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The materials production and processing facility at the Spanish National Centre for fusion technologies (TechnoFusión)

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Abstract: In response to the urgent request from the EU Fusion Program, a new facility (TechnoFusión) for research and development of fusion materials has been planned with support from the Regional Government of Madrid and the Ministry of Science and Innovation of Spain. TechnoFusión, the National Centre for Fusion Technologies, aims screening different technologies relevant for ITER and DEMO environments while promoting the contribution of international companies and research groups into the Fusion Programme. For this purpose, the centre will be provided with a large number of unique facilities for the manufacture, testing (a triple-beam multi-ion irradiation, a plasma–wall interaction device, a remote handling for under ionizing radiation testing) and analysis of critical fusion materials. Particularly, the objectives, semi-industrial scale capabilities and present status of the TechnoFusión Materials Production and Processing (MPP) facility are presented. Previous studies revealed that the MPP facility will be a very promising infrastructure for the development of new materials and prototypes demanded by the fusion technology and therefore some of them will be here briefly summarized.

Keywords: Fusion materials, Materials production technology, Materials facility.

1. Introduction

In the future fusion reactors, the interaction of the plasma and radiation with plasma facing materials (PFMs) and other component material of the reactor vessel is one of the most serious issues because these materials will be subjected to very high fluxes of energetic particles and heat. The key materials in a fusion reactor are that used in the structure of the plasma facing wall (Be, W alloys, C-based materials). PFMs and others next to the plasma have to operate under extreme conditions so that the plasma attains the optimal operating parameters to make the fusion reactors profitable devices for energy production. Perhaps, this is the more urgent issue to be resolved in order to make nuclear fusion an economical and safe energy resource.

Currently, with some particular exceptions (i.e. Eurofer or F8H2 steels), materials with properties satisfying the design conditions required in fusion reactors are only produced on a laboratory scale. Under such circumstances, the research results obtained from materials produced in different laboratories usually yield discrepancies due to differences in composition, fabrication techniques and processing conditions as well as to a shortage of material, which difficults the undertaking of a rigorous characterization. The lack of research laboratories with the capability to manufacture a quantity of material in a single batch sufficient for full characterization is evident. The European Union (EU) Fusion Program [1] has pointed out the urgent need of developing this capability in the European laboratories. Accordingly, the Material Production and Processing (MPP) facility at the Spanish National Centre for Fusion Technologies (TechnoFusión) is being designed for contributing to the EU Program on Fusion Materials.

This paper describes this facility, its main objectives in the framework of the EU Program on fusion materials, its present status, the laboratories and techniques required and some recent results in the development of W-alloys and nano-structured ferritic oxide dispersion strengthened (ODS) steels.

2. The TechnoFusión MPP facility

2.1. Objectives

Following the guidelines from the EU Program on Fusion Materials, the MPP facility at TechnoFusión is planned to give priority to the research and development of the following materials:

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- Low activation and radiation-resistant alloys for the blanket system (Eurofer, ODS steels and nano-structured steels).
- W and its ODS alloys for use in a divertor system cooled by He (operating temperatures 700–1350 °C).
- SiC_f/SiC composites for advanced blanket systems cooled by Li–Pb.
- Functionally graded materials, ceramics and coatings.

The main objectives and activities of the TechnoFusión MPP facility can be summarized as follows:

- Production of fusion materials within the framework of the EU Program.
- Pilot batch fabrication of structural alloys up to ∼50 kg by means of the vacuum induction melting (VIM) technique.
- Production of ODS steels, and ODS and non-ODS W alloys by mechanical alloying and subsequent consolidation by hot isostatic pressing (HIP) or spark plasma sintering (SPS).
- Development of nano-structured or ultrafine-grained alloys via mechanical alloying, HIP and SPS techniques.
- Development of severe plastic deformation techniques and thermomechanical treatments for improving the mechanical behaviour of the structural alloys.
- Development of multifunctional ceramics layers and coating techniques for W and other structural alloys using the vacuum plasma spraying (VPS) and SPS.

