CU 32: AM with Tungsten feedstock**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Characteristics and classification of Tungsten | 1 |
| Tungsten behaviour in Additive Manufacturing | 1.5 |
| Cracking phenomena in parts processed by Additive Manufacturing | 1 |
| **Total** | 3.5 |
| **WORKLOAD** | **7** |

| **Learning Outcomes – CU 32: AM with Tungsten feedstock** | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Tungsten processability with Additive Manufacturing<br>– Main causes of cracking and how to avoid |
| **SKILLS** | For Tungsten:<br>– Interpret the processability of W with different Additive Manufacturing processes and feedstock<br>– Discuss the applications, recommending processing parameters and shielding gases to achieve quality requirements for a specific part |

### 4.8.13 Competence Unit 33: Biomedical metallic materials

| **CU 33: Biomedical metallic materials**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Metallic alloys used for biomedical applications | 1 |
| Noble metals (Au, Ag, Pd, Pt) | 1 |
| Pure Ti, Pure Mg | 1 |
| Alloys: Ti6Al7Nb, Ti13Zr13Nb, NiTi, 316L stainless steel Co-Cr-Mo, | 1 |
| Ability to AM | 3 |
| **Total** | 7 |
| **WORKLOAD** | **10** |

| **Learning Outcomes –CU 33: Biomedical metallica materials** | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Biomedical metallic materials processability with AM<br>– Main causes of cracking and how to avoid |
| **SKILLS** | Describe in detail the theory, principles and applicability of<br>– Biomedical metallic materials processability with AM<br>– Main causes of cracking and how to avoid<br>– Heat treatments- types and techniques<br><br>For the Biomedical metallic materials<br>– Interpret the processability with AM<br>– Discuss the applications, recommending heat input, shielding gases to achieve quality requirements for a specific part<br>– Recommend methods to avoid cracking phenomena and solid-state micro cracks, providing alternatives where necessary. |

## 4.8.14 Competence Unit 34: Process selection

| CU 34: Process Selection | CONTACT HOURS |
|---|---|
| **SUBJECT TITLE** | |
| Economics and productivity | 7 |
| AM Job analysis | 21 |
| **Total** | 28 |
| **WORKLOAD** | **56** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Process selection** | **6 ADVANCED** | Evaluate, for a specific part, which AM processes can be used for its production | Analysing manufacturing suitability of a client's specific requests | **28** | **56** |
| | | | Proposing AM processes based on part design (in the conceptual design phase, together with the Design Engineer), materials, other manufacturing operations, required properties and applications | | |
| | | | Ensuring liaison with other technical areas (design, materials, etc.) to guarantee manufacturability of AM parts | | |
| | | | Using cost models to establish comparisons between different AM processes/materials and other required processes considering the full manufacturing chain | | |
| | | | Estimating manufacturing times according to each process | | |

| Learning Outcomes – CU 34: Process selection | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Technical adequacy of AM processes to part requirements<br>– Costing and manufacturing time assessment |
| **SKILLS** | Relate supply chain strategies to their effects on the performance of a manufacturing organisation<br>Define the objectives, principles, terminology and systems of management accounting, including costing<br>Elaborate quotations for clients, calculating the cost of a product made by AM, including labour costs, overhead costs, and consumable costs.<br>Compare AM production costs to traditional manufacturing costs determining the return on investment.<br>Estimate manufacturing duration based on the process and part designs specifications<br>Recommend AM processes for specific applications based on job requirements analysis |

## 4.8.15 Competence Unit 35: Metal AM integration

| CU 35: Metal AM integration | CONTACT HOURS |
|---|---|
| **SUBJECT TITLE** | |
| Production Management | 7 |
| AM Commercial Integration | 3,5 |
| Case studies | 10,5 |
| **Total** | 21 |
| **WORKLOAD** | **42** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Metal AM integration** | **6 ADVANCED** | Support the continuous technical and commercial integration of Metal AM in an industrial environment | Providing inputs for the design of production management procedures, based on the advantages and limitations of Metal AM processes | **21** | **42** |
| | | | Providing feedback to the management concerning Metal AM costs (e.g. collected from the production by the specialized engineers) | | |
| | | | Promoting AM capability to relevant stakeholders within the company, for its range of products | | |

| Learning Outcomes – CU 35: Metal AM integration | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– AM processes adoption on a company's business model<br>– Technical and commercial implementation plans for AM production |
| **SKILLS** | Analyse all the manufacturing processes existing in the company comparing AM with other manufacturing processes<br>Design AM cells including selection of AM machine and methods to manipulate the part, fixturing and sensing of the part, equipment for loading and unloading.<br>Design a factory layout that incorporates all required manufacturing operations<br>Provide inputs for a factory layout design that incorporates all required manufacturing operations<br>Recommend procedures for integration of AM processes within the company's manufacturing chain<br>Discuss the commercial aspects related to the integration of AM fostering the involvement of internal and external stakeholders in the adoption of AM |

## 4.8.16 Competence Unit 36: Coordination activities

| CU 36: Coordination activities<br>SUBJECT TITLE | CONTACT HOURS |
|---|---|
| Communications and coordination | 3 |
| Documentation | 4 |
| **Total** | 7 |
| **WORKLOAD** | **14** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Coordination activities** | **6 ADVANCED** | Coordinate the work with the AM team | Ensuring the link with external suppliers, as well as management, staff and other company departments | **7** | **14** |
| | | | Managing documentation related with the AM process | | |

| Learning Outcomes – CU 36: Coordination activities | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Communications and coordination procedures<br>– Document handling and control |
| **SKILLS** | Manage communications across all actors involved in the AM manufacturing chain<br>Establish procedures for information control and traceability<br>Control all the information generated within a given AM |

## 4.8.17 Competence Unit 37: Production of DED-Arc parts

| CU 37: Production of DED-Arc parts<br>SUBJECT TITLE | CONTACT HOURS |
|---|---|
| DED-Arc process simulation | 7 |
| DED-Arc part production | 21 |
| **Total** | 28 |
| **WORKLOAD** | **56** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Production of DED-Arc parts** | **7/ Expert** | Specify the process chain for the DED-Arc parts | Interpreting simulation results | **28** | **56** |
| | | | Running simple simulations (e.g. toolpath planning) | | |
| | | | Establishing manufacturing plan (e.g. Arc parameters, feedstock, gas, building plate, build file, post processing operations, standards) | | |
| | | | Providing technical counselling to support the decision of the acquisition of AM equipment | | |
| | | | Defining the production of DED-Arc parts together with other staff (e.g. including providing inputs to designers to optimize the shape of AM products) | | |
| | | | Specifying post processing operations (e.g. subtractive manufacturing, heat treatment, surface finishing and treatment) | | |
| | | | Defining AM staff's tasks distribution according to the workplan | | |

| Learning Outcomes – CU 37: Production of DED-Arc parts | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– DED-Arc part production specifications, including simulation information, process parameters, pre and post manufacturing operations and work instructions |
| **SKILLS** | Discuss Design for AM features with other AM staff<br>Interpret finite element analysis and numerical modelling to AM (e.g. topology optimisation, distortion, residual stresses)<br>Apply workflows for virtual pre-processing (e.g. part orientation)<br>Demonstrate competency in working with toolpath creation software<br>Select specific materials for different applications to meet part requirements.<br>Propose a suitable toolpath for a given part and identify the areas that will need thermal compensation<br>Propose methods to reduce distortion for a variety of part geometries and processes<br>Identify the cause of defects and propose methods for their mitigation<br>Identify the most suitable post processing technique for a specific AM process and application<br>Create a DED-Arc AMPS<br>Produce work instructions for the DED-Arc Operator |

## Competence Unit 38: Conformity of DED-Arc parts

| CvU38: Conformity of DED-Arc parts<br>SUBJECT TITLE | CONTACT HOURS |
|---|---|
| Quality Assurance and Quality Control | 6 |
| Repair of DED-Arc parts | 1 |
| Inspection and Testing Plan | 31,5 |
| Production chain qualification | 3,5 |
| **Total** | 42 |
| **WORKLOAD** | **84** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Conformity of DED-Arc parts** | **7/ Expert** | Ensure the conformity of the AM process and AM parts | Preparing QA/QC procedures (e.g. reception, handling and storage of feedstock and substrate, manufacturing process monitoring) | **42** | **84** |
| | | | Supporting the development of testing and inspection plan (including acceptance criteria for NDT and DT) | | |
| | | | Troubleshooting for causes of non-conformity in the production of AM parts | | |
| | | | Determining corrective actions for eliminating defects (e.g. metallurgical, deformation, warping) based on technical reports (e.g. DT, NDT) | | |
| | | | Ensuring the compliance of the AM production process and the AM parts with the relevant documents (e.g. standards, product specifications, legislation) | | |
| | | | Identifying requirements in terms of AM training | | |
| | | | Implementing AM process and AM parts certification procedures | | |
| | | | Developing procedures to repair parts (e.g. parts damaged in service; together with the client) | | |
| | | | Ensuring production chain qualification (i.e. equipment, operations, staff) | | |

| Learning Outcomes – CU38: Conformity of DED-Arc parts | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Quality Management<br>– Methods for DT and NDT<br>– Certification of DED-Arc parts<br>– Repair procedures |

| Learning Outcomes – CU38: Conformity of DED-Arc parts | |
|---|---|
| **SKILLS** | Apply the principles of quality management to process and part qualification |
| | Evaluate feedstock characteristics required to qualify a part |
| | Develop AM procedures according to appropriate standards and other documentation |
| | Select Non-Destructive Testing and Destructive Testing methods to characterise a part |
| | Interpret Destructive and Non-Destructive Testing reports |
| | Adapt AMPS based on results from testing results |
| | Integrate troubleshooting techniques in manufacturing process chain |
| | Propose methods to perform the repair and re-certification of a damaged DED-Arc part |
| | Guarantee process conformity to client's requests, standards and other requirements |

## 4.8.18 Competence Unit 39: Conformity of facilities featuring DED-Arc

| **CU 39: Conformity of facilities featuring DED-Arc**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Health, Safety & Environment in DED-Arc | 3 |
| Infrastructures/Facility Requirements | 3 |
| Group work | 1 |
| **Total** | 7 |
| **WORKLOAD** | **14** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Conformity of facilities featuring DED-Arc** | **7/Expert** | Support the implementation of facility conformity procedures featuring DED-Arc | Supporting the design of HSE procedures featuring DED-Arc (e.g. Control of Substances Hazardous to Health (COSHH), risk analysis, mitigation plans) | **7** | **14** |
| | | | Providing safety requirements to be implemented to ensure people' safety on the shop floor | | |
| | | | Provide inputs for waste management | | |
| | | | Preparing incident reports | | |

| **Learning Outcomes – CU39: Conformity of facilities featuring DED-Arc** | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– HSE in the DED-Arc process |
| **SKILLS** | Explain in detail the health and safety hazards associated with electricity, gases, fumes, fire, radiation and noise, grinding, spatter, flame, fire, combustion.<br>Predict the hazards, defining the health and safety requirements and working procedures, including the definition of the necessary PPE.<br>Recommend healthy and safe workplace practices to be implemented in a manufacturing plant. |

# 5 Metal AM DED-LB Process Engineer

## 5.1 Preface

The present document consists in European/International Metal AM Process Engineer DED-LB Guideline, developed in ADMIRE project.

This guideline for the European education, training, examination and qualification of additive manufacturing personnel has been prepared, evaluated and formulated by the International Additive Manufacturing Qualification Council (IAMQC). Contains general information for the public and organizations that implement this qualification.

Copies of this document can be downloaded from ADMIRE website: www.admire.eu or requested to Authorized Nominated Bodies for Metal Additive Manufacturing (AM ANBs) or EWF Management Team.

## 5.2 Metal AM DED-LB Process Engineer Introduction

This guideline covers the minimum requirements for education and training, which have been agreed upon by all International AM Qualification System (IAMQS) members, in terms of Learning Outcomes (Knowledge and Skills) and the recommended contact (teaching) hours to be devoted to achieving them. It will be revised periodically by International AM Qualification Council to take into account changes to reflect the "state of the art".

Students successfully completing examinations will be expected to be capable of applying the achieved learning outcomes at a level consistent with the qualification diploma level.

The modular course contents are given in the following structure (overview):

| COMPETENCE UNITS | E/IE DED-LB | |
|---|---|---|
| | Recommended Contact Hours* | Expected Workload** |
| CU 00: Additive manufacturing Process Overview | 7 | 14 |
| CU 01: DED-Arc Process | 42 | 84 |
| CU 08: DED-LB Process | 35 | 70 |
| CU 15: PBF-LB Process | 35 | 70 |
| CU 25: Post Processing | 14 | 28 |
| CU 34: Process selection | 28 | 56 |
| CU 35: Metal AM integration | 21 | 42 |
| CU 36: Coordination activities | 7 | 14 |
| CU 40: Production of DED-LB parts | 21 | 42 |
| CU 41: Conformity of DED-LB parts | 35 | 70 |
| CU 42: Conformity of facilities featuring DED-LB | 14 | 28 |
| **TOTAL** | **259** | **518** |
| **Optional CUs** | | |
| CU 26: Introduction to materials | 14 | 28 |
| **TOTAL** | **273** | **546** |
| **Materials CUs*** ** | | |
| CU 27: AM with steels feedstock (excluding Stainless Steel) | 21 | 42 |
| CU 28: AM with Stainless Steel feedstock | 14 | 28 |
| CU 29: AM with Aluminium feedstock | 7 | 14 |
| CU 30: AM with Nickel feedstock | 7 | 14 |
| CU 31: AM with Titanium feedstock | 14 | 28 |
| CU 32: AM with Tungsten feedstock | 3,5 | 7 |

| | | |
|---|---|---|
| CU 33: Biomedical metallic materials | 7 | 14 |

* Contact Hours are the minimum recommended teaching hours for the Standard Routes. A contact hour shall contain at least 50 minutes of direct teaching time.

** Workload is calculated in hours, corresponds to an estimation of the time students typically need to complete all learning activities required to achieve the defined learning outcomes in formal learning environments plus the necessary time for individual study.

***A minimum of 2 CUs shall be selected from the list **Materials CUs** in order to successfully complete the qualification

Within the International AM Qualification System´s qualifications, there are two types of Competence Units:

- Cross-cutting Competence Unit - A competence unit whose learning outcomes are not directly linked with one job function since the knowledge and skills achieved will be mobilized in several job functions and activities.
- Functional Competence Unit - A competence unit whose learning outcomes are directly linked with at least one job function and in which the knowledge and skills achieved will be mobilized in specific job functions and related activities.

The expected learning outcomes are described in two ways: generic outcome descriptors organized in knowledge, skills, autonomy and responsibility; and in detail for each competence unit, organized in job functions and related activities, knowledge and skills corresponding to a specific proficiency level within International AM Qualification System´s Framework levels (see Appendix I).

On each Competence Unit, objectives and scope are defined for a specific depth of knowledge and skills.

Recommended contact hours are distributed between theoretical (A), assigned projects/exercises (B), practical work-shop training(C), as showed in the following example:

| ***Qualification: E*xample 1** | |
|---|---|
| **CONTACT HOURS** | **X= (SUM A:C)** |
| **Subject Contents** | A + B + C |

## 5.3 Professional Profile

Metal AM Coordinators are the professionals with the specific knowledge, skills, autonomy and responsibility to assess the technical adequacy of AM processes to part requirements. His/her's main tasks are to:

- Evaluate manufacturing suitability for customers' requests defining which processes are fit for the request, based on the application, material, design and cost of the part.
- Coordinate the work with the AM Team

## 5.4 Routes to Qualification

Two distinct routes to gaining the qualifications described in this document have been agreed.

5. The Standard Route
6. Blended Learning Route

### 5.4.1 The Standard Route

The Standard Route requires successful completion of IAMQS approved courses which are designed to meet all the requirements in this Guideline. This is the route recommended by IAMQS as offering the fastest, most comprehensive manner in which the detailed knowledge may be covered.

