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Creating knowLedge and skilLs in AddItive Manufacturing

CLLAIM

Metal AM Inspector

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3.1 European AM Designer, Specialist, Operator and European AM Inspector's Occupational Standards

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3.2 LOs' Guideline for the AM Qualifications

Guideline - General information for the public and organizations that implement these qualifications
Metal AM Profiles
Approved: April 2019 - ©*Copyright CLLAIM*

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1. Preface

The present document consists in European Guideline for Metal AM Inspector, developed in the framework of the European project "Creating KnowLedge and SkilLs in AddItive Manufacturing / CLLAIM".

This guideline, for the European education, training, examination and qualification of additive manufacturing personnel, has been developed and approved by all partners involved in the project: EWF, CESOL, DVS, FhG, LZH, Lloyd's Register, IDONIAL, TWI. Contains general information for the public and organisations that implement this qualification.

This guideline was developed with a close relation to industry and standardization bodies. The guideline was validated in workshops directed to industry and education centres. Moreover, the guideline was validated by experts from EWF's International Additive Manufacturing Qualification Council and was built with close relation to ISO and ASTM.

Furthermore, this guideline englobes Occupational Standards and Learning Outcomes for the qualifications identified by the Industry as more relevant: Operator, Designer, Supervisor and Inspector.

Copies of this document can be downloaded from CLLAIM website: cllaimprojectam.eu or requested from European Union dissemination platform.

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2. Routes to Qualification

Three distinct routes to gaining the qualifications described in this document have been agreed to all AM profiles developed under project CLLAIM scope.

1. The Standard Route
2. Blended Learning Route
3. Alternative Route

2.1 The Standard Route

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

2.2 Blended Learning Route

The Cross-Cutting Competence Units (theoretical knowledge and skills) may be taught using Distance Learning Programs under the control of European harmonized system and all the Functional Competence Units (practical knowledge and skills) must be taught at the facilities of a Training Centre that has the capacity to do so.

2.3 Alternative Route

The alternative route allows those who have gained relevant knowledge and skills in a particular job function through formal, informal and non-formal means of education to proceed to examination without a compulsory attendance of an approved training course or specific Competence Unit addressed by it. The alternative route encompasses two possibilities for the validation of knowledge and skills, through: the direct recognition of the Competence Unit.

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3. Guideline for Metal AM Inspector

3.1 Introduction to Metal AM Inspector

This guideline covers the minimum requirements for education and training, in terms of Learning Outcomes (Knowledge and Skills) and the recommended contact (teaching) hours to be devoted to achieving them.

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	
	Recommended Contact Hours*	Expected Workload**
CU 00: Additive manufacturing Process Overview	7	14
CU 01: DED-Arc Process	14	28
CU 08: DED-LB Process	14	28
CU 15: PBF-LB Process	14	28
CU 22: PBF-EB Process	14	28
CU 63: Quality Assurance for Inspection	28	56
CU 64: Inspection-Examination and Testing	38.5	77
Total	129.5	259

* Recommended 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.

** Expected Workload is calculated in hours, corresponding 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.

Although the hours indicated in the above table are merely recommended, it is mandatory that in total the qualification has a minimum of 40 contact hours.

Within EWF´s qualifications, there are two types of Competence Units:

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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 EWF´s Systems 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 workshop training (C), etc., as shown in the following example:

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

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3.2 Occupational Standard

European Metal AM Inspectors are the professionals with the specific knowledge, skills, autonomy and responsibility to conduct inspections to Metal Additive Manufacturing parts production. Their main tasks are:

- Carry out quality assessments of the AM process at various critical stages;
- Perform inspection of all equipment ensuring adequate and controlled use;
- Conduct visual inspection to identify and evaluate imperfections in Metal AM parts and assess against agreed acceptance criteria;
- Verify all Metal AM related activities in production, including (but not limited to) the following points:
    i. Verify data and adequacy of material certificates (base and filler materials);
    ii. Verify identification and traceability of the materials used during the manufacturing process;
    iii. Verify the compliance of feedstock against applicable regulations, standards, codes and/or specifications
- Compile and verify completeness of the final inspection document package.

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3.3 General Access Conditions

The defined access conditions are given in detail for all training institutions participating in the European AM Qualification System.

The access conditions to European Operator Qualification admission are the following:

- National compulsory school diploma;
- Basic knowledge and skills related with quality assurance and HSE
- Visual acuity test.

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3.4 Qualification Outcome Descriptors

QUALIFICATION	EWF LEVEL	KNOWLEDGE	SKILLS	AUTONOMY AND RESPONSIBILITY
ED PBF	ADVANCED	Advanced knowledge and critical understanding of the theory, principles and applicability of metal additive manufacturing design for DED processes.	Advanced problem-solving skills including critical evaluation and design thinking, allowing to choose the proper technical and economical solutions, when designing for DED metal additive manufacturing processes, in complex and unpredictable conditions.	Manage complex DED processes design projects, taking responsibility for decision-making in unpredictable DED processes design applications.