2.2. Structure, equipments and techniques

The MPP facility will consist of three laboratories: two dedicated to the production and processing of materials, and a third one for the preparation of samples, and approximate analysis and control of the materials. The tasks of these areas are as follows:

Laboratory of metal casting and processing. It will be dedicated to the production of pilot batches of steel and other alloys by the VIM technique, as well as to the processing of materials by thermo-mechanical treatments such as forging, rolling, swaging and equal channel angular pressing.
Laboratory of powder metallurgy and ceramic materials. It will be in charge of the powder processing and fabrication of ODS alloys, and multifunctional ceramics, via HIP and SPS, as well as of the development of joinings and protective coatings using these techniques. Also, the development of protective coatings by the VPS technology is planned.
Laboratory of analysis and control of materials. It will comprise the facilities and instruments for performing the compositional and structural analyses of the materials developed at the facility, as well as their preliminary mechanical testing.

The MPP facility of TechnoFusión encompassing these three research and development areas will be housed in a building of new construction that has been specifically designed for this purpose (see Fig. 1). The laboratories will be furnished with the required installations, equipments and personnel for accomplishing the objectives of TechnoFusión. The following basic equipments will be available:

- A VIM furnace for fabricating of high purity steels and alloys having an accurate composition and a very low content of the interstitial impurities responsible for the worsening of mechanical properties. The basic features of this furnace would be:
  - Crucible volume: ∼3–8 l.
  - Maximum steel capacity: ∼50 kg.
  - Power supply for melting: ∼100 kW.
  - Base vacuum: $<10^{-5}$ mbar.
  - Vacuum chamber for pre-heating mould and for casting in vacuum
  - Electromagnetic stir for melt homogenization.
  - Automatic loading system.
- A HIP furnace for sintering of materials processed by powder metallurgy, and for joining and improvement of the cast alloys. Its basic features would be:
  - Maximum working pressure: ∼400 MPa.
  - Maximum working temperature: ∼2200 °C.
  - Hot zone dimensions: ∼200 mm Ø × 800 mm.
- A SPS furnace for fast sintering, joining, fabrication of nano-structured materials such as ODS alloys and functional ceramics, as well as coatings of functionally graded materials. The features would be:
  - Maximum working temperature: ∼2200 °C.
  - Maximum pressing force: ∼1250 kN.
  - Maximum current: 30 kA DC.
  - Power supply: 350 kVA.
  - Pulse duration: 1–255 ms.
  - Double wall chamber for sintering in vacuum and controlled atmospheres.
  - Systems for working in hydrogen and in vacuum.
- A VPS system for developing protective surface coatings for PFMs. The system would have the following capabilities:
  - A chamber with revolving stage for handling large workpieces.
  - Anode with a tungsten insert for torch operation with electrical currents exceeding 2.5 kA and input powers above 100 kW.
  - Reverse transferred-arc for substrate cleaning.
  - Plasma guns inducing to minimum heating of the substrate under coating conditions.
  - Variable operation conditions for growing graded coatings.
  - Growing rates as fast as 10 μm/min.
  - Coating thickness in the range 20 μm–2 mm
  - Variable projection distance, between 15 and 135 cm, to allow different coating conditions.
  - Capability for coating surfaces, with complex geometries, as large as 70 cm × 70 cm.
  - Advanced control of the chamber and plasma jet.
  - Plasma gun operation at spray pressures as low as 1 mbar.

3. Present status

The MPP facility project at TechnoFusión have been planned for the last two years by a design team of researchers accounting with support from the Regional Government of Madrid and the Ministry of Science and Innovation of Spain. The construction of a building in the region of Madrid to house the facility has been assumed and the building project is under way.

Meanwhile, the viability of some of these proposed techniques to produce fusion materials has been explored for the materials research group associated to TechnoFusión.

W is considered as a candidate material for PFCs in a future fusion power reactor because of its refractory characteristics, low tritium retention and low sputtering yielding. However, W, and the W alloys so far considered candidate for fusion applications, do not exhibit the mechanical behavior required for PFC applications. Thus, new W alloys and fabrication techniques are being explored in other to develop W materials with enhanced mechanical properties. Y_2O_3- and La_2O_3-reinforced W alloys have been fabricated by HIP as well as by SPS in an attempt to improve their mechanical characteristics by oxide dispersion strengthening and addition of alloying elements, such as Ti and V, that favor the sintering process of the W alloys [1–4]. The preliminary mechanical tests of these materials have indicated that these techniques