### 5.4.2 Blended Learning Route

The Cross-Cutting Competence Units (theoretical knowledge and skills) may be taught using Distance Learning Programs under the control of the AM ANB and all the Functional Competence Units (practical knowledge and skills) must be taught at the Authorized Training Bodies for Metal Additive Manufacturing (AM ATB) facilities.

## 5.5 General Access Conditions

The defined access conditions approved by IAMQS Technical Working Groups Area of competence "Implementation and Authorisation" of the IAMQS are given in detail for all countries participating in the IAMQS system.

The access conditions to Metal AM Coordinators admission are the following:

- Engineering degree in Mechanical, Materials, Aeronautic or similar.

## 5.6 Special Requirements

### 5.6.1 Standard Route

Applicants shall satisfy the access conditions, to be accepted for the attendance of a training course conducted by an IAMQS Member Organization.

There will be written, oral and practical examinations (where applicable) for the award of the applicable International AM Diploma.

It is not obligatory to follow exactly the order of the Competence Units given in this guideline and choice in the arrangement of the detailed knowledge is permitted, with the exception that **the first Competence Unit to be provided must be CU 00: Additive manufacturing Process Overview.**

Complementary to the Competence Units that are required for the purpose of the European/International Metal Additive Manufacturing Engineering Expert Diploma issuing, a set of optional Competence Units that can also be of added value for the student and can be implemented by the AM ATB as a supporting training and education offer.

For these optional Competence Units, separate Records of Achievement will be issued after examination approval. Whenever these optional Competence Units are considered mandatory for a certain IAMQS Qualification, they can be recognized for the purpose of such Qualification Diploma.

The examination of any Competence Unit for the purpose of being validated individually, not included in a Qualification course, shall be completed within a period of 1 year from the starting day of the Competence Unit.

If the Competence Unit “A” is done as a part of a qualification course, the examination shall be completed within a period of 4 years from the date of the completion of the first Competence Unit from the qualification where Competence Unit “A” is integrated in. Failure in the examination shall require re-examination.

## 5.7 Qualification Outcome Descriptors

| QUALIFICATION | IAMQS LEVEL | KNOWLEDGE | SKILLS | AUTONOMY AND RESPONSIBILITY |
|---|---|---|---|---|
| **E/I MAMC** | **ADVANCED** | Advanced knowledge and critical understanding of the theory, principles and applicability of metal additive manufacturing processes. | Advanced problem-solving skills including critical evaluation, allowing to choose the proper technical and economical solutions, when applying metal additive manufacturing processes, in complex and unpredictable conditions | Manage the selection of metal additive manufacturing processes in a highly complex context.<br>Act autonomously in decision making and of the metal additive manufacturing personnel's tasks |

## 5.8 Mandatory Competence Units Learning Outcomes

### 5.8.1 Competence Unit 00: Additive Manufacturing Processes Overview

| **CU 00: Additive Manufacturing Processes Overview**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Directed energy deposition | 1 |
| Powder bed fusion | 1 |
| Vat photopolymerization | 1 |
| Material jetting | 1 |
| Binder jetting | 1 |
| Material extrusion | 1 |
| Sheet lamination | 1 |
| **Total** | 7 |
| **WORKLOAD** | **14** |

| **Learning Outcomes – CU 00; Additive Manufacturing Processes Overview**Erro! A origem da referência não foi encontrada. | |
|---|---|
| **KNOWLEDGE** | Factual and broad knowledge of theory, principles and applicability of:<br>– Directed energy deposition<br>– Powder bed fusion<br>– Vat photopolymerization<br>– Material jetting<br>– Binder jetting<br>– Material extrusion<br>– Sheet lamination |
| **SKILLS** | Distinguish parts produced by different AM processes<br>Recognise the advantages and limitations of AM processes from a manufacturing process chain point of view<br>Identify the applicability of different AM processes, according to the characteristics of each process |

### 5.8.2 Competence Unit 01: DED-Arc Process

| CU 01 DED-Arc Process | RECOMENDED CONTACT HOURS | |
|---|---|---|
| LEVEL | INDEPENDENT (I) (applied to Operators and Engineers) | ADVANCED (A) (applied only to Enginners) |
| DED-Arc System (Hardware & Software) | 5 | 0 |
| DED-Arc Physical Principles, Processes and Parameters | 5 | 0 |
| DED-Arc Build platform, feedstock and other consumables | 3 | 0 |
| Post processing operations | 1 | 0 |
| DED-Arc Processes | 0 | 14 |
| DED-Arc Build platform, feedstock and other consumables | 0 | 5 |
| DED-Arc Equipment and accessories | 0 | 3 |
| DED-Arc Manufacturing strategy | 0 | 6 |
| **Subtotal Per Level** | **14** | **28** |
| **Cumulated Subtotal** | **14** | **42** |
| | | **WORKLOAD** |
| **PER LEVEL** | 28 | 56 |
| **CUMULATED** | **28** | **84** |

| LEARNING OUTCOMES – CU 01: DED-Arc Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only to Enginners)** |
| **KNOWLEDGE** | Factual and broad of:<br>– DED-Arc systems<br>– Arc physics<br>– Processable materials with DED-Arc<br>– Processing atmosphere requirements with DED-Arc<br>– Sensors and process controls with DED-Arc | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>— DED-Arc equipment, accessories, including build platform, feedstock and other consumables<br>— DED-Arc process parameters and variables, including post processing operations |

| LEARNING OUTCOMES – CU 01: DED-Arc Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only to Enginners)** |
| **SKILLS** | Describe the DED-Arc systems, including the components and their functions<br><br>Distinguish different types of feedstock<br><br>Associate the interaction of the process heat source with the feedstock<br><br>Recognise the DED-Arc parameters and the influence of their adjustment on the as built part (e.g. deformation)<br><br>Recognise the characteristics of the DED-Arc build platform, feedstock and other consumables<br><br>Identify the problems associated with inadequate preparation and set-up of the build platform, handling and storage of feedstock and application of the gases used in DED-Arc | Assess the possibility of manufacturing a specific part with DED-Arc based on the characteristics and limitations of the process<br><br>Relate the influence of the process parameters, build platform, feedstock and other consumables with the properties of the as built part.<br><br>Implement different methodologies related with to process parameters and deposition strategies for reducing distortion of as built parts<br><br>Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them.<br><br>Select specific materials for different applications to meet part requirements.<br><br>Identify specific metallurgical aspects of DED-Arc parts<br><br>Define DED-Arc parameters for manufacturing specific parts<br><br>Adjust process parameters, manufacturing strategy and set up to prevent part defects and process related issues |

### 5.8.3 Competence Unit 08: DED-LB Process

| CU 08: DED-LB Process | RECOMENDED CONTACT HOURS | |
|---|---|---|
| LEVEL | INDEPENDENT (I) (applied to Operators and Engineers) | ADVANCED (A) (applied only to Enginners) |
| DED-LB System (Hardware & Software) | 5 | 0 |
| DED-LB Physical Principles | 2 | 0 |
| DED-LB Parameters | 3 | 0 |
| Build platform, feedstock and other consumables | 3 | 0 |
| Post processing operations | 1 | 0 |
| DED-LB Processes | 0 | 7 |
| DED-LB Build platform, feedstock and other consumables | 0 | 5 |
| DED-LB Equipment and accessories | 0 | 2 |
| DED-LB Manufacturing strategy | 0 | 7 |
| **Subtotal Per Level** | **14** | **21** |
| **Cumulated Subtotal** | **14** | **35** |
| | | **WORKLOAD** |
| **PER LEVEL** | 28 | 42 |
| **CUMULATED** | **28** | **70** |

| LEARNING OUTCOMES – CU 08: DED-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only to Enginners)** |
| **KNOWLEDGE** | Factual and broad of:<br>– DED-LB systems<br>– Laser Characteristics<br>– Build platform<br>– Powder/wire<br>– Gases<br>– Processable materials with DED-LB | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– DED-LB equipment, accessories, including build platform, feedstock and other consumables<br>– DED-LB process parameters and variables, including post processing operation |

| LEARNING OUTCOMES – CU 08: DED-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only to Enginners)** |
| **SKILLS** | Describe the DED-LB systems, including the com-ponents and their functions<br><br>Distinguish different types of feedstock<br><br>Associate the interaction of the process heat source with the feedstock<br><br>Recognise the DED-LB parameters and the influence of their adjustment on the as built part (e.g. deformation)<br><br>Recognise the characteristics of the DED-LB build platform, feedstock and other consumables<br><br>Identify the problems associated with inadequate prepa-ration and set-up of the build platform, handling and storage of feedstock and application of the gases used in DED-LB<br><br>Recognise the basic principles of 3D CAD systems and machine control software | Explain how the DED-LB process works<br><br>Explain the influence of modifying process parameters on the as built part<br><br>Discuss the influence of build platform, feedstock and other consumables characteristics on part manufacturing<br><br>Identify areas that will need thermal compensation<br><br>Identify the cause of defects and propose methods for their mitigation<br><br>Discuss the adequacy of selected equipment and accessories on the part manufacturing<br><br>Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them<br><br>Select specific materials for different applications to meet part requirements<br><br>Identify specific metallurgical aspects of DED-LB parts<br><br>Identify the variables used to define the DED-LB manufacturing strategy |

### 5.8.4 Competence Unit 15: PBF-LB Process

| CU 15: PBF-LB Process | RECOMENDED CONTACT HOURS | |
|---|---|---|
| LEVEL | INDEPENDENT (I) (applied to Operators and Engineers) | ADVANCED (A) (applied only to Enginners) |
| PBF-LB Process Principles | 2 | 0 |
| PBF-LB System – Hardware and Software | 4 | 0 |
| PBF-LB Parameters | 3 | 0 |
| PBF-LB Feedstock | 2 | 0 |
| PBF-LB Consumables | 2 | 0 |
| Post Processing | 1 | 0 |
| PBF-LB Processes | 0 | 7 |
| PBF-LB Build substrate, feedstock and other consumables | 0 | 5 |
| PBF-LB Equipment and accessories | 0 | 2 |
| PBF-LB Manufacturing strategy | 0 | 7 |
| **Subtotal Per Level** | **14** | **21** |
| **Cumulated Subtotal** | **14** | **35** |
| | | **WORKLOAD** |
| **PER LEVEL** | 28 | 42 |
| **CUMULATED** | **28** | **70** |

| LEARNING OUTCOMES – CU 15: PBF-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only to Enginners)** |
| **KNOWLEDGE** | Factual and broad knowledge of:<br>– PBF-LB systems<br>– Laser characteristics<br>– Build platform<br>– Powder<br>– Gases<br>– Processable materials with PBF-LB | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– PBF-LB equipment, accessories, including build platform, feedstock and other consumables<br>– PBF-LB process parameters and variables, including post processing operation |

| LEARNING OUTCOMES – CU 15: PBF-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only to Enginners)** |
| **SKILLS** | Describe the PBF-LB systems, including the components and their functions<br>Recognise the characteristics of the PBF-LB build platform, feedstock and other consumables<br>Recognise the PBF-LB parameters and the influence of their adjustment on the as built part<br>Recognise the interaction of the process heat source with the feedstock<br>Identify the problems associated with inadequate preparation and setup of the build platform, handling and storage of feedstock and application of the gases used in PBF-LB | Explain how the PBF-LB process works<br>Explain the influence of modifying process parameters on the as built part<br>Discuss the influence of build platform, feedstock and other consumables characteristics on part manufacturing<br>Identify areas that will need thermal compensation<br>Identify the cause of defects and propose methods for their mitigation<br>Discuss the adequacy of selected equipment and accessories on the part manufacturing<br>Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them<br>Select specific materials for different applications to meet part requirements<br>Identify specific metallurgical aspects of PBF-LB parts<br>Identify the variables used to define the PBF-LB manufacturing strategy |

### 5.8.5 Competence Unit 25: Post Processing

| **CU 25: Post Processing**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| General considerations | 2 |
| Thermal treatment | 4 |
| Plastic deformation methods | 2 |
| Subtractive manufacturing | 2 |
| Finishing operations | 2 |
| Practical application | 2 |
| **Total** | 14 |
| **WORKLOAD** | **28** |

| **Learning Outcomes – CU 25: Post Processing** | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Post processing methods (heat treatment, cold work methods, subtractive manufacturing, finishing operations) |
| **SKILLS** | Discuss methods to reduce distortion, using different post processes, for a variety of part geometries and AM processes.<br>Explain the applicable post processing methods to several AM processes as built parts<br>Describe the effect of different heat treatments on microstructure, mechanical properties, residual stress and defects<br>Explain the requirements that the as built part needs to have/comply according to each post process |

## 5.8.6 Competence Unit 26: Introduction to materials

| **CU 26: Introduction to materials**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Structure and properties of metals and alloys | 3 |
| Solidification and Phase Diagrams | 3 |
| Solid state transformations and TTT diagrams | 4 |
| Failure mechanisms: fracture, fatigue, creep | 4 |
| **Total** | 14 |
| **WORKLOAD** | **28** |

| **Learning Outcomes – CU 26: Introduction to materials** | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Structure and properties of metals and alloys;<br>– Solidification and solid-state transformations<br>– Microstructures<br>– Degradation and Failure |
| **SKILLS** | Describe the structures of pure metals and alloys.<br>Explain, in detail, the principles of transformation and conditions of structure under which it occurs.<br>Interpret in detail the phase diagrams information and apply phase diagrams to define microstructures, mechanical properties and alloys.<br>Realise the mechanical properties of metallic materials according to their structures.<br>Describe the differences between elastic, plastic, cold and hot deformation that can occur in metals.<br>Explain the advantages and disadvantages of metals recrystallization, work hardening and strain ageing.<br>Interpret crystalline lattice distortion from given alloying elements and subsequent structural changes.<br>Compare the mechanisms of precipitation, types of precipitates and their location within the microstructure.<br>Explain the effect of loading conditions and temperature on the mechanical properties of metallic materials.<br>Explain in detail the differences between cracks and fractures comparing the mechanisms of different types of failures.<br>Assess types of failures. |

### 5.8.7 Competence Unit 27: AM with steels feedstock (excluding Stainless Steel)

| **CU 27: AM with Steels feedstock (excluding Stainless Steel)**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Characteristics and classification of Low alloy Carbon Steels | 3 |
| Characteristics and classification of Cr-Mo steels | 2 |
| Characteristics and classification of Maraging steels | 1,5 |
| Characteristics and classification of High strength steels | 1,5 |
| Behaviour in AM – General considerations | 2 |
| Behaviour in AM of Low alloy Carbon Steels | 2 |
| Behaviour in AM of Cr-Mo steels | 2 |
| Behaviour in AM of Maraging steels | 2 |
| Behaviour in AM of High strength steels | 2 |
| Cracking phenomena in parts processed by AM | 3 |
| **Total** | 21 |
| **WORKLOAD** | **42** |

| **Learning Outcomes –CU 27: AM with Steels feedstock (excluding Stainless Steel)** | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Different types of Steels as feedstock for producing AM parts, namely: carbon steels, Cr-Mo, maraging and high strength steels |
| **SKILLS** | Describe the theory, principles and applicability of steels:<br>– Describe processability with AM, including obtained properties and their relation with process parameters<br>– Describe main causes of cracking and how to avoid<br>– Identify possible imperfections, including metallurgical imperfections, and how to avoid<br>– Select types of heat treatments when necessary<br><br>For the following types of steels: low alloy, Cr-Mo, maraging and high strength steels:<br>– Explain in detail the effects of micro-alloying, relating grain refinement to mechanical properties.<br>– Discuss the AM conditions for a certain part taking into account the material ability for AM<br>– Discuss carbon equivalent (CE), t 8/5 concept and preheating temperature<br>– Discuss hardenability and maximum cooling rate<br>– Identify the type of heat treatments requirements for a certain part, inferring the heat treatment conditions (depending of the shape and size of the part, the application and the code). |

