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A qualification procedure to manufacture and repair aerospace parts with electron beam melting

L. Portolés [b,*], O. Jordá [b], L. Jordá [b], A. Uriondo [a,*], M. Esperon-Miguez [a], S. Perinpanayagam [a]

[a] IVHM-Boeing Centre, Cranfield University, Bedforshire MK43 0AL, United Kingdom
[b] AIMME-Instituto Tecnológico Metalmecánico, Parque Tecnológico, Avd. Leonardo Da Vinci, 38, 46980 Valencia, Spain

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ABSTRACT

This paper is focused on qualification procedures for metal parts manufactured using new additive manufacturing (AM) techniques in the aerospace industry. The main aim is to understand the interaction between these technologies and the stringent regulatory framework of this industry in order to develop correct quality assurance and quality control procedures in accordance with the certification process for the technology and spare parts. These include all the testing and validation necessary to implement them, as well as to maintain their capability throughout their life-cycle, specific procedures to manufacture or repair parts, work-flows and records, amongst others. An entire qualification procedure for electron beam melting (EBM) to reproduce and repair an aerospace part has been developed and it is presented in this paper. These will be part of the future quality assurance and quality management systems of those aerospace companies that implement AM in their supply chain.

1. Introduction

There is broad consensus on the potential applications of additive manufacturing (AM) technologies for repairing and manufacturing parts in the aerospace industry. There are many studies on the capability of this technology for designing parts in this industry [1–3]; repairing and manufacturing parts for turbo engines [4]; in the spare part supply chain in MRO processes [5–7], amongst others.

The main characteristics that make this technology attractive for this industry include optimal raw material usage, reduced raw material stock size, fewer machine operations, reduced hard tooling requirements and reduced lead times when compared to other conventional manufacturing processes like forging, casting or machining. The buy-to-fly ratio is a measure of the material efficiency in terms of the amount of raw material needed for manufacturing the final part. In contrast with traditional machining methods, which have buy-to-fly ratios between 5 and 20 [8], AM can achieve values close to one [9]. Groneck [10] highlights some advantages in terms of cost and cycle-time savings by switching from multi-piece built-up assembly to a single-piece.

In the aerospace sector, AM processes must be developed to meet the industry's stringent requirements and to ensure that products can achieve the robust performance levels established by traditional manufacturing methods, as well as, comply with the regulation framework.

Requirements for commercial aircraft parts are mainly based on the regulations of the European Aviation Safety Agency (EASA) and regulations of the Federal Aviation Administration (FAA). These regulations are extensive and detailed, but the most relevant regulations in the context of AM can be found in CS-25, Book 1, Subpart D, Subsections CS 25.603 and CS 25.605 [11].

1. **CS 25.603 Materials**. The suitability and durability of materials used for parts, the failure of which could adversely affect safety, must:
   - be established on the basis of experience or tests;
   - conform to approved specifications, that ensure their having the strength and other properties assumed in the design data (see AMC 25.603(b)); and
   - take into account the effects of environmental conditions, such as temperature and humidity.

* Corresponding authors.
E-mail addresses: lportoles@aimme.es (L. Portolés), a.uriondo@cranfield.ac.uk (A. Uriondo).

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2. **CS 25.605 Fabrication methods**.
   - Methods of fabrication used must produce a consistently sound structure. If a fabrication process (such as glueing, spot welding, or heat treating) requires close control to reach this objective, the process must be performed under an approved process specification; and
   - each new aircraft fabrication method must be substantiated by a test programme

With the lack of technology maturity in terms of design, qualification, process specifications and standardisation, it is difficult for the aerospace industry to develop a single specification and associated database for AM of a given alloy. The AM process itself is not sufficient to produce an airworthy component. Heat treatments, such as stress relief or hot isostatic pressing (HIP), are required to improve structural properties [12,13]. Machining the surface is required to reduce roughness, increase dimensional accuracy, and to prevent the initiation of surface cracks [14].Therefore, process specifications for each aircraft component should be defined from the beginning.

