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Overview of recent Russian materials and technologies R&D activities related to ITER and DEMO constructions

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Abstract

An overview is given of the activities and major achievements within recent R&D performed in Russia on materials and technologies for ITER and DEMO. In Russia, the basic materials manufacturing and technologies have been selected for ITER, for two reference DEMO breeding blanket concepts and for the related long term R&D. The review on the recent results of investigations on low activation materials (V–Ti–Cr alloys, Fe–12Cr–2W–V–Ta steel EK-181), beryllium and superconducting materials is presented. The fabrication of tubes, sheet and other forms from low activation materials is mentioned. The activity in beryllium materials both in the domestic studies and international cooperation is outlined. The progress in enhancement of the properties of superconducting materials for the ITER magnet system is presented, and the prospect of further developments in superconducting materials for DEMO magnet system is analyzed.

1. Introduction

The strategy of development of atomic energy for Russia includes the creation of industrial fusion reactors. That is why the ITER and DEMO projects are necessary and important steps toward the incorporation of fusion energy in the energy system of Russia. The development and use of high technological low activation, creep resistant and irradiation resistant structural materials in fusion reactors is of primary importance for the attainment of safe and ecologically acceptable fusion energy plants. The development of superconducting materials for fusion reactor magnet systems of also plays a principal and decisive role for providing fusion energy plant competitiveness. The complex of research on the development of low activation materials, beryllium materials and superconducting materials must be treated as a high technology area of material science. Main objectives of the RF research program are the development of low activation and beryllium materials and the appropriate technologies. These will create a sound base for the participation of Russia in the realization of international projects on the development of experimental breeding blanket modules of DEMO reactor and to provide the technical basis for the realization of the national conceptual project DEMO-RF.

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2. Low activation metallic structural materials

To a great extend the fundamental and technological criteria for the development of low activation metallic structural materials (decay time to the residual radioactivity of remote level (10^{-2} Sv/h) is less than 100 years) has been formulated in the countries devoted to the exploration of fusion energy application [1]. Using laboratory scale samples, it was demonstrated that their functional properties could be equal to the properties of the conventional analog alloys. The main activities in the development of low activation materials are focused on the implementation of industrial scale manufacturing processes with minimum impurities contamination, on the optimization of composition of the alloys and on achieving uniformity of microstructure. As a result, the base technologies of low activation V–4Ti–4Cr alloys (USA, Japan, Russia and China) and ferritic–martensitic steels Fe–9Cr–W–V–Ta (EUROFER-97, JLF-1, F82H, in EC, Japan and USA) and Fe–12Cr–W–V–Ta (EE-181, in Russia) were established. In Russia, the works on low activation materials beneficially uses the wide experience of the development and application of ferritic–martensitic 12% Cr steels, such as EP-450, EP-900 (in reactors BOR-60, BN-350, BN-600) and vanadium based alloys (in reactors for space application).

2.1. Low activation V–(4–10)Ti–(4–5)Cr alloys

The V–(4–10)Ti–(4–5)Cr alloys are the most promising materials for application in fusion reactors with liquid metal coolants (Li, Na), which combine low activation properties with attractive functional parameters relative to conventional structural materials and designed for operating temperatures as high as 700–750 °C. The basic composition of V–4Ti–4Cr was proposed in USA [2]. In Russia (in VNIINM), the alloys V–(4–10)Ti–(4–5)Cr are under exploration [3,4]. The 50 kg ingots of the alloy with base composition V–4Ti–4Cr has been fabricated and tested. On the base of developed 'Technical Standard' (VNIINM, OAO 'Uralredmet') the experimental industrial production of high purity vanadium has been established (2000–2002, OAO 'Uralredmet') and a reliable technology for melting V–Ti–Cr alloys has been developed [4]. The industrial technologies for fabrication of different products (sheet, tube and rod) from V–Ti–Cr alloys billets have been developed. The quality of these products has been analyzed [3,5] and confirmed to be high. The increase of the mass of ingots up to 100–300 kg while maintaining the quality is possible using the developed melting process [4]. The work on these enhanced weight ingots and fabrication of different products (sheet, tube and rod) is foreseen in 2006–2007. The established experimental industrial fabrication of the V–4Ti–4Cr products is technologically ready for the fabrication of experimental module of DEMO-RF to be installed in ITER. The recommended and experimentally measured chemical compositions of V–4Ti–4Cr alloys are given in [5]. One of the most important factors defining the quality of V–Ti–Cr alloys is the level of concentration of such impurities as oxygen and nitrogen. These concentrations are presented in Fig. 1. It can be seen that the developed manufacturing processes guarantee the acceptably low levels of O and N concentrations in ingots of V and V–Ti–Cr alloy. The calculated decay rates of residual radioactivity in the so-called 'pure' V–4Ti–4Cr (without any impurities), recommended specification (VV1) and real experimental (VVC2) ingots after their calculated 'irradiation' in the BN-600 and DEMO reactors are shown in Fig. 2. As is shown in Fig. 2 the time to attainment of 'remote level' of radioactivity in 'pure' composition is equal to only 3.5 years for BN-600 reactor and 6.0 years for DEMO-RF. The time to attainment of 'remote level' state for real composition VV2 is 25 years (DEMO-RF) and 20 years for BN-600.

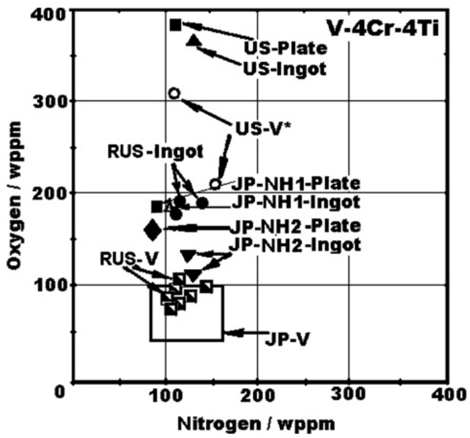

Fig. 1. Contamination by O and N in the ingots of V and V–4Ti–4Cr products (ingots, plates), produced in USA, Japan and RF.