### 5.8.8 Competence Unit 28: AM with Stainless Steel feedstock

| CU28: AM with Stainless Steel feedstock | CONTACT HOURS |
|---|---|
| **SUBJECT TITLE** | |
| Characteristics and classification of Stainless Steels – general considerations | 2 |
| Characteristics and classification of Austenitic Stainless Steels | 1 |
| Characteristics and classification of Martensitic Ferritic Stainless Steels | 1 |
| Characteristics and classification of Duplex Stainless Steels | 1 |
| Characteristics and classification of Precipitation hardened SS | 1 |
| Behaviour in Additive Manufacturing (AM) of Austenitic Stainless Steels | 2 |
| Behaviour in AM of Martensitic Ferritic Stainless Steels | 2 |
| Behaviour in AM of Duplex Stainless Steels | 1 |
| Behaviour in AM of Precipitation hardened Stainless Steels | 1 |
| Cracking phenomena in Stainless Steel parts processed by AM | 2 |
| **Total** | 14 |
| **WORKLOAD** | **28** |

| Learning Outcomes – CU 28: AM with Stainless Steel feedstock | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Different types of Stainless Steels as feedstock for producing AM parts, namely: Austenitic, Ferritic, Martensitic, Duplex and Precipitation hardened |
| **SKILLS** | Identify stainless steels type: austenitic, ferritic, martensitic, precipitation hardened, duplex and its ability to be processed by AM in all processes with different feedstock<br>Identify main problems for each Stainless Steels when AM processed by different AM processes and feedstock<br>Identify the material processability with AM, the type of heat source and feedstock<br>Discuss and predict how to prevent major cracking phenomena<br>Decide the type of post treatment required for a certain part (according to the type of stainless steel, the shape and size of the part, the application and any relevant documentation) |

### 5.8.9 Competence Unit 29: AM with Aluminium feedstock

| **CU 29: AM with Aluminium feedstock**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Characteristics and classification of Aluminium and its alloys | 2 |
| Aluminium and aluminium alloys and their behaviour in AM | 3 |
| Cracking phenomena in parts processed by AM | 2 |
| **Total** | 7 |
| **WORKLOAD** | **10** |

| **Learning Outcomes – CU 29: AM with Aluminium feedstock** | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Aluminium alloys and their processability with AM<br>– Main causes of cracking and how to avoid<br>– Types and objectives of heat treatment techniques |
| **SKILLS** | For the following metal and alloys – Aluminium:<br>– Interpret the processability with AM for each alloy with different AM processes and feedstock<br>– Discuss the applications, recommending processing parameters and shielding gases to achieve quality requirements for a specific part<br>– Distinguish heat treatable and non-heat treatable alloys and problems in AM<br>– Recommend methods to avoid cracking phenomena and solid-state micro fissures, providing alternatives where necessary. |

## 5.8.10 Competence Unit 30: AM with Nickel feedstock

| **CU 30: AM with Nickel feedstock**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Characteristics and classification of Nickel and its alloys | 2 |
| Nickel and nickel alloys and their behaviour in AM | 3 |
| Cracking phenomena in parts processed by AM | 2 |
| **Total** | 7 |
| **WORKLOAD** | **14** |

| **Learning Outcomes – CU 30: AM with Nickel feedstock** | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Nickel processability with AM<br>– Main causes of cracking and how to avoid<br>– Types and goals of heat treatment techniques |
| **SKILLS** | For the following metal and alloys – Nickel:<br>– Interpret the processability with AM for each alloy with different AM processes and feedstock<br>– Discuss the applications, recommending processing parameters and shielding gases to achieve quality requirements for a specific part<br>– Recommend methods to avoid cracking phenomena and solid-state micro fissures, providing alternatives where necessary. |

## 5.8.11 Competence Unit 31: AM with Titanium feedstock

| CU31: AM with Titanium feedstock | CONTACT HOURS |
|---|---|
| **SUBJECT TITLE** | |
| Characteristics and classification of Titanium and its alloys | 4 |
| Titanium and titanium alloys and their behaviour in AM | 6 |
| Cracking phenomena in parts processed by AM | 4 |
| **Total** | 14 |
| **WORKLOAD** | **28** |

| Learning Outcomes – CU 31: AM with Titanium feedstock | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Titanium processability with AM<br>– Main causes of cracking and how to avoid<br>– Types and goals of heat treatment techniques |
| **SKILLS** | Describe in detail the theory, principles and applicability of:<br>– Titanium processability with AM<br>– Main causes of cracking and how to avoid<br>– Heat treatments- types and techniques<br><br>For the following metal and its alloys – Titanium:<br>– Interpret the processability with AM<br>– Discuss the applications, recommending heat input, shielding gases to achieve quality requirements for a specific part<br>– Recommend methods to avoid cracking phenomena and solid-state micro cracks, providing alternatives where necessary. |

## 5.8.12 Competence Unit 32: AM with Tungsten feedstock

| **CU32: AM with Tungsten feedstock**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Characteristics and classification of Tungsten | 1 |
| Tungsten behaviour in AM | 1.5 |
| Cracking phenomena in parts processed by AM | 1 |
| **Total** | 3.5 |
| **WORKLOAD** | **7** |

| **Learning Outcomes – CU32: AM with Tungsten feedstock** | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Tungsten processability with AM<br>– Main causes of cracking and how to avoid |
| **SKILLS** | For Tungsten:<br>– Interpret the processability of W with different AM processes and feedstock<br>– Discuss the applications, recommending processing parameters and shielding gases to achieve quality requirements for a specific part |

## 5.8.13 Competence Unit 33: Biomedical metallic materials

| **CU 33: Biomedical metallic materials** | **CONTACT HOURS** |
|---|---|
| **SUBJECT TITLE** | |
| Metallic alloys used for biomedical applications | 1 |
| Noble metals (Au, Ag, Pd, Pt) | 1 |
| Pure Ti, Pure Mg | 1 |
| Alloys: Ti6Al7Nb, Ti13Zr13Nb, NiTi, 316L stainless steel Co-Cr-Mo, | 1 |
| Ability to AM | 3 |
| **Total** | 7 |
| **WORKLOAD** | **10** |

| **Learning Outcomes –CU 33: Biomedical metallica materials** | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Biomedical metallic materials processability with AM<br>– Main causes of cracking and how to avoid |
| **SKILLS** | Describe in detail the theory, principles and applicability of<br>– Biomedical metallic materials processability with AM<br>– Main causes of cracking and how to avoid<br>– Heat treatments- types and techniques<br><br>For the Biomedical metallic materials<br>– Interpret the processability with AM<br>– Discuss the applications, recommending heat input, shielding gases to achieve quality requirements for a specific part<br>– Recommend methods to avoid cracking phenomena and solid-state micro cracks, providing alternatives where necessary. |

## 5.8.14 Competence Unit 34: Process selection

| CU 34: Process Selection | CONTACT HOURS |
|---|---|
| **SUBJECT TITLE** | |
| Economics and productivity | 7 |
| AM Job analysis | 21 |
| **Total** | 28 |
| **WORKLOAD** | **56** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Process selection** | **6 ADVANCED** | Evaluate, for a specific part, which AM processes can be used for its production | Analysing manufacturing suitability of a client's specific requests | **28** | **56** |
| | | | Proposing AM processes based on part design (in the conceptual design phase, together with the Design Engineer), materials, other manufacturing operations, required properties and applications | | |
| | | | Ensuring liaison with other technical areas (design, materials, etc.) to guarantee manufacturability of AM parts | | |
| | | | Using cost models to establish comparisons between different AM processes/materials and other required processes considering the full manufacturing chain | | |
| | | | Estimating manufacturing times according to each process | | |

| Learning Outcomes – CU 34: Process selection | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Technical adequacy of AM processes to part requirements<br>– Costing and manufacturing time assessment |
| **SKILLS** | Relate supply chain strategies to their effects on the performance of a manufacturing organisation<br>Define the objectives, principles, terminology and systems of management accounting, including costing<br>Elaborate quotations for clients, calculating the cost of a product made by AM, including labour costs, overhead costs, and consumable costs.<br>Compare AM production costs to traditional manufacturing costs determining the return on investment.<br>Estimate manufacturing duration based on the process and part designs specifications<br>Recommend AM processes for specific applications based on job requirements analysis |

## 5.8.15 Competence Unit 35: Metal AM integration

| CU 35: Metal AM integration<br>SUBJECT TITLE | CONTACT HOURS |
|---|---|
| Production Management | 7 |
| AM Commercial Integration | 3,5 |
| Case studies | 10,5 |
| **Total** | 21 |
| **WORKLOAD** | **42** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Metal AM integration** | **6/ADVANCED** | Support the continuous technical and commercial integration of Metal AM in an industrial environment | Providing inputs for the design of production management procedures, based on the advantages and limitations of Metal AM processes | **21** | **42** |
| | | | Providing feedback to the management concerning Metal AM costs (e.g. collected from the production by the specialized engineers) | | |
| | | | Promoting AM capability to relevant stakeholders within the company, for its range of products | | |

| Learning Outcomes – CU 35: Metal AM integration | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– AM processes adoption on a company's business model<br>– Technical and commercial implementation plans for AM production |
| **SKILLS** | Analyse all the manufacturing processes existing in the company comparing AM with other manufacturing processes<br>Design AM cells including selection of AM machine and methods to manipulate the part, fixturing and sensing of the part, equipment for loading and unloading.<br>Design a factory layout that incorporates all required manufacturing operations<br>Provide inputs for a factory layout design that incorporates all required manufacturing operations<br>Recommend procedures for integration of AM processes within the company's manufacturing chain<br>Discuss the commercial aspects related to the integration of AM fostering the involvement of internal and external stakeholders in the adoption of AM |

## 5.8.16 Competence Unit 36: Coordination activities

| CU36: Coordination activities | CONTACT HOURS |
|---|---|
| **SUBJECT TITLE** | |
| Communications and coordination | 3 |
| Documentation | 4 |
| **Total** | 7 |
| **WORKLOAD** | **14** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Coordination activities** | **6 ADVANCED** | Coordinate the work with the AM team | Ensuring the link with external suppliers, as well as management, staff and other company departments | **7** | **14** |
| | | | Managing documentation related with the AM process | | |

| Learning Outcomes – CU 36: Coordination activities | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Communications and coordination procedures<br>– Document handling and control |
| **SKILLS** | Manage communications across all actors involved in the AM manufacturing chain<br>Establish procedures for information control and traceability<br>Control all the information generated within a given AM |

## 5.8.17 Competence Unit 40: Production of DED-LB parts

| CU 40: Production of DED-LB parts | CONTACT HOURS |
|---|---|
| **SUBJECT TITLE** | |
| DED-LB process simulation | 7 |
| DED-LB part production | 7 |
| Case studies | 7 |
| **Total** | 21 |
| **WORKLOAD** | **42** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Production of DED-LB parts** | **7/Expert** | Specify the process chain for the DED-LB parts | Interpreting reports of simulation results | **21** | **42** |
| | | | Run simple simulations in toolpath planning | | |
| | | | Establishing manufacturing plan (e.g. toolpath generation, Laser parameters, feedstock, gas, building plate, build file, post processing operations, standards) | | |
| | | | Providing technical counselling to the decision of the acquisition of AM equipment | | |
| | | | Defining the production of DED-LB parts together with other staff (e.g. including providing inputs to designers to optimize the shape of AM products) | | |
| | | | Specifying post processing operations (e.g. subtractive manufacturing, heat treatment, surface finishing and treatment) to fulfil the product requirements | | |
| | | | Design the tooling concept | | |
| | | | Defining AM staff's tasks distribution according to the workplan | | |

| Learning Outcomes – CU 40: Production of DED-LB parts | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– DED-LB part production specifications, including simulation information, process parameters, pre and post manufacturing operations and work instructions |
| **SKILLS** | Discuss Design for AM features with other AM staff.<br>Adapt CAD files to build files (e.g. toolpath)<br>Interpret reports of finite element analysis and numerical modelling to AM (e.g. topology optimisation, distortion, residual stresses)<br>Apply workflows for virtual pre-processing (e.g. part orientation)<br>Demonstrate competency in working with toolpath creation software<br>Select specific materials for different applications to meet part requirements<br>Propose a suitable toolpath for a given part and identify the areas that will need thermal compensation.<br>Propose methods to reduce distortion for a variety of part geometries and processes.<br>Identify the cause of defects and propose methods for their mitigation.<br>Identify the most suitable post processing technique for a specific AM process and application<br>Create a DED-LB AMPS<br>Produce work instructions for the DED-LB Operator |

## Competence Unit 41: Conformity of DED-LB parts

| CU 41: Conformity of DED-LB parts<br>SUBJECT TITLE | CONTACT HOURS |
|---|---|
| Quality Assurance and Quality Control | 7 |
| Inspection and Testing Plan | 21 |
| Production chain qualification | 7 |
| **Total** | 35 |
| **WORKLOAD** | **70** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Conformity of DED-LB parts** | **7/Expert** | Ensure the conformity of the AM process and AM parts | Preparing QA/QC procedures (e.g. reception, handling and storage of feedstock, manufacturing process monitoring) | **35** | **70** |
| | | | Supporting the development of testing and inspection plan (including acceptance criteria for NDT and DT) | | |
| | | | Troubleshooting for causes of non-conformity in the production of AM parts | | |
| | | | Determining corrective actions for eliminating defects (e.g. metallurgical, deformation, warping) based on technical reports (e.g. DT, NDT) | | |
| | | | Ensuring the compliance of the AM production process and the AM parts with the relevant documents (e.g. standards, product specifications, legislation) | | |
| | | | Identifying requirements in terms of AM training | | |
| | | | Implementing AM process and AM parts certification procedures | | |
| | | | Developing procedures to repair parts (e.g. parts damaged in service; together with the client) | | |
| | | | Ensuring production chain qualification (i.e. equipment, operations, staff) | | |

| Learning Outcomes – CU 41: Conformity of DED-LB parts | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Quality Management<br>– Methods for DT and NDT, monitoring control and inline control systems<br>– Certification of DED-LB parts<br>– Repair procedures |
| **SKILLS** | Apply the principles of quality management to process and part qualification<br>Evaluate feedstock characteristics required to qualify a part<br>Develop AM procedures according to appropriate standards and other documentation<br>Select Non-Destructive Testing and Destructive Testing methods to characterise a part<br>Interpret Destructive and Non-Destructive Testing reports<br>Adapt AMPS based on results from testing results<br>Integrate troubleshooting techniques in manufacturing process chain<br>Propose methods to perform the repair and re-certification of a damaged DED-LB part<br>Guarantee process conformity to client's requests, standards and other requirements<br>Define the manufacturing and approval of test artefacts<br>Interpret inline control and monitoring systems data and define correction strategies |

## 5.8.18 Competence Unit 42: Conformity of facilities featuring DED-LB

| **CU 42: Conformity of facilities featuring DED-LB**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Health, Safety & Environment in DED-LB | 10 |
| Infrastructures/Facility Requirements | 3 |
| Group work | 1 |
| **Total** | 14 |
| **WORKLOAD** | **28** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Conformity of facilities featuring DED-LB** | **7/Expert** | Support the implementation of facility conformity procedures featuring DED-LB | Supporting the design of Health, Safety and Environment (HSE) procedures featuring DED-LB (e.g. Control of Substances Hazardous to Health (COSHH), risk analysis, mitigation plans) | **14** | **28** |
| | | | Providing safety requirements to be implemented to ensure people's safety on the shop floor | | |
| | | | Providing inputs for waste management | | |
| | | | Preparing incident reports | | |

| **Learning Outcomes – CU 42: Conformity of facilities featuring DED-LB** | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– HSE in the DED-LB process |
| **SKILLS** | Explain in detail the health and safety hazards associated with Laser, electricity, gases, fumes, fire, radiation and noise, grinding, spatter, flame, fire, combustion.<br>Predict the hazards, defining the health and safety requirements and working procedures, including the definition of the necessary PPE.<br>Recommend healthy and safe workplace practices to be implemented in a manufacturing plant. |

# 6 Metal AM PBF-LB Process Engineer

## 6.1 Preface

The present document consists in European/International Metal AM Process Engineer PBF-LB Guideline, developed in ADMIRE project.