Nowadays, the literature about how AM manufacturing parameters and post processes affect the final material are very extensive. Facchini et al. [15] have studied how to modify the mechanical properties of Ti6Al4V AM parts with heat treatments. Murr et al. [16] studied microstructure differences for Ti6Al4V concluding that the hardness in SLM (41 HRC) is bigger than in EBM (32 HRC) for Ti6Al4V components. Thijs et al. [17] observed in their studies that if more material remains for a longer duration at higher temperatures during the AM process, the volume of precipitates will increase and thus the microhardness will be higher. Strondl et al. [18] have studied the microstructure evolution and phase analysis of Inconel 718 with EBM without any post-process (HIP). They obtained a matrix consisting of γ-phase grains oriented in almost the same direction, like a single crystal.

There is also literature related to qualification procedures in the aerospace sector. Frazier et al. [19] describes the qualification approach followed by the U.S navy for structural metallic components. Brice, from the Langley Research Centre at NASA, reviews and discusses how difficult it is to qualify novel manufacturing processes and materials in the aerospace sector [20].

The contribution of this paper is developing and applying to a real case a qualification procedure (QP) for EBM following the aerospace industry practices and taking into account certain particularities of the manufacturing process.

The QP is an important issue for implementing AM in the aerospace market. This can be defined as a methodology by which all critical parameters and their allowance ranges are identified, and the repeatability of the process is also guaranteed. In other words, the QP is the method used for the assessment of all the variables/factors suitable to influence both technical requirements of the final part and process reproducibility. The QP requires the assessment and control of key raw materials, consumables, and process parameters; the development of a fixed practice for each AM component; the verification of each fixed practice via NDI and destructive testing; and part-specific acceptance testing (both NDI and destructive testing) to ensure the integrity of parts.

This paper presents a QP for EBM to reach the reproducibility of the results. This result would be the basis for future QA/QC procedures.

2. Qualification procedure for EBM

This QP presents a methodology to assess all the variables/factors that can influence both, technical requirements of the final part and process reproducibility. It takes into account potential dependencies between different process variables in the specification procedure. As it has been mentioned above, these dependencies change from one technology to another and for different materials, which will require a particular QP for each combination. Nevertheless, from a high level perspective, all of them should share a common framework that takes into consideration the key aspects of using AM in the aerospace industry. Fig. 1 outlines all QP steps that need to be followed for each combination of AM technology and material.

2.1. Process specification development

In this step, a process specification has to be developed for manufacturing/repairing each aircraft component. As part of the process specification, the AM process and post-processes must be established based on technical requirements (see Table 1).

Therefore, the process specification for manufacturing or repairing a component should be established based on all the information previously gathered. Each process specification should include at least:

- **Manufacturing technologies**. All the manufacturing/repairing techniques used for achieving the final part.

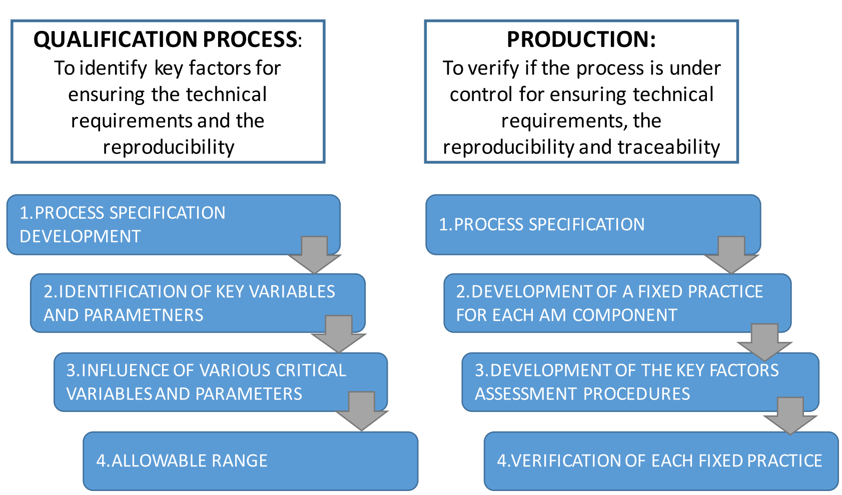

Fig. 1. General description of the qualification procedure.