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3.5 Mandatory Competence Units Learning Outcomes

3.5.1 Competence Unit 00: Additive Manufacturing Processes Overview

CU 00: Additive Manufacturing Processes Overview	RECCOMMENDED CONTACT HOURS
SUBJECT TITLE	
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	
KNOWLEDGE	Factual and broad knowledge of theory, principles and applicability of: – Directed energy deposition – Powder bed fusion – Vat photopolymerization – Material jetting – Binder jetting – Material extrusion – Sheet lamination
SKILLS	Distinguish parts produced by different AM processes Recognise the advantages and limitations of AM processes from a manufacturing process chain point of view Identify the applicability of different AM processes, according to the characteristics of each process

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3.5.2 Competence Unit 01: DED-Arc Process

CU01: DED-Arc Process SUBJECT TITLE	CONTACT HOURS
DED-Arc Process principles	2
DED-Arc System (hardware & software)	5
DED-Arc Parameters	3
DED-Arc Build platform, feedstock and other consumables	3
Post processing operations	1
Total	14
WORKLOAD	28

Learning Outcomes – CU01: DED-Arc Process	
KNOWLEDGE	Factual and broad knowledge of: – DED-Arc systems – Arc physics – Processable materials with DED-Arc – Processing atmosphere requirements with DED-Arc – Sensors and process controls with DED-Arc
SKILLS	Describe the DED–Arc systems, including the components and their functions Distinguish different types of feedstock Associate the interaction of the process heat source with the feedstock Recognise the DED–Arc parameters and the influence of their adjustment on the as built part (e.g. deformation) Recognise the characteristics of the DED–Arc build platform, feedstock and other consumables Identify the problems associated with inadequate preparation and set-up of the AM equipment, build platform, handling and storage of feedstock and application of the gases used in DED–Arc

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3.5.3 Competence Unit 08: DED-LB Process

CU 08: DED-LB Process	RECCOMMENDED
SUBJECT TITLE	CONTACT HOURS
DED-LB Process principles	2
DED-LB System (hardware & software)	4
DED-LB parameters	3
Build platform, feedstock and other consumables	4
Post processing operations	1
Total	14
WORKLOAD	28

Learning Outcomes – CU08: DED-LB Process	
KNOWLEDGE	Factual and broad of: – DED-LB systems – Laser Characteristics – Build platform – Powder/wire – Gases – Processable materials with DED-LB
SKILLS	Describe the DED-LB systems, including the components and their functions Distinguish different types of feedstock Associate the interaction of the process heat source with the feedstock Recognise the DED-LB parameters and the influence of their adjustment on the as built part (e.g. deformation) Recognise the characteristics of the DED-LB build platform, feedstock and other consumables 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-LB Recognise the basic principles of 3D CAD systems and machine control software

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3.5.4 Competence Unit 15: PBF-LB Process

CU 15: PBF-LB Process	RECCOMMENDED
SUBJECT TITLE	CONTACT HOURS
PBF-LB Process principles	2
PBF-LB System – Hardware and Software	4
PBF-LB Parameters	3
PBF-LB Build platform, feedstock and other consumables	4
Post Processing	1
Total	14
WORKLOAD	28

Learning Outcomes – CU15: PBF-LB Process	
KNOWLEDGE	Factual and broad knowledge of: – PBF-LB systems – Laser characteristics – Build platform – Powder – Gases – Processable materials with PBF-LB
SKILLS	Describe the PBF-LB systems, including the components and their functions Recognise the characteristics of the PBF-LB build platform, feedstock and other consumables Recognise the PBF-LB parameters and the influence of their adjustment on the as built part Recognise the interaction of the process heat source with the feedstock 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

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3.5.5 Competence Unit 22: PBF-EB Process

CU 22: PBF-EB Process SUBJECT TITLE	RECCOMMENDED CONTACT HOURS
PBF-EB Process principles	2
PBF-EB System – Hardware and Software	4
PBF-EB Parameters	3
PBF-EB Build platform, feedstock and other consumables	4
Parameters	3
Post Processing	1
Total	14
WORKLOAD	28

Learning Outcomes – CU22: PBF-EB Process	
KNOWLEDGE	Factual and broad knowledge of: – EB systems – EB characteristics – Build platform – Wire /Powder – Vacuum pressure – Advantages and limitations of the process – Processable materials with EB
SKILLS	Describe the EB systems, including the components and their functions Outline the main advantages and limitations of EB over conventional and other AM processes, namely based on Electron beam Recognise the characteristics of the EB build platform, feedstock and other consumables Recognise the EB parameters and the influence of their adjustment on the as built part Recognise the interaction of the process heat source with the feedstock Identify the problems associated with inadequate preparation and setup of the build platform, handling and storage of feedstock used in EB