This guideline for the European education, training, examination and qualification of additive manufacturing personnel has been prepared, evaluated and formulated by the International Additive Manufacturing Qualification Council (IAMQC). Contains general information for the public and organizations that implement this qualification.

Copies of this document can be downloaded from ADMIRE website: www.admire.eu or requested to Authorized Nominated Bodies for Metal Additive Manufacturing (AM ANBs) or EWF Management Team.

## 6.2 Metal AM PBF-LB Process Engineer Introduction

This guideline covers the minimum requirements for education and training, which have been agreed upon by all International AM Qualification System (IAMQS) members, in terms of Learning Outcomes (Knowledge and Skills) and the recommended contact (teaching) hours to be devoted to achieving them. It will be revised periodically by International AM Qualification Council to take into account changes to reflect the "state of the art".

Students successfully completing examinations will be expected to be capable of applying the achieved learning outcomes at a level consistent with the qualification diploma level.

The modular course contents are given in the following structure (overview):

| COMPETENCE UNITS | E/IE PBF-LB | |
|---|---|---|
| | Recommended Contact Hours* | Expected Workload** |
| CU 00: Additive manufacturing Process Overview | 7 | 14 |
| CU 01: DED-Arc Process | 42 | 84 |
| CU 08: DED-LB Process | 35 | 70 |
| CU 15: PBF-LB Process | 35 | 70 |
| CU 25: Post Processing | 14 | 28 |
| CU 34: Process selection | 28 | 56 |
| CU 35: Metal AM integration | 21 | 42 |
| CU 36: Coordination activities | 7 | 14 |
| CU 43: Production of PBF-LB parts | 21 | 42 |
| CU 44: Conformity of PBF-LB parts | 35 | 70 |
| CU 45: Conformity of facilities featuring PBF-LB | 14 | 28 |
| **TOTAL** | **259** | **518** |
| **Optional CUs** | | |
| CU 26: Introduction to materials | 14 | 28 |
| **TOTAL** | **273** | **546** |
| **Materials CUs*** ** | | |
| CU 27: AM with steels feedstock (excluding Stainless Steel) | 21 | 42 |
| CU 28: AM with Stainless Steel feedstock | 14 | 28 |
| CU 29: AM with Aluminium feedstock | 7 | 14 |
| CU 30: AM with Nickel feedstock | 7 | 14 |
| CU 31: AM with Titanium feedstock | 14 | 28 |
| CU 32: AM with Tungsten feedstock | 3,5 | 7 |

| | | |
|---|---|---|
| CU 33: Biomedical metallic materials | 7 | 14 |

* Contact Hours are the minimum recommended teaching hours for the Standard Routes. A contact hour shall contain at least 50 minutes of direct teaching time.

** Workload is calculated in hours, corresponds to an estimation of the time students typically need to complete all learning activities required to achieve the defined learning outcomes in formal learning environments plus the necessary time for individual study.

***A minimum of 2 CUs shall be selected from the list **Materials CUs** in order to successfully complete the qualification

Within the International AM Qualification System´s qualifications, there are two types of Competence Units:

- Cross-cutting Competence Unit - A competence unit whose learning outcomes are not directly linked with one job function since the knowledge and skills achieved will be mobilized in several job functions and activities.
- Functional Competence Unit - A competence unit whose learning outcomes are directly linked with at least one job function and in which the knowledge and skills achieved will be mobilized in specific job functions and related activities.

The expected learning outcomes are described in two ways: generic outcome descriptors organized in knowledge, skills, autonomy and responsibility; and in detail for each competence unit, organized in job functions and related activities, knowledge and skills corresponding to a specific proficiency level within International AM Qualification System´s Framework levels (see Appendix I).

On each Competence Unit, objectives and scope are defined for a specific depth of knowledge and skills.

Recommended contact hours are distributed between theoretical (A), assigned projects/exercises (B), practical work-shop training(C), as showed in the following example:

| ***Qualification: E*xample 1** | |
|---|---|
| **CONTACT HOURS** | **X= (SUM A:C)** |
| **Subject Contents** | A + B + C |

## 6.3 Professional Profile

Metal AM Coordinators are the professionals with the specific knowledge, skills, autonomy and responsibility to assess the technical adequacy of AM processes to part requirements. His/her's main tasks are to:

- Evaluate manufacturing suitability for customers' requests defining which processes are fit for the request, based on the application, material, design and cost of the part.
- Coordinate the work with the AM Team

## 6.4 Routes to Qualification

Two distinct routes to gaining the qualifications described in this document have been agreed.

7. The Standard Route
8. Blended Learning Route

### 6.4.1 The Standard Route

The Standard Route requires successful completion of IAMQS approved courses which are designed to meet all the requirements in this Guideline. This is the route recommended by IAMQS as offering the fastest, most comprehensive manner in which the detailed knowledge may be covered.

### 6.4.2 Blended Learning Route

The Cross-Cutting Competence Units (theoretical knowledge and skills) may be taught using Distance Learning Programs under the control of the AM ANB and all the Functional Competence Units (practical knowledge and skills) must be taught at the Authorized Training Bodies for Metal Additive Manufacturing (AM ATB) facilities.

## 6.5 General Access Conditions

The defined access conditions approved by IAMQS Technical Working Groups Area of competence "Implementation and Authorisation" of the IAMQS are given in detail for all countries participating in the IAMQS system.

The access conditions to Metal AM Coordinators admission are the following:

- Engineering degree in Mechanical, Materials, Aeronautic or similar.

## 6.6 Special Requirements

### 6.6.1 Standard Route

Applicants shall satisfy the access conditions, to be accepted for the attendance of a training course conducted by an IAMQS Member Organization.

There will be written, oral and practical examinations (where applicable) for the award of the applicable International AM Diploma.

It is not obligatory to follow exactly the order of the Competence Units given in this guideline and choice in the arrangement of the detailed knowledge is permitted, with the exception that **the first Competence Unit to be provided must be CU 00: Additive manufacturing Process Overview.**

Complementary to the Competence Units that are required for the purpose of the European/International Metal Additive Manufacturing Engineering Expert Diploma issuing, a set of optional Competence Units that can also be of added value for the student and can be implemented by the AM ATB as a supporting training and education offer.

For these optional Competence Units, separate Records of Achievement will be issued after examination approval. Whenever these optional Competence Units are considered mandatory for a certain IAMQS Qualification, they can be recognized for the purpose of such Qualification Diploma.

The examination of any Competence Unit for the purpose of being validated individually, not included in a Qualification course, shall be completed within a period of 1 year from the starting day of the Competence Unit.

If the Competence Unit “A” is done as a part of a qualification course, the examination shall be completed within a period of 4 years from the date of the completion of the first Competence Unit from the qualification where Competence Unit “A” is integrated in. Failure in the examination shall require re-examination.

## 6.7 Qualification Outcome Descriptors

| QUALIFICATION | IAMQS LEVEL | KNOWLEDGE | SKILLS | AUTONOMY AND RESPONSIBILITY |
|---|---|---|---|---|
| **E/I MAMC** | **ADVANCED** | Advanced knowledge and critical understanding of the theory, principles and applicability of metal additive manufacturing processes. | Advanced problem-solving skills including critical evaluation, allowing to choose the proper technical and economical solutions, when applying metal additive manufacturing processes, in complex and unpredictable conditions | Manage the selection of metal additive manufacturing processes in a highly complex context.<br>Act autonomously in decision making and of the metal additive manufacturing personnel's tasks |

## 6.8 Mandatory Competence Units Learning Outcomes

### 6.8.1 Competence Unit 00: Additive Manufacturing Processes Overview

| **CU 00: Additive Manufacturing Processes Overview**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Directed energy deposition | 1 |
| Powder bed fusion | 1 |
| Vat photopolymerization | 1 |
| Material jetting | 1 |
| Binder jetting | 1 |
| Material extrusion | 1 |
| Sheet lamination | 1 |
| **Total** | 7 |
| **WORKLOAD** | **14** |

| **Learning Outcomes – CU 00: Additive Manufacturing Processes Pverview** | |
|---|---|
| **KNOWLEDGE** | Factual and broad knowledge of theory, principles and applicability of:<br>– Directed energy deposition<br>– Powder bed fusion<br>– Vat photopolymerization<br>– Material jetting<br>– Binder jetting<br>– Material extrusion<br>– Sheet lamination |
| **SKILLS** | Distinguish parts produced by different AM processes<br>Recognise the advantages and limitations of AM processes from a manufacturing process chain point of view<br>Identify the applicability of different AM processes, according to the characteristics of each process |

### 6.8.2 Competence Unit 01: DED-Arc Process

| CU 01 DED-Arc Process | RECOMENDED CONTACT HOURS | |
|---|---|---|
| LEVEL | INDEPENDENT (I) (applied to Operators and Engineers) | ADVANCED (A) (applied only to Enginners) |
| DED-Arc System (Hardware & Software) | 5 | 0 |
| DED-Arc Physical Principles, Processes and Parameters | 5 | 0 |
| DED-Arc Build platform, feedstock and other consumables | 3 | 0 |
| Post processing operations | 1 | 0 |
| DED-Arc Processes | 0 | 14 |
| DED-Arc Build platform, feedstock and other consumables | 0 | 5 |
| DED-Arc Equipment and accessories | 0 | 3 |
| DED-Arc Manufacturing strategy | 0 | 6 |
| **Subtotal Per Level** | **14** | **28** |
| **Cumulated Subtotal** | **14** | **42** |
| | | **WORKLOAD** |
| **PER LEVEL** | 28 | 56 |
| **CUMULATED** | **28** | **84** |

| LEARNING OUTCOMES – CU 01: DED-Arc Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only to Enginners)** |
| **KNOWLEDGE** | Factual and broad of:<br>– DED-Arc systems<br>– Arc physics<br>– Processable materials with DED-Arc<br>– Processing atmosphere requirements with DED-Arc<br>– Sensors and process controls with DED-Arc | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– DED-Arc equipment, accessories, including build platform, feedstock and other consumables<br>– DED-Arc process parameters and variables, including post processing operations |

| LEARNING OUTCOMES – CU 01: DED-Arc Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only to Enginners)** |
| **SKILLS** | Describe the DED-Arc systems, including the components and their functions<br><br>Distinguish different types of feedstock<br><br>Associate the interaction of the process heat source with the feedstock<br><br>Recognise the DED-Arc parameters and the influence of their adjustment on the as built part (e.g. deformation)<br><br>Recognise the characteristics of the DED-Arc build platform, feedstock and other consumables<br><br>Identify the problems associated with inadequate preparation and set-up of the build platform, handling and storage of feedstock and application of the gases used in DED-Arc | Assess the possibility of manufacturing a specific part with DED-Arc based on the characteristics and limitations of the process<br><br>Relate the influence of the process parameters, build platform, feedstock and other consumables with the properties of the as built part.<br><br>Implement different methodologies related with to process parameters and deposition strategies for reducing distortion of as built parts<br><br>Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them.<br><br>Select specific materials for different applications to meet part requirements.<br><br>Identify specific metallurgical aspects of DED-Arc parts<br><br>Define DED-Arc parameters for manufacturing specific parts<br><br>Adjust process parameters, manufacturing strategy and set up to prevent part defects and process related issues |

### 6.8.3 Competence Unit 08: DED-LB Process

| CU 08: DED-LB Process | RECOMENDED CONTACT HOURS | |
|---|---|---|
| LEVEL | INDEPENDENT (I) (applied to Operators and Engineers) | ADVANCED (A) (applied only to Enginners) |
| DED-LB System (Hardware & Software) | 5 | 0 |
| DED-LB Physical Principles | 2 | 0 |
| DED-LB Parameters | 3 | 0 |
| Build platform, feedstock and other consumables | 3 | 0 |
| Post processing operations | 1 | 0 |
| DED-LB Processes | 0 | 7 |
| DED-LB Build platform, feedstock and other consumables | 0 | 5 |
| DED-LB Equipment and accessories | 0 | 2 |
| DED-LB Manufacturing strategy | 0 | 7 |
| **Subtotal Per Level** | **14** | **21** |
| **Cumulated Subtotal** | **14** | **35** |
| | | **WORKLOAD** |
| **PER LEVEL** | 28 | 42 |
| **CUMULATED** | **28** | **70** |

| LEARNING OUTCOMES – CU 08: DED-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only to Enginners)** |
| **KNOWLEDGE** | Factual and broad of:<br>– DED-LB systems<br>– Laser Characteristics<br>– Build platform<br>– Powder/wire<br>– Gases<br>– Processable materials with DED-LB | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– DED-LB equipment, accessories, including build platform, feedstock and other consumables<br>– DED-LB process parameters and variables, including post processing operation |

| LEARNING OUTCOMES – CU 08: DED-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only to Enginners)** |
| **SKILLS** | Describe the DED-LB systems, including the com-ponents and their functions<br><br>Distinguish different types of feedstock<br><br>Associate the interaction of the process heat source with the feedstock<br><br>Recognise the DED-LB parameters and the influence of their adjustment on the as built part (e.g. deformation)<br><br>Recognise the characteristics of the DED-LB build platform, feedstock and other consumables<br><br>Identify the problems associated with inadequate prepa-ration and set-up of the build platform, handling and storage of feedstock and application of the gases used in DED-LB<br><br>Recognise the basic principles of 3D CAD systems and machine control software | Explain how the DED-LB process works<br><br>Explain the influence of modifying process parameters on the as built part<br><br>Discuss the influence of build platform, feedstock and other consumables characteristics on part manufacturing<br><br>Identify areas that will need thermal compensation<br><br>Identify the cause of defects and propose methods for their mitigation<br><br>Discuss the adequacy of selected equipment and accessories on the part manufacturing<br><br>Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them<br><br>Select specific materials for different applications to meet part requirements<br><br>Identify specific metallurgical aspects of DED-LB parts<br><br>Identify the variables used to define the DED-LB manufacturing strategy |

### 6.8.4 Competence Unit 15: PBF-LB Process

| CU 15: PBF-LB Process | RECOMENDED CONTACT HOURS | |
|---|---|---|
| LEVEL | INDEPENDENT (I) (applied to Operators and Engineers) | ADVANCED (A) (applied only for Enginners) |
| PBF-LB Process Principles | 2 | 0 |
| PBF-LB System – Hardware and Software | 4 | 0 |
| PBF-LB Parameters | 3 | 0 |
| PBF-LB Feedstock | 2 | 0 |
| PBF-LB Consumables | 2 | 0 |
| Post Processing | 1 | 0 |
| PBF-LB Processes | 0 | 7 |
| PBF-LB Build substrate, feedstock and other consumables | 0 | 5 |
| PBF-LB Equipment and accessories | 0 | 2 |
| PBF-LB Manufacturing strategy | 0 | 7 |
| **Subtotal Per Level** | **14** | **21** |
| **Cumulated Subtotal** | **14** | **35** |
| | | **WORKLOAD** |
| **PER LEVEL** | 28 | 42 |
| **CUMULATED** | **28** | **70** |

| LEARNING OUTCOMES – CU 15: PBF-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only for Enginners)** |
| **KNOWLEDGE** | Factual and broad knowledge of:<br>– PBF-LB systems<br>– Laser characteristics<br>– Build platform<br>– Powder<br>– Gases<br>– Processable materials with PBF-LB | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– PBF-LB equipment, accessories, including build platform, feedstock and other consumables<br>– PBF-LB process parameters and variables, including post processing operation |

| LEARNING OUTCOMES – CU 15: PBF-LB Process | | |
|---|---|---|
| **LEVEL** | **INDEPENDENT (applied to Operators and Engineers)** | **ADVANCED (applied only for Enginners)** |
| **SKILLS** | Describe the PBF-LB systems, including the components and their functions<br>Recognise the characteristics of the PBF-LB build platform, feedstock and other consumables<br>Recognise the PBF-LB parameters and the influence of their adjustment on the as built part<br>Recognise the interaction of the process heat source with the feedstock<br>Identify the problems associated with inadequate preparation and setup of the build platform, handling and storage of feedstock and application of the gases used in PBF-LB | Explain how the PBF-LB process works<br>Explain the influence of modifying process parameters on the as built part<br>Discuss the influence of build platform, feedstock and other consumables characteristics on part manufacturing<br>Identify areas that will need thermal compensation<br>Identify the cause of defects and propose methods for their mitigation<br>Discuss the adequacy of selected equipment and accessories on the part manufacturing<br>Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them<br>Select specific materials for different applications to meet part requirements<br>Identify specific metallurgical aspects of PBF-LB parts<br>Identify the variables used to define the PBF-LB manufacturing strategy |

