



Co-funded by the
Erasmus+ Programme
of the European Union

Project title:

Creating knowLedge and skillS in Additive Manufacturing



Reference number:

2017-3309/591838-EPP-1-2017-1-ES-EPPKA2-SSA

PBF LB Operator Guideline

Guideline - General information for the public and organizations that implement these qualifications
European PBF LB Operator

Approved: April 2019

page 1 of 26



LEGAL NOTICE

This document may not be copied, reproduced, or modified in whole or in part for any purpose without written permission of CLLAIM project Consortium.

All rights reserved. This document may change without notice.



Index

1. Preface	4
2. Routes to Qualification	5
2.1 The Standard Route.....	5
2.2 Blended Learning Route	5
2.3 Alternative Route	5
3. Guideline for Metal AM Operator PBF – LB	6
3.1 Introduction to Metal AM Operator PBF - LB.....	6
3.2 Occupational Standard	8
3.3 General Access Conditions.....	9
3.4 Qualification Outcome Descriptors.....	10
3.5 Mandatory Competence Units Learning Outcomes.....	11
3.5.1 Competence Unit 00: Additive Manufacturing Processes Overview.....	11
3.5.2 Competence Unit 15: PBF-LB Process	12
3.5.3 Competence Unit 16: Quality Assurance (QA) in PBF-LB	13
3.5.4 Competence Unit 17: Health, Safety and Environment (HSE) in PBF-LB	14
3.5.5 Competence Unit 18: Hardware, software and build file set-up for PBF-LB.....	15
3.5.6 Competence Unit 19: Monitoring and managing the manufacturing of PBF-LB parts	17
3.5.7 Competence Unit 20: Post processing of PBF-LB parts	18
3.5.8 Competence Unit 21: Maintenance of PBF-LB systems	19
3.5.9 Competence Unit 48: Powder Handling.....	21
3.5.10 Competence Unit 49: Laser Beam Characterisation.....	22
4. Appendix I: EWF Sectoral Systems Framework.....	23
5. Appendix II: List of Competence Units.....	26



1. Preface

The present document consists in European Operator PBF LB Guideline, developed in the framework of an European project “Creating KnowLedge and SkillS in Addltive 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.

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.

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.

3. Guideline for Metal AM Operator PBF – LB

3.1 Introduction to Metal AM Operator PBF - LB

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	EO PBF-LB	
	Recommended Contact Hours*	Expected Workload**
CU 00: Additive manufacturing Process Overview	7	14
CU 15: PBF-LB Process	14	28
CU 16: Quality Assurance (QA) in PBF-LB	7	14
CU 17: Health, Safety and Environment (HSE) in PBF-LB	3,5	7
CU 18: Hardware, software and build file set-up for PBF-LB	14	28
CU 19: Monitoring and managing the manufacturing of PBF-LB parts	3,5	7
CU 20: Post-processing of PBF-LB parts	7	14
CU 21: Maintenance of PBF-LB systems	7	14
Subtotal (without optional CUs)	63	126
CU 48: Powder Handling	14	28
CU 49: Laser Beam Characterisation	7	14
Total	84	168

* 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 CLLAIM’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 CLLAIM'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	
RECOMMENDED CONTACT HOURS	X = SUM (A:C)
Subject Contents	A + B + C

3.2 Occupational Standard

EO PBF-LB is the professional with the specific knowledge, skills, autonomy and responsibility to operate metal AM machines using PBF-LB Process. His/her main tasks are to:

- Operate powder bed-based laser beam machines for AM, including fitting and setting up, maintenance and repair.

He/She will be able to:

- Remove parts and prepare them for post-processing steps;
- Verify Laser beam measurement and positioning in laser powder-bed machines for AM;
- Self-manage the handling of powder (approval, storage, contamination, traceability);
- Develop solutions on basic and specific problems related with laser powder-bed fusion machines



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 Metal AM Operator Qualification admission are the following:

- National compulsory school diploma

3.4 Qualification Outcome Descriptors

QUALIFICATION	EFW LEVEL	KNOWLEDGE	SKILLS	AUTONOMY AND RESPONSIBILITY
EO PBF-LB	INDEPENDENT	Factual and broad concepts in the field of PBF-LB metal additive manufacturing process.	Fundamental cognitive and practical skills required to develop proper solutions and application of procedures and tools on simple and specific of PBF-LB manufacturing problems	Self-manage of professional activities and simple standard applications of PBF-LB manufacturing in predictable contexts but subject to change.