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3.5.6 Competence Unit 63: Quality Assurance for Inspection

CU63: Quality Assurance for Inspection SUBJECT TITLE	RECCOMMENDED CONTACT HOURS
Quality Assurance and Quality Control in AM	7
AM Standards	3.5
Equipment Qualification	7
Parts Qualification	6
General Requirements of training of personnel involved in AM production	2
Measurement, inspection and control	2.5
Total	28
WORKLOAD	**56**

CU	EQF/ EWF LEVEL	JOB FUNCTION	JOB REQUIRED ACTIVITIES	CONTACT HOURS	WORKLOAD
Quality Assurance for Metal AM Processes)	4	Apply Quality Assurance /Quality Control checks.	Verifying if plant facilities and equipment are adequate to parts production	14	28
			Verifying if parts production is in compliance with applicable standards/codes		
			Identifying non-conformities related with all AM production value chain		
			Verifying the adequacy of qualification records of staff engaged in the AM process.		

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Learning Outcomes – CU63: Quality Assurance and Quality Control for Inspection	
KNOWLEDGE	Factual and broad of knowledge: – Quality Assurance and Quality Control principles in Metal AM production – Machine Qualification – Parts Qualification – Standards applied to AM production – Metal AM personnel role and activities – Measurement, inspection and control during Metal AM production
SKILLS	Outline the role, responsibilities, attitude and code of ethics of Metal AM inspectors in construction codes and quality standards. Review Metal AM personnel's approval/qualification for acceptance with applicable standards and specification. Review Metal AM Systems approval/qualification for acceptance with applicable standards and specification. Check an AMPS for acceptance with applicable standards and specification. Recognise methods of measurement used in the control of Metal AM. Recognise working procedures for the measurement of Metal AM parameters. Recognise the need for calibration of equipment, and the methods to validate calibration. Interpret inspection and quality non-conformities identifying the applicable corrective measures.

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3.5.7 Competence Unit 64: Inspection-Examination and Testing

CU64: Inspection-Examination and Testing SUBJECT TITLE	RECCOMMENDED CONTACT HOURS
Imperfections in AM outputs	7
Thermal treatment processes	7
Microscopy and associated techniques used in metallurgical assessments	3,5
Destructive Testing	7
Non-Destructive Examination	7
Metrology	3,5
Final Inspection (proof testing, documentation review)	3,5
Total	38,5
WORKLOAD	**77**

CU	EQF/ EWF LEVEL	JOB FUNCTION	JOB REQUIRED ACTIVITIES	CONTACT HOURS	WORKLOAD
Inspection-Examination and Testing	4	Perform Metal AM production inspections	Verifying the requirements of inspection equipment and its suitability for the testing requirements of the AM part (i.e. calibration and certification for metallurgical and mechanical testing).	50.5	110
			Verifying records of equipment and test procedures used for metallurgical and mechanical testing in the AM process.		
			Selecting appropriate test procedures for the inspection activities carried out during an after the AM		

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			process, when necessary.		
			Carrying out audits of AM build materials supply and storage to be used for the AM part manufacture		
			Verifying if the manufacturing process is in compliance with the applicable standards		
			Signing off the final Inspection document package per AM part/s		

Learning Outcomes – CU64: Inspection-Examination and Testing	
KNOWLEDGE	Factual and broad of: – Inspection and testing plans; – Characterization and evaluation of Metal AM manufacturing imperfections; – Destructive Testing (DT) and Non- destructive testing (NDT) tests characteristics, application and type of delivered information; – Typical quality control and quality assurance documentation used in Metal AM inspection
SKILLS	Identify, on the test reports, the relevant information and content. Identify the causes of Metal AM parts imperfections, with reference to the different Metal AM processes and Metal AM materials. Recognise the different types of Metal AM imperfections identifying the different levels of imperfection significance including comparison between imperfection families. Apply standards criteria for imperfections acceptance/rejection. Select the appropriate test that is requested by the standard regarding a specific activity, identifying the range and application of the most common NDT test methods. Identify the purpose of visual inspection at all stages of Metal AM manufacturing naming the objective and limitations of tools used to aid visual inspection. Perform visual inspection and report in detail the defects identified during an inspection. Review interpreting DT and NDT test results reports to verify its compliance with the requirements of the Metal AM manufacturing. Outline the roles of the respective levels of personnel in Metal AM manufacturing (preparing procedures, conducting tests, evaluating and reporting the results of tests) Describe the typical structure of Inspection Testing Plan (ITP) Review and validate the main inspections records and reports identifying on the test reports the relevant information and content.

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