### 6.8.5 Competence Unit 25: Post Processing

| Erro! A origem da referência não foi encontrada.**CU 25: Post Processing**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| General considerations | 2 |
| Thermal treatment | 4 |
| Plastic deformation methods | 2 |
| Subtractive manufacturing | 2 |
| Finishing operations | 2 |
| Practical application | 2 |
| **Total** | 14 |
| **WORKLOAD** | **28** |

| **Learning Outcomes – CU 25: Post Processing** | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Post processing methods (heat treatment, cold work methods, subtractive manufacturing, finishing operations) |
| **SKILLS** | Discuss methods to reduce distortion, using different post processes, for a variety of part geometries and AM processes.<br>Explain the applicable post processing methods to several AM processes as built parts<br>Describe the effect of different heat treatments on microstructure, mechanical properties, residual stress and defects<br>Explain the requirements that the as built part needs to have/comply according to each post process |

## 6.8.6 Competence Unit 26: Introduction to materials

| **CU 26: Introduction to materials**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Structure and properties of metals and alloys | 3 |
| Solidification and Phase Diagrams | 3 |
| Solid state transformations and TTT diagrams | 4 |
| Failure mechanisms: fracture, fatigue, creep | 4 |
| **Total** | 14 |
| **WORKLOAD** | **28** |

| **Learning Outcomes – CU 26: Introduction to materials** | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Structure and properties of metals and alloys;<br>– Solidification and solid-state transformations<br>– Microstructures<br>– Degradation and Failure |
| **SKILLS** | Describe the structures of pure metals and alloys.<br>Explain, in detail, the principles of transformation and conditions of structure under which it occurs.<br>Interpret in detail the phase diagrams information and apply phase diagrams to define microstructures, mechanical properties and alloys.<br>Realise the mechanical properties of metallic materials according to their structures.<br>Describe the differences between elastic, plastic, cold and hot deformation that can occur in metals.<br>Explain the advantages and disadvantages of metals recrystallization, work hardening and strain ageing.<br>Interpret crystalline lattice distortion from given alloying elements and subsequent structural changes.<br>Compare the mechanisms of precipitation, types of precipitates and their location within the microstructure.<br>Explain the effect of loading conditions and temperature on the mechanical properties of metallic materials.<br>Explain in detail the differences between cracks and fractures comparing the mechanisms of different types of failures.<br>Assess types of failures. |

### 6.8.7 Competence Unit 27: AM with steels feedstock (excluding Stainless Steel)

| **CU 27: AM with Steels feedstock (excluding Stainless Steel)**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Characteristics and classification of Low alloy Carbon Steels | 3 |
| Characteristics and classification of Cr-Mo steels | 2 |
| Characteristics and classification of Maraging steels | 1,5 |
| Characteristics and classification of High strength steels | 1,5 |
| Behaviour in AM – General considerations | 2 |
| Behaviour in AM of Low alloy Carbon Steels | 2 |
| Behaviour in AM of Cr-Mo steels | 2 |
| Behaviour in AM of Maraging steels | 2 |
| Behaviour in AM of High strength steels | 2 |
| Cracking phenomena in parts processed by AM | 3 |
| **Total** | 21 |
| **WORKLOAD** | **42** |

| **Learning Outcomes –CU 27: AM with Steels feedstock (excluding Stainless Steel)** | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Different types of Steels as feedstock for producing AM parts, namely: carbon steels, Cr-Mo, maraging and high strength steels |
| **SKILLS** | Describe the theory, principles and applicability of steels:<br>– Describe processability with AM, including obtained properties and their relation with process parameters<br>– Describe main causes of cracking and how to avoid<br>– Identify possible imperfections, including metallurgical imperfections, and how to avoid<br>– Select types of heat treatments when necessary<br><br>For the following types of steels: low alloy, Cr-Mo, maraging and high strength steels:<br>– Explain in detail the effects of micro-alloying, relating grain refinement to mechanical properties.<br>– Discuss the AM conditions for a certain part taking into account the material ability for AM<br>– Discuss carbon equivalent (CE), t 8/5 concept and preheating temperature<br>– Discuss hardenability and maximum cooling rate<br>– Identify the type of heat treatments requirements for a certain part, inferring the heat treatment conditions (depending of the shape and size of the part, the application and the code). |

### 6.8.8 Competence Unit 28: AM with Stainless Steel feedstock

| CU28: AM with Stainless Steel feedstock | CONTACT HOURS |
|---|---|
| **SUBJECT TITLE** | |
| Characteristics and classification of Stainless Steels – general considerations | 2 |
| Characteristics and classification of Austenitic Stainless Steels | 1 |
| Characteristics and classification of Martensitic Ferritic Stainless Steels | 1 |
| Characteristics and classification of Duplex Stainless Steels | 1 |
| Characteristics and classification of Precipitation hardened SS | 1 |
| Behaviour in Additive Manufacturing (AM) of Austenitic Stainless Steels | 2 |
| Behaviour in AM of Martensitic Ferritic Stainless Steels | 2 |
| Behaviour in AM of Duplex Stainless Steels | 1 |
| Behaviour in AM of Precipitation hardened Stainless Steels | 1 |
| Cracking phenomena in Stainless Steel parts processed by AM | 2 |
| **Total** | 14 |
| **WORKLOAD** | **28** |

| Learning Outcomes – AM with Stainless Steel feedstock | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Different types of Stainless Steels as feedstock for producing AM parts, namely: Austenitic, Ferritic, Martensitic, Duplex and Precipitation hardened |
| **SKILLS** | Identify stainless steels type: austenitic, ferritic, martensitic, precipitation hardened, duplex and its ability to be processed by AM in all processes with different feedstock<br>Identify main problems for each Stainless Steel when AM processed by different AM processes and feedstock<br>Identify the material processability with AM, the type of heat source and feedstock<br>Discuss and predict how to prevent major cracking phenomena<br>Decide the type of post treatment required for a certain part (according to the type of stainless steel, the shape and size of the part, the application and any relevant documentation) |

### 6.8.9 Competence Unit 29: AM with Aluminium feedstock

| **CU 29: AM with Aluminium feedstock**Erro! A origem da referência não foi encontrada.<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Characteristics and classification of Aluminium and its alloys | 2 |
| Aluminium and aluminium alloys and their behaviour in AM | 3 |
| Cracking phenomena in parts processed by AM | 2 |
| **Total** | 7 |
| **WORKLOAD** | **14** |

| **Learning Outcomes – CU 29: AM with Aluminium feedstock** | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Aluminium alloys and their processability with AM<br>– Main causes of cracking and how to avoid<br>– Types and objectives of heat treatment techniques |
| **SKILLS** | For the following metal and alloys – Aluminium:<br>– Interpret the processability with AM for each alloy with different AM processes and feedstock<br>– Discuss the applications, recommending processing parameters and shielding gases to achieve quality requirements for a specific part<br>– Distinguish heat treatable and non-heat treatable alloys and problems in AM<br>– Recommend methods to avoid cracking phenomena and solid-state micro fissures, providing alternatives where necessary. |

## 6.8.10 Competence Unit 30: AM with Nickel feedstock

| **CU 30: AM with Nickel feedstock**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Characteristics and classification of Nickel and its alloys | 2 |
| Nickel and nickel alloys and their behaviour in AM | 3 |
| Cracking phenomena in parts processed by AM | 2 |
| **Total** | 7 |
| **WORKLOAD** | **14** |

| **Learning Outcomes – CU 30: AM with Nickel feedstock** | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Nickel processability with AM<br>– Main causes of cracking and how to avoid<br>– Types and goals of heat treatment techniques |
| **SKILLS** | For the following metal and alloys – Nickel:<br>– Interpret the processability with AM for each alloy with different AM processes and feedstock<br>– Discuss the applications, recommending processing parameters and shielding gases to achieve quality requirements for a specific part<br>– Recommend methods to avoid cracking phenomena and solid-state micro fissures, providing alternatives where necessary. |

## 6.8.11 Competence Unit 31: AM with Titanium feedstock

| CU 31: AM with Titanium feedstock | CONTACT HOURS |
|---|---|
| **SUBJECT TITLE** | |
| Characteristics and classification of Titanium and its alloys | 4 |
| Titanium and titanium alloys and their behaviour in AM | 6 |
| Cracking phenomena in parts processed by AM | 4 |
| **Total** | 14 |
| **WORKLOAD** | **28** |

| Learning Outcomes – CU 31:AM with Titanium feedstock | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Titanium processability with AM<br>– Main causes of cracking and how to avoid<br>– Types and goals of heat treatment techniques |
| SKILLS | Describe in detail the theory, principles and applicability of:<br>– Titanium processability with AM<br>– Main causes of cracking and how to avoid<br>– Heat treatments- types and techniques<br><br>For the following metal and its alloys – Titanium:<br>– Interpret the processability with AM<br>– Discuss the applications, recommending heat input, shielding gases to achieve quality requirements for a specific part<br>– Recommend methods to avoid cracking phenomena and solid-state micro cracks, providing alternatives where necessary. |

## 6.8.12 Competence Unit 32: AM with Tungsten feedstock

| CU 32: AM with Tungsten feedstock | CONTACT HOURS |
|---|---|
| **SUBJECT TITLE** | |
| Characteristics and classification of Tungsten | 1 |
| Tungsten behaviour in AM | 1.5 |
| Cracking phenomena in parts processed by AM | 1 |
| **Total** | 3.5 |
| **WORKLOAD** | **7** |

| Learning Outcomes – CU 32: AM with Tungsten feedstock | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Tungsten processability with AM<br>– Main causes of cracking and how to avoid |
| **SKILLS** | For Tungsten:<br>– Interpret the processability of Tungsten with different AM processes and feedstock<br>– Discuss the applications, recommending processing parameters and shielding gases to achieve quality requirements for a specific part |

## 6.8.13 Competence Unit 33: Biomedical metallic materials

| **CU33: Biomedical metallic materials**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Metallic alloys used for biomedical applications | 1 |
| Noble metals (Au, Ag, Pd, Pt) | 1 |
| Pure Ti, Pure Mg | 1 |
| Alloys: Ti6Al7Nb, Ti13Zr13Nb, NiTi, 316L stainless steel Co-Cr-Mo, | 1 |
| Ability to AM | 3 |
| **Total** | 7 |
| **WORKLOAD** | **14** |

| **Learning Outcomes –CU33: Biomedical metallica materials** | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Biomedical metallic materials processability with AM<br>– Main causes of cracking and how to avoid |
| **SKILLS** | Describe in detail the theory, principles and applicability of<br>– Biomedical metallic materials processability with AM<br>– Main causes of cracking and how to avoid<br>– Heat treatments- types and techniques<br><br>For the Biomedical metallic materials<br>– Interpret the processability with AM<br>– Discuss the applications, recommending heat input, shielding gases to achieve quality requirements for a specific part<br>– Recommend methods to avoid cracking phenomena and solid-state micro cracks, providing alternatives where necessary. |

## 6.8.14 Competence Unit 34: Process selection

| CU 34: Process Selection<br>SUBJECT TITLE | CONTACT HOURS |
|---|---|
| Economics and productivity | 7 |
| AM Job analysis | 21 |
| **Total** | 28 |
| **WORKLOAD** | **56** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Process selection** | **6 ADVANCED** | Evaluate, for a specific part, which AM processes can be used for its production | Analysing manufacturing suitability of a client' specific requests | **28** | **56** |
| | | | Proposing AM processes based on part design (in the conceptual design phase, together with the Design Engineer), materials, other manufacturing operations, required properties and applications | | |
| | | | Ensuring liaison with other technical areas (design, materials, etc.) to guarantee manufacturability of AM parts | | |
| | | | Using cost models to establish comparisons between different AM processes/materials and other required processes considering the full manufacturing chain | | |
| | | | Estimating manufacturing times according to each process | | |

| Learning Outcomes – CU 34: Process selection | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Technical adequacy of AM processes to part requirements<br>– Costing and manufacturing time assessment |
| **SKILLS** | Relate supply chain strategies to their effects on the performance of a manufacturing organisation<br>Define the objectives, principles, terminology and systems of management accounting, including costing<br>Elaborate quotations for clients, calculating the cost of a product made by AM, including labour costs, overhead costs, and consumable costs.<br>Compare AM production costs to traditional manufacturing costs determining the return on investment.<br>Estimate manufacturing duration based on the process and part designs specifications<br>Recommend AM processes for specific applications based on job requirements analysis |

## 6.8.15 Competence Unit 35: Metal AM integration

| CU35: Metal AM integration<br>SUBJECT TITLE | CONTACT HOURS |
|---|---|
| Production Management | 7 |
| AM Commercial Integration | 3,5 |
| Case studies | 10,5 |
| **Total** | 21 |
| **WORKLOAD** | **42** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Metal AM integration** | **6/ADVANCED** | Support the continuous technical and commercial integration of Metal AM in an industrial environment | Providing inputs for the design of production management procedures, based on the advantages and limitations of Metal AM processes | **21** | **42** |
| | | | Providing feedback to the management concerning Metal AM costs (e.g. collected from the production by the specialized engineers) | | |
| | | | Promoting AM capability to relevant stakeholders within the company, for its range of products | | |

| Learning Outcomes – CU 35: Metal AM integration | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– AM processes adoption on a company's business model<br>– Technical and commercial implementation plans for AM production |
| **SKILLS** | Analyse all the manufacturing processes existing in the company comparing AM with other manufacturing processes<br>Design AM cells including selection of AM machine and methods to manipulate the part, fixturing and sensing of the part, equipment for loading and unloading.<br>Design a factory layout that incorporates all required manufacturing operations<br>Provide inputs for a factory layout design that incorporates all required manufacturing operations<br>Recommend procedures for integration of AM processes within the company's manufacturing chain<br>Discuss the commercial aspects related to the integration of AM fostering the involvement of internal and external stakeholders in the adoption of AM |

## 6.8.16 Competence Unit 36: Coordination activities

| CU36: Coordination activities<br>SUBJECT TITLE | CONTACT HOURS |
|---|---|
| Communications and coordination | 3 |
| Documentation | 4 |
| **Total** | 7 |
| **WORKLOAD** | **14** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Coordination activities** | **6 ADVANCED** | Coordinate the work with the AM team | Ensuring the link with external suppliers, as well as management, staff and other company departments | **7** | **14** |
| | | | Managing documentation related with the AM process | | |

| Learning Outcomes – CU 36: Coordination activities | |
|---|---|
| **KNOWLEDGE** | Advanced knowledge and critical understanding of the theory, principles and applicability of:<br>– Communications and coordination procedures<br>– Document handling and control |
| **SKILLS** | Manage communications across all actors involved in the AM manufacturing chain<br>Establish procedures for information control and traceability<br>Control all the information generated within a given AM |