3.5 Mandatory Competence Units Learning Outcomes

Each of the Competence Units that compile the Guideline for Metal AM Operator PBF LB is listed below.

3.5.1 Competence Unit 00: Additive Manufacturing Processes Overview

CU 00: Additive Manufacturing Processes Overview	RECCOMMEN DED 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 – CU 00: Additive Manufacturing Processes Overview	
KNOWLEDGE	Factual and broad knowledge of theory, principles and applicability of: <ul style="list-style-type: none"> – 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

3.5.2 Competence Unit 15: PBF-LB Process

CU 15: PBF-LB Process	RECOMMENDED CONTACT HOURS
SUBJECT TITLE	
PBF-LB Process Principles	2
PBF-LB System – Hardware and Software	4
PBF-LB Parameters	3
PBF-LB Feedstock	2
PBF-LB Consumables	2
Post Processing	1
Total	14
WORKLOAD	28

Learning Outcomes – CU15: PBF-LB Process	
KNOWLEDGE	Factual and broad knowledge of: <ul style="list-style-type: none"> – 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

3.5.3 Competence Unit 16: Quality Assurance (QA) in PBF-LB

CU 16: Quality Assurance (QA) in PBF-LB	RECOMMENDED CONTACT HOURS
SUBJECT TITLE	
General QA principles	2,5
AM Machine QA	1,5
AM Parts QA	1
Visual Inspection Overview	2
Total	7
WORKLOAD	14

Learning Outcomes – Quality Assurance (QA) in PBF-LB	
KNOWLEDGE	Factual and broad knowledge of: <ul style="list-style-type: none"> – Quality Assurance in PBF-LB – Visual Inspection
SKILLS	Recognise the broader use of QA within engineering Recognise the scope of the PBF-LB operator qualification within the AM industry Support the qualification and requalification procedures of PBF-LB equipment Identify the main procedures, equipment and their role Prepare test reports based on the requirements specified by the manufacturer Read a manufacturing plan Compare geometry and dimensions specified in the technical drawings with the as built parts Use simple measurement devices and techniques to carry out a basic visual inspection of the as built part Identify problems in the as build parts distinguishing between imperfections and defects Report defects suggesting either their removal with post processing operations, further inspection or part disposal

3.5.4 Competence Unit 17: Health, Safety and Environment (HSE) in PBF-LB

CU17: Health, Safety and Environment (HSE) in PBF-LB	RECOMMENDED
SUBJECT TITLE	CONTACT HOURS
Health, Safety and Environment	3,5
Total	3,5
WORKLOAD	7

Learning Outcomes – CU17: Health, Safety and Environment (HSE) in PBF-LB	
KNOWLEDGE	Factual and broad of: <ul style="list-style-type: none"> – Health, Safety and Environment related to PBF-LB
SKILLS	Identify the main hazards and safety measures associated with PBF-LB systems

3.5.5 Competence Unit 18: Hardware, software and build file set-up for PBF-LB

CU 18: Hardware, software and build file set-up for PBF-LB	RECOMENDED CONTACT HOURS
SUBJECT TITLE	
PBF-LB machine set-up requirements	4
Pre-build check list	3
Consumables, feedstock & substrate	3
Build files	1
Work documentation	2
Practical implementation of HSE procedures (while fit and set up the machine)	1
Total	14
WORKLOAD	28

CU	EQF/ EWF LEVEL	JOB FUNCTIONS	JOB REQUIRED ACTIVITIES	CONTACT HOURS	WORKLOAD
Hardware, software and build file set-up for PBF-LB	4 Independent	Hardware, software and build file set-up for PBF-LB	Verifying the PBF-LB system set-up according to the procedure determined by the machine manufacturer and required operational conditions	14	28
			Preparing and verifying the build substrate and feedstock conditions		
			Performing: build file loading, process preparation, process starts, in process observation and mal function detection and mitigation		
			Build observation		
			Following HSE procedures during machine and build file set-up		