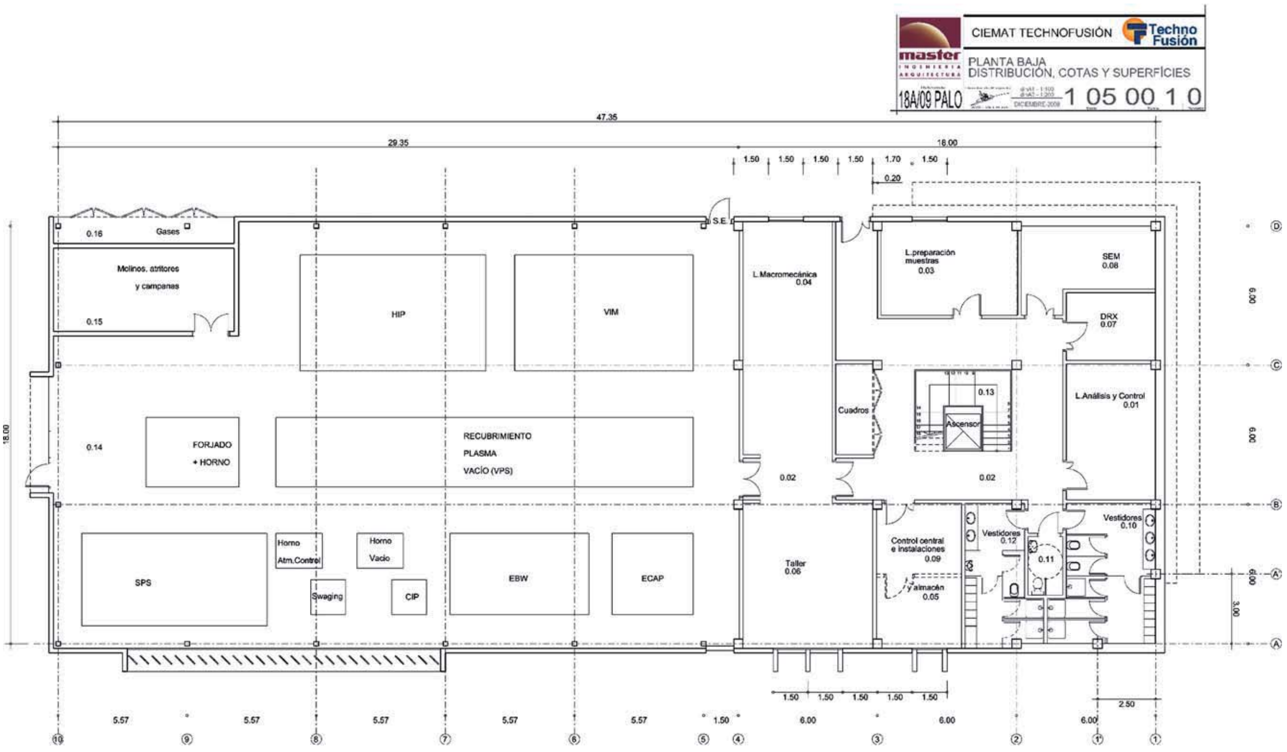

Fig. 1. Actual distribution layout for the equipment of TechnoFusión MPP facility.

can be successful in producing W alloys with enhanced properties [5,6].

Dispersion strengthening appears to be the most promising approach to expand the operating temperature window of the steels for nuclear applications. The processing conditions for achieving ODS Fe-(12−14) wt% Cr alloys and ODS Eurofer steel, both with a ultrafine-grained microstructure, have been also investigated, and their microstructural and mechanical characteristics reported elsewhere [7–11].

These previous results have revealed that the TechnoFusión MPP facility will be a very promising infrastructure for the development of the new materials demanded by the fusion technology.

4. Conclusions

Fusion reactors would not be economically viable and safe without the development of new structural materials. Therefore, the TechnoFusión MPP facility has been devised to conduct an intense research and development on fusion materials, in response to the insistent demand of the international fusion programs for developing new materials that can satisfy the design conditions of the future fusion reactors.

The guidelines of the MPP facility at TechnoFusión, presently in progress, track the proposes of the UE Program on fusion materials and can be summarized as follows:

- to carry out a strong technological development to produce pilot batches of advanced materials for fusion applications,
- to provide the materials research groups with materials for a full evaluation of their microstructure and properties to establish the comprehensive database essential for the design of the future power fusion reactors.

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