## 6.8.17 Competence Unit 43: Production of PBF-LB parts

| CU 43: Production of PBF-LB parts | CONTACT HOURS |
|---|---|
| **SUBJECT TITLE** | |
| PBF-LB process simulation | 7 |
| PBF-LB manufacturing strategy | 7 |
| Case studies | 7 |
| **Total** | 21 |
| **WORKLOAD** | **42** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Production of PBF-LB parts** | **7/Expert** | Specify the process chain for the PBF-LB parts | Interpreting simulation results and design | **21** | 42 |
| | | | Run basic simulations | | |
| | | | Establishing manufacturing plan (e.g. build file, parts nesting, supports, post processing operations, Laser parameters, feedstock, gas, building plate, standards) | | |
| | | | Defining the production of PBF-LB parts together with other staff (e.g. including providing inputs to designers to optimize the shape of AM products) | | |
| | | | Providing technical counselling to the decision of the acquisition of AM equipment | | |
| | | | Preparing instructions for PBF-LB operators | | |
| | | | Defining AM staff's tasks distribution according to the workplan | | |
| | | | Interpreting simulation results and design | | |

| Learning Outcomes – CU 43: Production of PBF-LB parts | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– PBF-LB part production specifications, including simulation information, process parameters, pre and post manufacturing operations and work instructions |
| **SKILLS** | Discuss design for AM features with other AM staff<br>Interpret finite element analysis and numerical modelling to AM (e.g. topology optimisation, distortion, residual stresses, hatching, nesting)<br>Apply workflows for virtual pre-processing (e.g. part orientation, supports)<br>Demonstrate competency in working with scanning strategy software<br>Select specific materials for different applications to meet part requirements.<br>Propose methods to reduce distortion for a variety of part geometries and processes.<br>Identify the cause of defects and propose methods for their mitigation.<br>Identify the most suitable post processing technique for a specific AM process and application<br>Create a PBF-LB AMPS.<br>Produce work instructions for the PBF-LB Operator |

## 6.8.18 Competence Unit 44: Conformity of PBF-LB parts

| **CU 44: Conformity of PBF-LB parts**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Quality Assurance and Quality Control | 10,5 |
| Inspection and Testing Plan | 17,5 |
| Production chain qualification | 7 |
| **Total** | 35 |
| **WORKLOAD** | **70** |

| **CU** | **EQF/ EWF LEVEL** | **JOB FUNCTIONS–** | **JOB REQUIRED ACTIVITIES** | **CONTACT HOURS** | **WORKLOAD** |
|---|---|---|---|---|---|
| **Conformity of PBF-LB parts** | **7/Expert** | Ensure the conformity of the AM process and AM parts | Preparing QA/QC procedures (e.g. reception, handling and storage of feedstock, manufacturing process monitoring) | 35 | 70 |
| | | | Supporting the development of testing and inspection plan (including acceptance criteria for NDT and DT) | | |
| | | | Troubleshooting for causes of non-conformity in the production of AM parts | | |
| | | | Determining corrective actions for eliminating defects (e.g. metallurgical, deformation, warping) based on technical reports (e.g. DT, NDT) | | |
| | | | Ensuring the compliance of the AM production process and the AM parts with the relevant documents (e.g. standards, product specifications, legislation) | | |
| | | | Identifying requirements in terms of AM training | | |
| | | | Implementing AM process and AM parts certification procedures | | |
| | | | Developing procedures to repair parts (e.g. parts damaged in service; together with the client) | | |
| | | | Ensuring production chain qualification (i.e. equipment, operations, staff) | | |

| **Learning Outcomes – CU 44: Conformity of PBF-LB parts** | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– Quality Management<br>– Methods for DT and NDT<br>– Certification of PBF-LB parts<br>– Repair procedures |

| Learning Outcomes – CU 44: Conformity of PBF-LB parts | |
|---|---|
| **SKILLS** | Apply the principles of quality management to process and part qualification<br>Evaluate feedstock characteristics required to qualify a part<br>Develop AM procedures according to appropriate standards and other documentation<br>Select Non-Destructive Testing and Destructive Testing methods to characterise a part<br>Interpret Destructive and Non-Destructive Testing reports<br>Adapt AMPS based on results from testing results<br>Integrate troubleshooting techniques in manufacturing process chain<br>Propose methods to perform the repair and re-certification of a damaged PBF-LB part<br>Guarantee process conformity to client's requests, standards and other requirements |

## 6.8.19 Competence Unit 45: Conformity of facilities featuring PBF-LB

| **CU 45: Conformity of facilities featuring PBF-LB**<br>**SUBJECT TITLE** | **CONTACT HOURS** |
|---|---|
| Health, Safety & Environment in PBF-LB | 10 |
| Infrastructures/ Facility Requirements | 3 |
| Group work | 1 |
| **Total** | 14 |
| **WORKLOAD** | **28** |

| CU | EQF/ EWF LEVEL | JOB FUNCTIONS | JOB REQUIRED ACTIVITIES | CONTACT HOURS | WORKLOAD |
|---|---|---|---|---|---|
| **Conformity of facilities featuring PBF-LB** | **7/Expert** | Support the implementation of facility conformity procedures featuring PBF-LB | Supporting the design of HSE procedures featuring PBF-LB (e.g. Control of Substances Hazardous to Health (COSHH), risk analysis, mitigation plans) | **14** | **28** |
| | | | Providing safety requirements to be a implemented to ensure people' safety on the shop floor | | |
| | | | Providing inputs for waste management | | |
| | | | Preparing incident reports | | |

| **Learning Outcomes – CU 45: Conformity of facilities featuring PBF-LB** | |
|---|---|
| **KNOWLEDGE** | Highly specialised knowledge and critical assessment of theory, principles and applicability of:<br>– HSE in the PBF-LB process |
| **SKILLS** | Explain in detail the health and safety hazards associated with Laser, electricity, gases, fumes, fire, radiation and noise, spatter, flame, fire, combustion.<br>Predict the hazards, defining the health and safety requirements and working procedures, including the definition of the necessary PPE.<br>Recommend healthy and safe workplace practices to be implemented in a manufacturing plant. |

# 7 Section II Practical Application of the Final Metal AM MSc Curriculum

In this section, the initial Curriculum developed for the Metal AM MSc Engineer will be higlighted. This Curriculum was developed as the Initial Metal AM MSc Curriculum, which was then updated to the Curriculum of the previous section.

This Section englobes a Curriculum which was fully implemented on one of ADMIRE Partner's University: Cranfield University and partially implemented in other Partner's Universities: Instituto Superior Tecnico, Bremen Universitat and Birmingham University.

This Curriculum is fully aligned with the Final Metal AM MSc Curriculum previously defined and can be used as a future example for European Universities that decide to adopt the Final Metal AM MSc Curriculum.

## 7.1 Metal AM Engineer Professional Profile

Firstly, after being widely validated by industry the Professional Profile was stabilized and afterwards, following up on this description. The content remained the same (please refer to Table 4 – Degree's Output Profile) when comparing to the Professional Profile, excluding the description "Coordinate the tasks distribution between the operators according to the workplan as well as manage the link between them and the management", which was removed, since the learners most likely won't practise this task during the MSc.

| **Metal AM Engineer Professional Profile** |
|---|
| • *Evaluate manufacturing suitability for clients' requests defining which process is fit for the request, developing cost models and providing feedback concerning operating costs;*<br>• *Develop and execute custom and standard manufacturing plans for additive manufacturing, from validation of design, development, pre and post processing operations, parts conformity and to identifying causes and corrective actions of technical production problems;*<br>• *Coordinate the tasks distribution between the operators according to the workplan as well as manage the link between them and the management.*<br>• *Apply a wide variety of engineering techniques, will contribute to projects in a teaming environment and will investigate, transfer, and adapt processes, techniques, or methods to new applications.* |

## 7.2 Initial Metal AM MSc Curriculum

In this section the Initial Metal AM MSc Curriculum is illustrated.

There is a clear parallelism between the job functions and the job activities and the modular structure of the Metal AM MSc, as depicted in the following figure - Description of the Initial Metal AM MSc Curriculum. A more detailed explanation on the alignment between the Job functions and Job Activities of the Metal AM Engineer and the learning outcomes of each mandatory module is described in the following sub chapters.

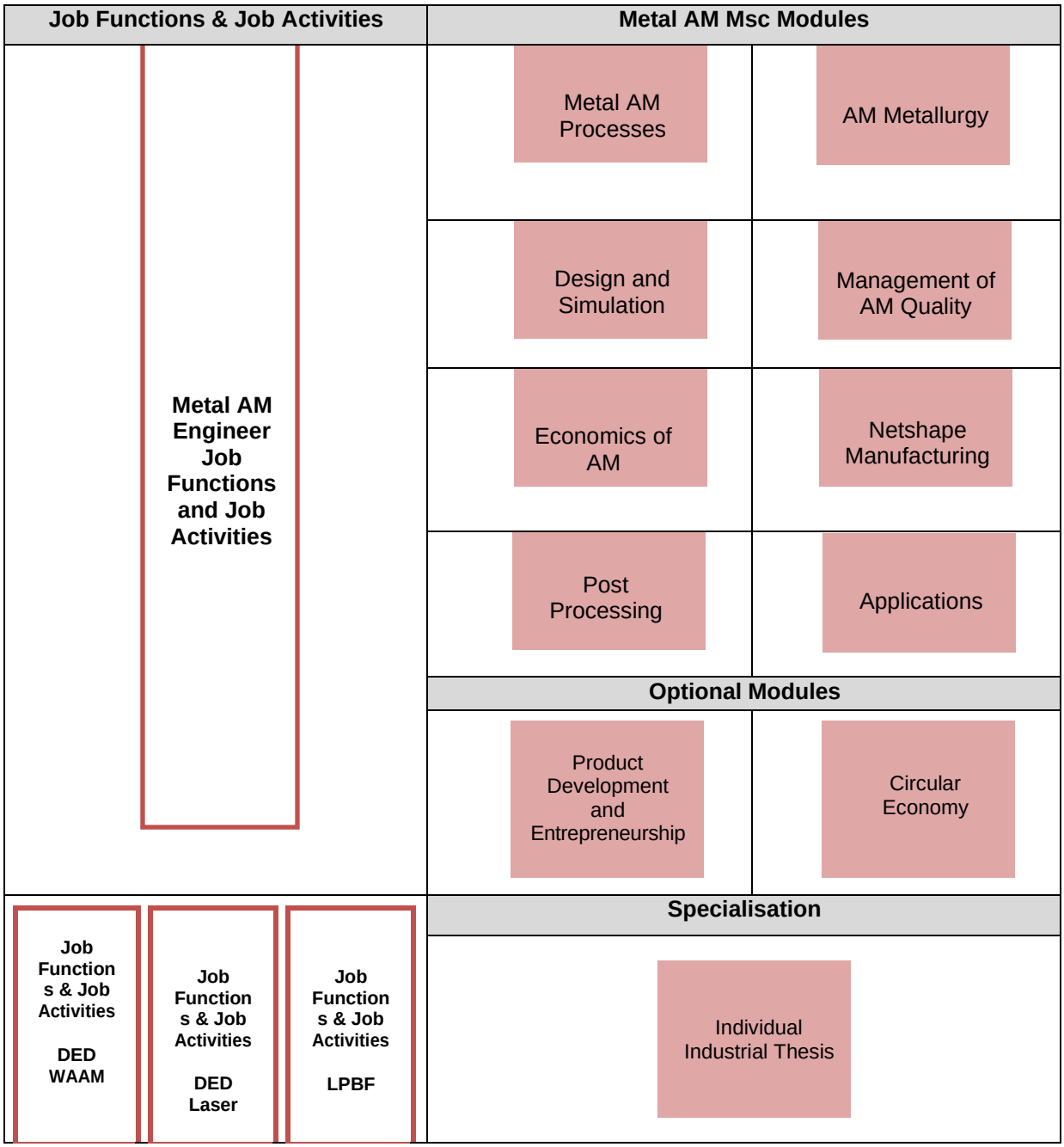


*Figure 3 Description of the Initial Metal AM MSc Curriculum*

### 7.2.1 Initial Metal AM Engineer MSc Curriculum Job Functions and Job Activities

After the long iterative and validation process with industrial stakeholders the following job functions and job activities were acknowledged.

The content of the folowing tables stands for the job functions and activities expected to be performed without completing any specialisation, the following sub chapters contemple the Job Functions and Activities for a specialization in one of the main Metal AM Processes (Direct Energy Deposition – Wire plus Arc, Direct Energy Deposition Laser and Laser Powder Bed Fusion).

| Job Function | Job Activities |
|---|---|
| Evaluate, for a specific part, which AM processes can be used for its production | – Evaluating manufacturing suitability of a client's specific requests<br>– Proposing AM processes based on part design *(in the conceptual design phase, together with the Design Engineer)*, materials, other manufacturing operations, required properties and applications<br>– Ensuring liaison with other technical areas *(design, materials, etc.)* to guarantee manufacturability of AM parts<br>– Using cost models to establish comparisons between different AM processes/materials and other required processes considering the full manufacturing chain<br>– Estimating manufacturing times according to each process |

| | |
|---|---|
| Support the continuous technical and commercial integration of Metal AM in an industrial environment | – Analysing all the manufacturing processes existing in the company *(compare AM with other manufacturing processes)*<br>– Analysing the manufacturing processes associated to an AM process *(address the influence of AM in the company manufacturing chain)*<br>– Designing production management procedures, based on the advantages and limitations of Metal AM processes<br>– Providing feedback to the management concerning operating costs *(e.g. collected from the production by the specialized engineers)*<br>– Promoting AM capability to relevant stakeholders within the company, for its range of products |
| Coordinate the work with the AM team | – Coordinate the link with external suppliers, as well as management, staff and other company departments<br>– Managing documentation related with the AM process<br>– Ensuring production chain qualification *(i.e. equipment, operations, staff)* |

### *7.2.2* Initial Metal AM Engineer MSc Curriculum Engineer Job Functions and Job Activities

**Direct Energy Deposition - Wire plus Arc Additive Manufacturing (DED WAAM)**

| Job Function | Job Activities |
|---|---|
| Specify the process chain for the DED (Wire plus Arc) parts | – Interpreting simulation results<br>– Run simple simulations *(e.g. toolpath planning)*<br>– Designing the toolpath followed by insertion of process parameters *(e.g. partitioning, build strategy management, interface management, build sequence)*<br>– Establishing manufacturing plan *(e.g. Arc parameters, feedstock, gas, building plate, build file, post processing operations, standards)*<br>– Providing technical counselling to support the decision of the acquisition of AM equipment<br>– Defining the production of DED (Wire plus Arc) parts together with other staff *(e.g. including providing inputs to designers to optimize the shape of AM products)*<br>– Specifying post processing operations *(e.g. subtractive manufacturing, heat treatment, surface finishing and treatment)*<br>– Defining AM staff's tasks distribution according to the workplan |

| | |
|---|---|
| Ensure the conformity of the AM process and AM parts | – Preparing QA/QC procedures *(e.g. reception, handling and storage of feedstock and substrate, manufacturing process monitoring)*<br>– Supporting the development of testing and inspection plan *(including acceptance criteria for NDT and DT)*<br>– Troubleshooting for causes of non-conformity in the production of AM parts<br>– Determining corrective actions for eliminating defects *(e.g. metallurgical, deformation, warping)* based on technical reports *(e.g. DT, NDT)*<br>– Ensuring the compliance of the AM production process and the AM parts with the relevant documents *(e.g. standards, product specifications, legislation)*<br>– Identifying requirements in terms of AM training<br>– Implementing AM process and AM parts certification procedures<br>– Developing procedures to repair parts *(e.g. parts damaged in service; together with the client)* |
| Support the implementation of facility conformity procedures featuring DED (Wire plus Arc) | – Supporting the design of HSE procedures featuring DED (Wire plus Arc) *(e.g. risk analysis, mitigation plans)*<br>– Ensuring people's safety requirements on the shop floor<br>– Ensuring waste management<br>– Preparing incident reports |