Learning Outcomes – CU 18: Hardware, software and build file set-up for PBF-LB	
KNOWLEDGE	Factual and broad knowledge of: Variables of PBF-LB and related operational conditions parameters PBF-LB equipment requirements Materials used for PBF-LB Type of files and work documentation HSE procedures under PBF-LB
SKILLS	Prepare the machine for operation, according to the AM procedure specification Prepare the feedstock, build platform and the machine in accordance to the material being used Verify if the PBF-LB machine complies with the machine manufacturer and/or internal specifications Load files to PBF-LB machines Verify if the PBF-LB machines are working in accordance with the job specification, in terms of process parameters Comply with HSE procedures associated to PBF-LB machines Interpret technical information related to the PBF-LB process and machines

3.5.6 Competence Unit 19: Monitoring and managing the manufacturing of PBF-LB parts

CU 19: Monitoring and managing the manufacturing of the PBF-LB parts	RECOMENDED CONTACT HOURS
SUBJECT TITLE	
Machine functionalities and monitoring systems	2
HSE Procedures	0,5
Documentation	1
Total	3,5
WORKLOAD	7

CU	EQF/ EWF LEVEL	JOB FUNCTIONS	JOB REQUIRED ACTIVITIES	CONTACT HOURS	WORKLOAD
Monitoring and managing the manufacturing of PBF-LB parts	4 Independent	Monitoring and managing the manufacturing of PBF-LB parts	Following HSE procedures when printing AM parts	3,5	7
			Following and completing work documentation according to quality/parts requirements		
			Reporting issues and implementing corrective or preventive actions based on parts' requirements feedback from the Engineer		

Learning Outcomes – CU 19: Monitoring and managing the manufacturing of the PBF-LB parts	
KNOWLEDGE	Factual and broad of: <ul style="list-style-type: none"> – Manufacturing of PBF-LB parts – Machine functionalities and monitoring systems
SKILLS	Load powder following mandatory safety procedures Apply HSE procedures when manufacturing parts Interpret technical documentation related to the requirements of the as built parts Identify the main reasons for failure during the manufacturing process Prepare reports on the manufacturing process, including identified issues

3.5.7 Competence Unit 20: Post processing of PBF-LB parts

CU 20: Post processing of PBF-LB parts	RECOMENDED CONTACT HOURS
SUBJECT TITLE	
Post-build cycle operations	3
Manual tools and methods for post-processing operations	4
Total	7
WORKLOAD	14

CU	EQF/ EWF LEVEL	JOB FUNCTIONS	JOB REQUIRED ACTIVITIES	CONTACT HOURS	WORKLOAD
Post processing of PBF-LB parts	4 Independent	Prepare PBF-LB parts for post processing	Providing information from monitoring data about critical areas for extended testing	7	14
			Applying simple manual operations to parts (cleaning, subtractive & post processing)		
			Handing parts for post processing operations		
			Following applicable HSE procedures		

Learning Outcomes – CU 20: Post processing of PBF-LB parts

KNOWLEDGE	Factual and broad of: <ul style="list-style-type: none"> – Powder removal processes – Manual Tools and Methods for subtractive operations – Procedures for different post-processing methods and materials
	SKILLS

3.5.8 Competence Unit 21: Maintenance of PBF-LB systems

CU 21: Maintenance of PBF-LB systems	RECOMENDED CONTACT HOURS
SUBJECT TITLE	
General maintenance aspects	2
Optical elements	0,5
Parts maintenance	1,5
Gas supply system	0,5
Auxiliary elements maintenance	1,5
Application driven material change	1
Total	7
WORKLOAD	14

CU	EQF/ EWF LEVEL	JOB FUNCTIONS	JOB ACTIVITIES	REQUIRED	CONTACT HOURS	WORKLOAD
Maintenance of PBF-LB systems	4 Independent	Maintain and repair the PBF-LB system	Implementing equipment manufacturer's maintenance routines	7	14	
			Cleaning and replacing materials components (e.g. powder bed, cleaning agent, filters, cover glass)			
			Reporting problems to the Engineer			
			Following applicable HSE procedures			

Learning Outcomes – CU21: Maintenance of PBF-LB systems

KNOWLEDGE	Factual and broad of:
	<ul style="list-style-type: none"> – Maintenance aspects associated with PBF-LB systems

