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Additive manufacturing of ITER first wall panel parts by two approaches: Selective laser melting and electron beam melting

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HIGHLIGHTS

- A novel way using additive manufacturing to fabricated ITER First Wall Panel parts is proposed.
- ITER First Wall Panel parts successfully manufactured by both SLM and EBM are compared.
- Physical and mechanical properties of SLM and EBM SS316L are clearly compared.
- Problems encountered for large scale part building were discussed and possible solutions are given.

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ABSTRACT

Fabrication of ITER First Wall (FW) Panel parts by two additive manufacturing (AM) technologies, selective laser melting (SLM) and electron beam melting (EBM), was supported by Fusion for Energy (F4E). For the first time, AM is applied to manufacture ITER In-Vessel parts with complex design. Fully dense SS316L was prepared by both SLM and EBM after developing optimized laser/electron beam parameters. Characterizations on the density, magnetic permeability, microstructure, defects and inclusions were carried out. Tensile properties, Charpy-impact properties and fatigue properties of SLM and EBM SS316L were also compared. ITER FW Panel parts were successfully fabricated by both SLM and EBM in a one-step building process. The SLM part has smoother surface, better size accuracy while the EBM part takes much less time to build. Issues with removing support structures might be solved by slightly changing the design of the internal cooling system. Further investigation of the influence of neutron irradiation on materials properties between the two AM technologies is needed.

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1. Introduction

Optimization of the manufacturing process for designed components is of great importance to ITER [1]. The geometry complexity of many target components and the high level criteria of material properties make this task difficult, costly and time consuming. For example, one established method consists of many steps including machining various parts and assembly, pre-joining and joining parts by hot isostatic pressing diffusion bonding followed by post machining and heat treatment [2]. New manufacturing approaches to simplify the fabrication process, to lower the cost and manufacturing lead-time and to increase the manufacturing success rates, are needed for DEMO and future nuclear fusion reactors. Many researchers have tried to apply a novel technology called additive manufacturing (AM), commonly known as 3D printing, on fabricating nuclear related materials and small-scale components due to its one-step building character regardless of component complexity and its time saving feature [3–7].

As its name suggests, AM prints the 3D components directly from powder precursors according to computer-aided design (CAD) models. This is very different from the conventional manufacturing processes that remove material from ingots to form the desired shape and resulting in a loss of material. On contrary, AM is a net shape technology that adds further material upon an existing solidified core [8]. There are many different AM methods depending on the energy source, materials and material feeding systems

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Table 1
Features of the SLM and EBM building processes.

	Source	Preheating	Spot size	Layer thickness	Building speed	Environment
SLM	Laser	No	small	small	fast	N_2 or Ar
EBM	Electron	Yes	large	large	Very fast	Vacuum

while in metal AM field there are three main approaches: powder-bed system [9–12], powder-feed system [13] and-wire feed system [14]. Both Selective Laser Melting (SLM) [15] and Electron Beam Melting (EBM) [16] belong to the powder-bed system where component geometry and surface finishing can be accurately controlled. Although both methods use computer controlled local melting patterns and a layer-by-layer printing of the same precursor powder, the final SLM and EBM components exhibit different features and properties. This can be ascribed to the different interaction mechanisms between the material and the laser or electron beams and the involvement of different building parameters and environment, etc. Some of the building process features of the two AM approaches are listed in Table 1.

Being aware of the advantages of AM and with the aim to apply the most appropriate AM technology on nuclear fusion engineering, Fusion for Energy (F4E) has supported the present study to investigate the possibility of using SLM or EBM to fabricate ITER First Wall (FW) Panel parts made of 316L stainless steels (SS316L). This is the first time AM is applied in an attempt to produce ITER In-Vessel machine parts with complex design. Preliminary results on mechanical properties have proven that SLM and EBM SS316L both can meet the RCC-MR code requirements after necessary optimizations [17]. The RCC-MR code is used for conservative comparison of materials properties and this paper focuses on the assessment of the two AM methods. Emphases are put on engineering aspects: the achieved physical/mechanical properties, the FW Panel parts manufacturing process and the engineering problems encountered. Suggestions on how to further tune in parameters and how to build components in large scale are also provided.