**Direct Energy Deposition - Laser (DED Laser)**

| Job Function | Job Activities |
|---|---|
| Specify the process chain for the DED (Laser) parts | – Interpreting simulation results<br>– Run simple simulations in toolpath planning<br>– Establishing manufacturing plan *(e.g. Laser parameters, feedstock, gas, building plate, build file, post processing operations, standards)*<br>– Providing technical counselling to the decision of the acquisition of AM equipment<br>– Defining the production of DED (Laser) parts together with other staff *(e.g. including providing inputs to designers to optimize the shape of AM products)*<br>– Specifying post processing operations *(e.g. subtractive manufacturing, heat treatment, surface finishing and treatment)* to fulfil the product requirements<br>– Defining AM staff's tasks distribution according to the workplan |
| Ensure the conformity of the AM process and AM parts | – Preparing QA/QC procedures *(e.g. reception, handling and storage of feedstock, manufacturing process monitoring)*<br>– Supporting the development of testing and inspection plan *(including acceptance criteria for NDT and DT)*<br>– Troubleshooting for causes of non-conformity in the production of AM parts<br>– Determining corrective actions for eliminating defects *(e.g. metallurgical, deformation, warping)* based on technical reports *(e.g. DT, NDT)*<br>– Ensuring the compliance of the AM production process and the AM parts with the relevant documents *(e.g. standards, product specifications, legislation)* |

| | |
|---|---|
| | – Identifying requirements in terms of AM training<br>– Implementing AM process and AM parts certification procedures<br>– Developing procedures to repair parts *(e.g. parts damaged in service; together with the client)* |
| Support the implementation of facility conformity procedures featuring DED (Laser) | – Supporting the design of HSE procedures featuring DED (Laser) *(e.g. risk analysis, mitigation plans)*<br>– Ensuring people's safety requirements on the shop floor<br>– Ensuring waste management<br>– Preparing incident reports |

**Laser Powder Bed Fusion (LPBF)**

| Job Function | Job Activities |
|---|---|
| Specify the process chain for the LPBF parts | – Interpreting simulation results and design<br>– Run simple simulations<br>– Establishing manufacturing plan *(e.g. build file, parts nesting, supports, post processing operations, Laser parameters, feedstock, gas, building plate, standards)*<br>– Defining the production of LPBF parts together with other staff *(e.g. including providing inputs to designers to optimize the shape of AM products)*<br>– Providing technical counselling to the decision of the acquisition of AM equipment<br>– Preparing instructions for LPBF operators<br>– Defining AM staff's tasks distribution according to the workplan |
| Ensure the conformity of the AM process and AM parts | – Preparing QA/QC procedures *(e.g. reception, handling and storage of feedstock, manufacturing process monitoring)*<br>– Supporting the development of testing and inspection plans *(including acceptance criteria for NDT and DT)*<br>– Troubleshooting for causes of non-conformity in the production of AM parts<br>– Determining corrective actions for eliminating defects *(e.g. metallurgical, deformation, warping)* based on technical reports *(e.g. DT, NDT)*<br>– Ensuring the compliance of the AM production process and the AM parts with the relevant documents *(e.g. standards, product specifications, legislation)*<br>– Identifying requirements in terms of AM training<br>– Implementing AM process and AM parts certification procedures |

| | |
|---|---|
| | – Developing procedures to repair parts *(e.g. parts damaged in service; together with the client)* |
| Support the implementation of facility conformity procedures featuring LPBF | – Supporting the design of HSE procedures featuring LPBF *(e.g. risk analysis, mitigation plans)*<br>– Ensuring people's safety requirements on the shop floor<br>– Ensuring waste management<br>– Preparing incident reports |

### 7.2.3 Initial Metal AM MSc Engineer Job Activities and the Learning Outcomes

After the job functions being closed, an extensive analysis of the Learning Outcomes (please refer to D. 3.1 – Draft Guideline of the Metal AM MSc's Purposes and Strategies Alignment) against the Job Activities was carried out, in order to determine consistency between the professional standards and the curricula. This analysis encompassed only the learning outcomes of the mandatory modules.

| **Metal AM Processes** | | |
|---|---|---|
| **Learning Outcomes** | **Job Activities** | **Job Functions** |
| 1. Explain how the different AM processes work and describe the machine architecture. | – Analysing all the manufacturing processes existing in the company (compare AM with other manufacturing processes)<br>– Analysing the manufacturing processes associated to an AM process (address the influence of AM in the company manufacturing chain)<br>– Designing production management procedures, based on the advantages and limitations of Metal AM processes | – Support the continuous technical and commercial integration of Metal AM in an industrial environment |
| 2. Select the best suited AM process for a specific application. | – Evaluating manufacturing suitability of a client's specific requests<br>– Proposing AM processes based on part design (in the conceptual design phase, together with the Design Engineer), materials, other manufacturing operations, required properties and applications<br>– | – Evaluate, for a specific part, which AM processes can be used for its production |

| | | |
|---|---|---|
| – 3. Propose methods to reduce distortion for a variety of part geometries and processes. | – Specifying post processing operations (e.g. subtractive manufacturing, heat treatment, surface finishing and treatment)<br>– | – Specify the process chain for the DED (Wire plus Arc) parts<br>– Specify the process chain for the DED (Laser) parts<br>– Specify the process chain for the LPBF parts<br>– |
| – 4. Propose a suitable tool path for a given part and identify the areas that will need thermal compensation. | – Interpreting simulation results<br>– Run simple simulations (e.g. toolpath planning)<br>– Designing the toolpath followed by insertion of process parameters (e.g. partitioning, build strategy management, interface management, build sequence)<br>– | – Specify the process chain for the DED (Wire plus Arc) parts<br>– Specify the process chain for the DED (Laser) parts<br>– Specify the process chain for the LPBF parts |
| – 5. Identify the cause of defects and propose methods for their mitigation. | – Troubleshooting for causes of non-conformity in the production of AM parts<br>– Determining corrective actions for eliminating defects (e.g. metallurgical, deformation, warping) based on technical reports (e.g. DT, NDT)<br>– Ensuring the compliance of the AM production process and the AM parts with the relevant documents (e.g. standards, product specifications, legislation)<br>– | – Ensure the conformity of the AM process and AM parts |

*Figure 4 Metal AM Processes LOs*

| AM Metallurgy | | |
|---|---|---|
| **Learning Outcomes** | **Job Activities** | **Job Functions** |
| 1. Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them. | - Troubleshooting for causes of non-conformity in the production of AM parts<br>- Determining corrective actions for eliminating defects (e.g. metallurgical, deformation, warping) based on technical reports (e.g. DT, NDT)<br>- Ensuring the compliance of the AM production process and the AM parts with the relevant documents (e.g. standards, product specifications, legislation) | - Ensure the conformity of the AM process and AM parts. |
| 2. Apply phase diagrams and continuous temperature transformation diagrams to a range of alloys to explain the microstructural changes that occur. | - Troubleshooting for causes of non-conformity in the production of AM parts<br>- Determining corrective actions for eliminating defects (e.g. metallurgical, deformation, warping) based on technical reports (e.g. DT, NDT)<br>- Ensuring the compliance of the AM production process and the AM parts with the relevant documents (e.g. standards, product specifications, legislation) | - Ensure the conformity of the AM process and AM parts |

| | | |
|---|---|---|
| 3. Describe the evolution of microstructure during AM and principles of formation of metallurgical phases for a range of alloys. | - Troubleshooting for causes of non-conformity in the production of AM parts<br>- Determining corrective actions for eliminating defects (e.g. metallurgical, deformation, warping) based on technical reports (e.g. DT, NDT)<br>- Ensuring the compliance of the AM production process and the AM parts with the relevant documents (e.g. standards, product specifications, legislation) | - Ensure the conformity of the AM process and AM parts |
| 4. Relate material microstructure to mechanical performance. | - | - |
| 5. Select specific materials for different applications to meet the requirements of the design brief. | – Evaluating manufacturing suitability of a client's specific requests<br>– Proposing AM processes based on part design (in the conceptual design phase, together with the Design Engineer), materials, other manufacturing operations, required properties and applications.<br>– Establishing manufacturing plan (e.g. Arc parameters, feedstock, gas, building plate, build file, post processing operations, standards) | - Evaluate, for a specific part, which AM processes can be used for its production<br>- Specify the process chain for the DED (Wire plus Arc) parts<br>- Specify the process chain for the DED Laser parts<br>- Specify the process chain for the LPBF parts |
| 6. Describe the effect of different heat treatments on microstructure, | - Specifying post processing operations (e.g. subtractive manufacturing, heat treatment, surface finishing and treatment) | - Specify the process chain for the DED (Wire plus Arc) parts |

| | | |
|---|---|---|
| mechanical properties, residual stress and defects. | | |
| 7. Recommend procedures and methods necessary to prevent formation of undesirable phases and defects for dissimilar metallic AM parts. | 8. Troubleshooting for causes of non-conformity in the production of AM parts<br>9. Determining corrective actions for eliminating defects (e.g. metallurgical, deformation, warping) based on technical reports (e.g. DT, NDT)<br>10. Ensuring the compliance of the AM production process and the AM parts with the relevant documents (e.g. standards, product specifications, legislation)<br>11. | - Ensure the conformity of the AM process and AM parts |
| 12. Describe the principles of metal corrosion. | | |

*Figure 5 AM Metallurgy LOs*

| Design and Simulation | | |
|---|---|---|
| **Learning Outcomes** | **Job Activities** | **Job Functions** |
| 1. Demonstrate knowledge and skills in foundational concepts of Topology Optimisation (TO) and Design for AM. | – Ensuring liaison with other technical areas (design, materials, etc.) to guarantee manufacturability of AM parts<br>– Interpreting simulation results<br>– Defining the production of DED (Wire plus Arc) parts together with other staff (e.g. including providing inputs to designers to optimize the shape of AM products) | - Evaluate, for a specific part, which AM processes can be used for its production<br>- Specify the process chain for the DED (Wire plus Arc) parts<br>- Specify the process chain for the DED Laser parts<br>- Specify the process chain for the DED LPBF parts |
| 2. Describe and apply workflows for Design and TO with the software being used for the course. | – Interpreting simulation results<br>– Run simple simulations (e.g. toolpath planning)<br>– Designing the toolpath followed by insertion of process parameters (e.g. partitioning, build strategy management, interface management, build sequence. | - Specify the process chain for the DED (Wire plus Arc) parts<br>- Specify the process chain for the DED Laser parts<br>- Specify the process chain for the DED LPBF parts |

| | | |
|---|---|---|
| | – Proposing AM processes based on part design (in the conceptual design phase, together with the Design Engineer), materials, other manufacturing operations, required properties and applications.<br>– Ensuring liaison with other technical areas (design, materials, etc.) to guarantee manufacturability of AM parts | - Evaluate, for a specific part, which AM processes can be used for its production |
| 3. Demonstrate competency in working with CAD and STL file formats. | - Run simple simulations (e.g. toolpath planning)<br>- Designing the toolpath followed by insertion of process parameters (e.g. partitioning, build strategy management, interface management, build sequence | - Specify the process chain for the DED (Wire plus Arc) parts<br>- Specify the process chain for the DED Laser parts<br>- Specify the process chain for the DED LPBF parts |
| 4. Perform basic TO calculations, based on. AM-specific restrictions in design and manufacturing | - Interpreting simulation results.<br>- Run simple simulations (e.g. toolpath planning).<br>- Designing the toolpath followed by insertion of process parameters (e.g. partitioning, build strategy management, interface management, build sequence. | - Specify the process chain for the DED (Wire plus Arc) parts<br>- Specify the process chain for the DED Laser parts<br>- Specify the process chain for the LPBF parts |

| | | |
|---|---|---|
| 5. Describe and apply workflows for virtual Pre-processing (key items: part orientation, supports). | - Designing the toolpath followed by insertion of process parameters (e.g. partitioning, build strategy management, interface management, build sequence). | - Specify the process chain for the DED (Wire plus Arc) parts.<br>- Specify the process chain for the DED Laser parts.<br>- Specify the process chain for the LPBF parts. |
| 6. Optimise a build-up orientation and support volume. | - Interpreting simulation results<br>- Run simple simulations (e.g. toolpath planning)<br>- Designing the toolpath followed by insertion of process parameters (e.g. partitioning, build strategy management, interface management, build sequence). | - Specify the process chain for the DED (Wire plus Arc) parts.<br>- Specify the process chain for the DED Laser parts.<br>- Specify the process chain for the LPBF parts. |
| 7. Apply finite element analysis and numerical modelling to AM (key items: distortion, residual stresses, hatching, nesting). | - Interpreting simulation results<br>- Run simple simulations (e.g. toolpath planning), | - Specify the process chain for the DED (Wire plus Arc) parts.<br>- Specify the process chain for the DED Laser parts.<br>- Specify the process chain for the LPBF parts. |
| 8. Produce an optimised build job for a metal part. Demonstrate significance of simulation software to improve the performance of metal AM. | - Interpreting simulation results<br>- Run simple simulations (e.g. toolpath planning)<br>- Designing the toolpath followed by insertion of process parameters (e.g. partitioning, build strategy management, interface management, build sequence)<br>- Establishing manufacturing plan (e.g. Arc parameters, feedstock, | - Specify the process chain for the DED (Wire plus Arc) parts.<br>- Specify the process chain for the Laser parts.<br>- Specify the process chain for the LPBF parts. |

| | | |
|---|---|---|
| | gas, building plate, build file, post processing operations, standards)<br>- Defining the production of DED (Wire plus Arc) parts together with other staff (e.g. including providing inputs to designers to optimize the shape of AM products) | |