Learning Outcomes – CU21: Maintenance of PBF-LB systems

SKILLS	<ul style="list-style-type: none"> Change protective lens and clean the nozzle Assess the need to perform maintenance operations in PBF-LB system Perform maintenance operations in PBF-LB system Identify the consumables for the different machine parts Report the need to execute specific maintenance Support other technicians during system maintenance Verify the cleanliness of the optic system Verify if the optical system is working correctly Monitoring and calibration status Verify the level of wear of a mechanical component Verify the system gas flow Adequate maintenance routines to the material type Verify the condition and make use of the personal protective equipment
---------------	--

3.5.9 Competence Unit 48: Powder Handling

CU 48: Powder Handling	RECOMENDED CONTACT HOURS
SUBJECT TITLE	
Overview of Powder Manufacturing Processes	3
Chemical Composition and Physical Properties	4
Particle Size Distribution	2
Powder storage, handling, ageing and documentation	3
Powder reusability	1
HSE procedures	1
Total	14
WORKLOAD	28

CU	EQF/ EWF LEVEL	JOB FUNCTIONS	JOB REQUIRED ACTIVITIES	CONTACT HOURS	WORKLOAD
Power Handling	4 Independent	Manage powders for Metal AM	Implementing procedures for powder delivery and storage	14	28
			Preparing and analysing powder according to technical documentation		
			Performing powder reconditioning (e.g. sieving) after build cycle		
			Following HSE procedures		

Learning Outcomes – CU 48: Powder Handling	
KNOWLEDGE	Factual and broad of: <ul style="list-style-type: none"> – Powder handling, storage and reconditioning
SKILLS	Complete technical documentation related to powders for metal AM Characterise powders according to instructions from the engineer Ensure powder conditioning according to the AM Procedure Specification Control the reusability of powders Handle powders according to HSE procedures

3.5.10 Competence Unit 49: Laser Beam Characterisation

CU 49: Laser Beam and Characterisation	RECOMENDED CONTACT HOURS
SUBJECT TITLE	
Laser Beam parameters and conditions	2
Measurement Equipment	5
Total	7
WORKLOAD	1

CU	EQF/ EWF LEVEL	JOB FUNCTIONS	JOB REQUIRED ACTIVITIES	CONTACT HOURS	WORKLOAD
Laser Beam Characterisation	4 Independent	Verify Laser Beam	Checking of the Laser beam characteristics and properties	7	14

Learning Outcomes – CU 49: Laser Beam Characterisation	
KNOWLEDGE	Factual and broad of: <ul style="list-style-type: none"> – Laser Beam characteristics and properties – Measurement equipment
SKILLS	Safely carry out power measurements including power stability Safely carry out beam profiling in different areas of the build platform Use other measurement equipment to determine other Laser beam properties Carry out measurement in accordance with existing standards and/or internal specifications

4. Appendix I: EWF Sectoral Systems Framework

AM PROFILE	EQF LEVEL	CLLAIM LEVEL	KNOWLEDGE	SKILLS	AUTONOMY AND RESPONSIBILITY	QUALIFICATION SYSTEM
	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. Fully responsible for the definition and revision of personnel’s tasks.	
DESIGNERS	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	Manage the applications of metal additive manufacturing processes in a highly complex context.	AM



				additive manufacturing processes, in complex and unpredictable conditions	Act autonomously in decision making and definition in the definition of the metal additive manufacturing personnel's tasks.
OPERATORS INSPECTORS SUPERVISORS	5	SPECIALIZED	Specialised, factual and theoretical of theory, principles and applicability of metal additive manufacturing processes	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. 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	Self-manage of professional activities and simple standard applications of



					application of metal additive procedures and tools manufacturing processes in on simple and specific metal additive manufacturing contexts but subject to change. problems. Supervise routine tasks and similar function workers, as well as take responsibility for decision making in basic work.	
--	--	--	--	--	---	--

5. Appendix II: List of Competence Units

CODE	Designation
CU 00	Additive manufacturing Process Overview
CU 15	PBF-LB Process
CU 16	Quality Assurance (QA) in PBF-LB
CU 17	Health, Safety and Environment (HSE) in PBF-LB
CU 18	Hardware, software and build file set-up for PBF-LB
CU 19	Monitoring and managing the manufacturing of PBF-LB parts
CU 20	Post-processing of PBF-LB parts
CU 21	Maintenance of PBF-LB systems