2. Materials and experimental procedures

(1) Powder precursors

The SS316L precursor powder is gas atomized spherical granules prepared by Carpenter (Carpenter powder products AB, Torshälla, Sweden). 200 kg powder with the size 10–45 μm for SLM and 300 kg powder with the size 53–150 μm for EBM were delivered for the parameter developments and the component building. The two batches of powder are both almost spherical shaped as shown in Fig. 1, although some small satellite particles are found attached to larger powder granules. The apparent density and flow ability are checked and results show that both powders are suitable for the AM process. The chemical compositions of the precursor powders are listed in Table 2 and a phase analysis by X-ray diffraction confirmed that both are fully austenite. [17]

(2) SLM and EBM facilities and fabrication procedures

SLM was performed by a laser melting facility (AM250, Renishaw plc, Staffordshire, United Kingdom). A sketch illustrating its working principle is shown in Fig. 2a. A dis-continuous Nd:YAG fiber laser with 200 W maximum power output together with the scanning system produces a scanning laser spot of about 75 μm in diameter. At first, a model is programed and is processed so that the proper scan patterns of every layer (50 μm thick) of the 3D-body are produced (CAD). Secondly, the laser beam with optimized focal length will start scanning and melt the first powder bed according to this pattern (CAM). Thirdly, after the first powder layer is done, the building plate (250 × 250 × 20 mm) is lowered down 50 μm and a new layer of fresh powder is dispersed evenly on top by the recoater. The laser scans and melts the new layer and, finally, by repeating this layer-by-layer solidification manner, a solid 3D component is formed. Un-melted powder is collected and sieved for recirculation.

EBM was performed by an electron beam melting facility (Arcam A2, Arcam AB, Mölndal, Sweden). The process principle sketch is shown in Fig. 2b. Similar to SLM, the CAD patterns of each layer are produced. Thereafter, a defocused electron beam scans the powder granule bed to perform a preheating process. In the preheating process, the powder layer is heated up to above 800 °C (measured by the thermocouple attached on the start plate) where granules are gently bounded to each other. Directly after pre-heating, the scanning electron beam fully melts the powder granule layer following the CAD generated pattern. After one layer is finished, the start plate is lowered down 100 μm and a rake disperses a new layer of powder granules and the process is repeated. When completed, the solid 3D component together with un-melted powder slowly cools down to room temperature.

Scanning strategies and parameters are developed in order to obtain high volume density of the as-build SS316L parts. For this purpose, hundreds of cubic blocks with the size 10 × 10 × 10 mm were produced for density characterization. Tensile test specimens (as-build size Φ17 × 150 mm), Charpy impact test specimens

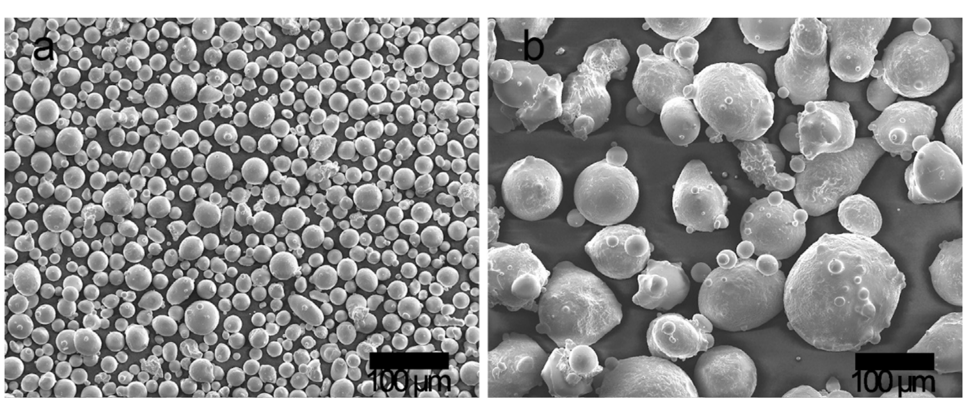

Fig. 1. SS316L precursor powders used for SLM (a) and EBM (b) as seen by secondary SEM.

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