*Figure 6 Design and Simulation LOs*

| Management of AM Quality | | |
|---|---|---|
| **Learning Outcomes** | **Job Activities** | **Job Functions** |
| 1. Apply the principles of quality management to process and part qualification. | - Preparing QA/QC procedures (e.g. reception, handling and storage of feedstock and substrate, manufacturing process monitoring)<br>- Implementing AM process and AM parts certification procedures<br>- Ensuring the compliance of the AM production process and the AM parts with the relevant documents (e.g. standards, product specifications, legislation) | - Ensure the conformity of the AM process and AM parts – Conformity of DED (wire plus arc), DED Laser and LPBF parts. |
| | – Designing production management procedures, based on the advantages and limitations of Metal AM processes | - Support the continuous technical and commercial integration of Metal AM in an industrial environment |
| | –Coordinate the link with external suppliers, as well as management, staff and other company departments<br>– Managing documentation related with the AM process. | - Coordinate the work with the AM team. |

| | | |
|---|---|---|
| | –Ensuring production chain qualification (i.e. equipment, operations, staff) | |
| 2. Evaluate/assess feedstock characteristics required to qualify a part. | - Evaluating manufacturing suitability of a client's specific requests.<br>- Proposing AM processes based on part design (in the conceptual design phase, together with the Design Engineer), materials, other manufacturing operations, required properties and applications.<br><br>–Troubleshooting for causes of non-conformity in the production of AM parts.<br>–Determining corrective actions for eliminating defects (e.g. metallurgical, deformation, warping) based on technical reports (e.g. DT, NDT).<br>–Ensuring the compliance of the AM production process and the AM parts with the relevant documents (e.g. standards, product specifications, legislation) | - Evaluate, for a specific part, which AM processes can be used for its production<br><br>- Ensure the conformity of the AM process and AM parts |

| | | |
|---|---|---|
| 3. Select the suitable destructive testing method to characterise a part. | - Supporting the development of testing and inspection plan (including acceptance criteria for NDT and DT)<br>- Preparing QA/QC procedures (e.g. reception, handling and storage of feedstock and substrate, manufacturing process monitoring)<br>- Ensuring the compliance of the AM production process and the AM parts with the relevant documents (e.g. standards, product specifications, legislation) | - Ensure the conformity of the AM process and AM parts |
| 4. Select the suitable non-destructive testing method to characterise a part. | - Supporting the development of testing and inspection plan (including acceptance criteria for NDT and DT)<br>- Preparing QA/QC procedures (e.g. reception, handling and storage of feedstock and substrate, manufacturing process monitoring)<br>- Ensuring the compliance of the AM production process and the AM | - Ensure the conformity of the AM process and AM parts |

| | | |
|---|---|---|
| | parts with the relevant documents (e.g. standards, product specifications, legislation) | |
| 5. Integrate troubleshooting techniques in manufacturing process chain. | - Ensuring liaison with other technical areas (design, materials, etc.) to guarantee manufacturability of AM parts<br><br>– Analysing all the manufacturing processes existing in the company *(compare AM with other manufacturing processes)*<br>– Analysing the manufacturing processes associated to an AM process *(address the influence of AM in the company manufacturing chain)*<br>– Designing production management procedures, based on the advantages and limitations of Metal AM processes<br><br>– Coordinate the link with external suppliers, as well as management, staff and other company departments<br>– Managing documentation related with the AM process<br>Ensuring production chain qualification<br>*(i.e. equipment, operations, staff)* | - Evaluate, for a specific part, which AM processes can be used for its production<br><br>- Support the continuous technical and commercial integration of Metal AM in an industrial environment<br><br>- Coordinate the work with the AM team. |

| | | |
|---|---|---|
| | – Establishing manufacturing plan (e.g. Arc parameters, feedstock, gas, building plate, build file, post processing operations, standards)<br>– Defining the production of DED (Wire plus Arc) parts together with other staff (e.g. including providing inputs to designers to optimize the shape of AM products)<br>– Specifying post processing operations (e.g. subtractive manufacturing, heat treatment, surface finishing and treatment)<br>– Defining AM staff's tasks distribution according to the workplan | - Specify the process chain for the DED (Wire plus Arc) parts. |
| | – Preparing QA/QC procedures (e.g. reception, handling and storage of feedstock and substrate, manufacturing process monitoring)<br>– Troubleshooting for causes of non-conformity in the production of AM parts<br>– Determining corrective actions for eliminating defects (e.g. metallurgical, deformation, warping) | - Ensure the conformity of the AM process and AM parts |

| | | |
|---|---|---|
| | based on technical reports (e.g. DT, NDT)<br>– Ensuring the compliance of the AM production process and the AM parts with the relevant documents (e.g. standards, product specifications, legislation)<br>– Developing procedures to repair parts *(e.g. parts damaged in service; together with the client)* | |
| 6. Assess applicable standards against the requirements for the qualification of a part. | - Evaluating manufacturing suitability of a client's specific requests<br>- Proposing AM processes based on part design (in the conceptual design phase, together with the Design Engineer), materials, other manufacturing operations, required properties and applications<br><br>– Troubleshooting for causes of non-conformity in the production of AM parts<br>– Determining corrective actions for eliminating defects (e.g. metallurgical, deformation, warping) based on technical reports (e.g. DT, NDT) | - Evaluate, for a specific part, which AM processes can be used for its production<br><br>- Ensure the conformity of the AM process and AM parts |

| | | |
|---|---|---|
| | – Ensuring the compliance of the AM production process and the AM parts with the relevant documents (e.g. standards, product specifications, legislation)<br>– Implementing AM process and AM parts certification procedures | |
| 7. Interpret Destructive and Non-Destructive Examinations. | - Supporting the development of testing and inspection plan (including acceptance criteria for NDT and DT) | - Ensure the conformity of the AM process and AM parts |
| 8. Recommend healthy and safe workplace practices to be implemented in a manufacturing plant. | - Supporting the design of HSE procedures featuring DED (Wire plus Arc) (e.g. risk analysis, mitigation plans)<br>- Ensuring people's safety requirements on the shop floor<br>- Preparing incident reports | - Support the implementation of facility conformity procedures featuring DED (Wire plus Arc) |
| 9. Iterate AM process specifications the results coming from testing results. | | |

*Figure 7 Management of AM Quality LOs*

| Economics of AM | | |
|---|---|---|
| **Learning Outcomes** | **Job Activities** | **Job Functions** |
| 1. Define the objectives, principles, terminology and systems of management accounting, including costing | - Ensuring liaison with other technical areas (design, materials, etc.) to guarantee manufacturability of AM parts<br>- Using cost models to establish comparisons between different AM processes/materials and other required processes considering the full manufacturing chain<br>- Estimating manufacturing times according to each process | - Evaluate, for a specific part, which AM processes can be used for its production |
| | – Providing feedback to the management concerning operating costs (e.g. collected from the production by the specialized engineers)<br>– Promoting AM capability to relevant stakeholders within the company, for its range of products | - Support the continuous technical and commercial integration of Metal AM in an industrial environment |
| | – Coordinate the link with external suppliers, as well as management, staff and other company departments | - Coordinate the work with the AM team |

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| 2. Relate supply chain strategies to their effects on the performance of a manufacturing organisation | - Ensuring liaison with other technical areas (design, materials, etc.) to guarantee manufacturability of AM parts<br><br>– Analysing all the manufacturing processes existing in the company *(compare AM with other manufacturing processes)*<br>– Analysing the manufacturing processes associated to an AM process *(address the influence of AM in the company manufacturing chain)*<br>– Designing production management procedures, based on the advantages and limitations of Metal AM processes<br>– Promoting AM capability to relevant stakeholders within the company, for its range of products<br><br>– Coordinate the link with external suppliers, as well as management, staff and other company departments | - Evaluate, for a specific part, which AM processes can be used for its production<br><br>- Support the continuous technical and commercial integration of Metal AM in an industrial environment.<br><br>- Coordinate the work with the AM team. |

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| | – Establishing manufacturing plan (e.g. Arc parameters, feedstock, gas, building plate, build file, post processing operations, standards)<br>– Defining the production of DED (Wire plus Arc) parts together with other staff (e.g. including providing inputs to designers to optimize the shape of AM products)<br>– Specifying post processing operations (e.g. subtractive manufacturing, heat treatment, surface finishing and treatment)<br>– Defining AM staff's tasks distribution according to the workplan | - Specify the process chain for the DED (Wire plus Arc) parts. |
| 3. Calculate the cost of a product made by AM, including labour costs, overhead costs, and consumable costs. | - Using cost models to establish comparisons between different AM processes/materials and other required processes considering the full manufacturing chain.<br>- Estimating manufacturing times according to each process<br>- Providing technical counselling to support the decision of the acquisition of AM equipment<br>- | - Evaluate, for a specific part, which AM processes can be used for its production.<br>- Specify the process chain for the DED (Wire plus Arc) parts |

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| 4. Compare the cost of product made by AM with the cost of traditional manufacturing and determine the return on investment. | - Using cost models to establish comparisons between different AM processes/materials and other required processes considering the full manufacturing chain<br>- Estimating manufacturing times according to each process<br><br>– Providing technical counselling to support the decision of the acquisition of AM equipment.<br><br>– Analysing all the manufacturing processes existing in the company *(compare AM with other manufacturing processes)*<br>– Analysing the manufacturing processes associated to an AM process *(address the influence of AM in the company manufacturing chain)* | - Evaluate, for a specific part, which AM processes can be used for its production<br><br>- Specify the process chain for the DED (Wire plus Arc) parts<br><br>- Support the continuous technical and commercial integration of Metal AM in an industrial environment |
| 5. Defend different management styles, team roles, different cultures, and how | - Coordinate the link with external suppliers, as well as management, staff and other company departments. | - Coordinate the work with the AM team. |

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| the management of human diversity can impact organisational performance. | - Defining AM staff's tasks distribution according to the workplan<br>- Identifying requirements in terms of AM training | - Specify the process chain for the DED (Wire plus Arc) parts<br>- Ensure the conformity of the AM process and AM parts |
| Discriminate the relationship between the structure, aspects, and tools applicable in project management activities. | - | - |

*Figure 8 Economics of AM LOs*

| Netshape Manufacturing | | |
|---|---|---|
| **Learning Outcomes** | **Job Activities** | **Job Functions** |
| 1. Discuss the applicability of other Netshape manufacturing processes: casting, forming, powder processing as a complement or substitute of AM.<br>2. Identify the benefits, challenges and limitations associated with the use of Netshape manufacturing techniques.<br>3. Select a suitable Netshape manufacturing process for fabricating shapes and structures.<br>4. Define the AM process requirements and parameters, based on the characteristics of the Netshape manufacturing process. | - Evaluating manufacturing suitability of a client's specific requests<br>- Proposing AM processes based on part design (in the conceptual design phase, together with the Design Engineer), materials, other manufacturing operations, required properties and applications<br>- Ensuring liaison with other technical areas (design, materials, etc.) to guarantee manufacturability of AM parts<br>- Using cost models to establish comparisons between different AM processes/materials and other required processes considering the full manufacturing chain<br>– Analysing all the manufacturing processes existing in the company *(compare AM with other manufacturing processes)*<br>- Analysing the manufacturing processes associated to an AM process *(address the influence of AM in the company manufacturing chain* | - Evaluate, for a specific part, which AM processes can be used for its production.<br>- Support the continuous technical and commercial integration of Metal AM in an industrial environment |

*Figure 9 Netshape Manufacturing LOs*

| Post Processing | | |
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| **Learning Outcomes** | **Job Activities** | **Job Functions** |
| 1. Describe the different post processing techniques for removal of support structures, improvement of surface characteristics and structural integrity. | - Analysing the manufacturing processes associated to an AM process (address the influence of AM in the company manufacturing chain) | - Support the continuous technical and commercial integration of Metal AM in an industrial environment |
| 2. Explain the benefits and limitations of each post processing technique with respect to each AM process. | - Specifying post processing operations (e.g. subtractive manufacturing, heat treatment, surface finishing and treatment) for DED (wire plus arc), DED laser and LPBF. | - Specify the process chain for the DED (Wire plus Arc) parts |
| 3. Identify the most suitable post processing technique for a specific AM process and application. | | |
| 4. Explain the benefits of in-process cold work on the properties and microstructure of parts. | | |

*Figure 10 Post-Processing LOs*

| Applications | | |
|---|---|---|
| **Learning Outcomes** | **Job Activities** | **Job Functions** |
| 1. Design a programme of experiments for producing a simple structure and demonstrate the effect of the main input parameters.<br>2. Analyse data produced from these experiments so that the relationship between process inputs and outputs is understood. | - Interpreting simulation results<br>- Run simple simulations (e.g. toolpath planning)<br>- Designing the toolpath followed by insertion of process parameters (e.g. partitioning, build strategy management, interface management, build sequence)<br>- Establishing manufacturing plan (e.g. Arc parameters, feedstock, gas, building plate, build file, post processing operations, standards) | - Specify the process chain for the DED parts<br>- Specify the process chain for the DED Laser<br>- Specify the process chain for LPBF |
| 3. Design an AM cell for manufacturing a specific AM part that includes selection of a robot, and methods to manipulate the part, fixturing and sensing of the part, equipment for loading and unloading, labour requirements and an estimation of the time to manufacture (same for powder-bed). | - Evaluating manufacturing suitability of a client's specific requests<br>- Proposing AM processes based on part design (in the conceptual design phase, together with the Design Engineer), materials, other manufacturing operations, required properties and applications | - Evaluate, for a specific part, which AM processes can be used for its production |

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| | - Estimating manufacturing times according to each process<br><br>– Analysing all the manufacturing processes existing in the company *(compare AM with other manufacturing processes)*<br>– Analysing the manufacturing processes associated to an AM process *(address the influence of AM in the company manufacturing chain)*<br>– Designing production management procedures, based on the advantages and limitations of Metal AM processes | - Support the continuous technical and commercial integration of Metal AM in an industrial environment |
| 4. Calculate the cost of a typical robotic welding operation including labour costs, overhead costs, and consumable costs. | | |
| 5. Design a factory layout that incorporates all required operations (feedstock storage, machine preparation, material preparation, AM cell and the finishing operations for the part). | - Evaluating manufacturing suitability of a client's specific requests<br>- Proposing AM processes based on part design (in the conceptual design phase, | - Evaluate, for a specific part, which AM processes can be used for its production |

| | | |
|---|---|---|
| 6. Construct a project plan for the installation of the AM system. | together with the Design Engineer), materials, other manufacturing operations, required properties and applications<br>- Estimating manufacturing times according to each process<br><br>– Analysing all the manufacturing processes existing in the company *(compare AM with other manufacturing processes)*<br>– Analysing the manufacturing processes associated to an AM process *(address the influence of AM in the company manufacturing chain)*<br>– Designing production management procedures, based on the advantages and limitations of Metal AM processes | - Support the continuous technical and commercial integration of Metal AM in an industrial environment |
| 7. Propose methods for shielding of the part to prevent oxidation, and thermal management. | - Establishing manufacturing plan (e.g. Arc parameters, feedstock, gas, building plate, build file, post processing operations, standards) | - Specify the process chain for the DED (Wire plus Arc) parts |

*Figure 11 Application of LOs*

# Annex I: International AM Qualification (IAMQS)* System Framework

| FIELD OF ACTIVITIY | | EQF LEVEL | EWF LEVEL | KNOWLEDGE | SKILLS | AUTONOMY AND RESPONSIBILITY | EWF QUALIFICATION SYSTEM |
|---|---|---|---|---|---|---|---|
| INSPECTORS COORDINATORS/MANAGERS &SUPERVISORS/ | OPERATORS | 7 | EXPERT | Highly specialised and forefront knowledge including original thinking, research and critical assessment of theory, principles and applicability of metal additive manufacturing processes. | Highly specialised problem- solving skills including critical and original evaluation, allowing to define or develop the best technical and economical solutions, when applying metal additive manufacturing processes, in complex and unpredictable conditions | Manage and transform the metal additive manufacturing processes in a highly complex context.<br>Fully responsible for the definition and revision of personnel's tasks. | AM |
| | | 6 | ADVANCED | Advanced knowledge and critical understanding of the theory, principles and applicability of metal additive manufacturing processes. | Advanced problem-solving skills including critical evaluation, allowing to choose the proper technical and economical solutions, when applying metal additive manufacturing processes, in complex and unpredictable conditions | Manage the applications of metal additive manufacturing processes in a highly complex context.<br>Act autonomously in decision making and definition in the definition of the metal additive manufacturing personnel's tasks. | |
| | | 5 | SPECIALIZED | Specialised, factual and theoretical of theory, principles and applicability of metal additive manufacturing proce.sses | Specialised range of cognitive and practical skills, allowing to develop solutions or choose the appropriate methods, when applying metal additive manufacturing processes in common/regular problems. | Manage and supervise common or standard metal additive manufacturing processes, in an unpredictable context.<br>Take responsibility in standard work and supervise the metal additive manufacturing personnel's tasks. | |
| | | 4 | INDEPENDENT | Factual and broad concepts in the field of metal additive manufacturing processes. | Fundamental cognitive and practical skills required to develop proper solutions and application of procedures and tools on simple and specific metal additive manufacturing problems. | Self-manage of professional activities and simple standard applications of metal additive manufacturing processes in predictable contexts but subject to change.<br>Supervise routine tasks and similar function workers, as well as take responsibility for decision making in basic work. | |

**General reference descriptors transversal to all qualifications. Each Qualification has its own specific descriptors in terms of Knowledge, skills, autonomy and responsibility.**

*The Management of the International AM Qualification System is done by EWF.

# Annex II: Alignment between the initial and final Metal AM MSC Curriculum

For a full overview of the alignment made between the initial and final Metal AM MSc Curriculum modules and competence units please check the following document.

ADMIRE_European AM MSc Curriculum_A