THE BELGIUM CONTRIBUTION TO THE DEVELOPMENT OF STEELS FOR FUSION APPLICATIONS.

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A number of important in-vessel components of future nuclear fusion reactors is planned to be produced out of reduced activation ferritic martensitic (RAFM) steels. These components will include breading blanket, supports for divertor, pipes and other elements to be placed inside of the vacuum vessel and therefore be subject for significant irradiation damage level. In the currently considered scenario in Europe, the end of life fluence of DEMO-1 is about 20 dpa [1]. Accordingly, the in-vessel structural materials must withstand the harsh operational conditions sustaining acceptable mechanical properties. Thanks to the extensive experimental investigations performed on RAFM steels, two specific challenges related to the irradiation ageing of the steels were recognized, namely: (i) low-temperature embrittlement (LTE) and (ii) high-temperature creep (HTC) deformation [1, 2]. The LTE occurs under irradiation at temperature below 350 ºC, which practically excludes the application of well-known pressurized water reactor (PWR) cooling system using water pushing to use liquid metal or gas-cooled systems instead. Accordingly, to achieve the justifiable thermal efficiency the outlet temperature must be raised above 550 ºC, which is considered as the upper operational temperature for the RAFM steels developed up to now. The latter is defined by the creep strength and creep lifetime. It is therefore necessary to improve the operational limit of the baseline RAFM steel (EUROFER97) in terms of resistance against LTE and/or enhancement of high temperature strength. Important condition is to stay within the low-activation limit (i.e. respect chemical limitations) as well as to employ commercially viable technology for the production.

In the present work, we deliver the results of one decade efforts carried out mostly in Belgium which are dedicated to improvement of the EUROFER97 via several routes. The development routes include the following approaches: (i) reduction of manganese and carbon content coupled with alternation of other chemical elements and followed by quench & rolling procedures: so-called Clean Steels; (ii) alternation of spatial distribution and morphology of carbonitrides by varying carbon, vanadium and tantalum content followed by heat treatment optimization: MA1 and MA2; (iii) doping with zirconium/titanium and increase of tantalum content outside of the EUROFER97 specification: Zr/Ti alloys. Quantification of the improvement of the newly developed grades compared to EUROFER97 in terms of ductile to brittle transition temperature (DBTT), proof stress, uniform elongation and ductility is presented in Fig.1.

In addition to the improvement shown in Fig.1, the first results of the neutron irradiation campaigns and long-term creep tests become available. The results prove that the irradiation ageing of the advanced grades occurs via similar mechanism as in EUROFER97, which enables us to translate the trends revealed earlier for EUROFER97 to predict the extension of the irradiation effects in the advanced steels. The creep tests show that the lifetime of the strength-improved materials appropriately increases if compared to the EUROFER97 steel. The physical explanation for the enhanced properties is provided thanks to the in-depth characterization of the microstructure, coupling it with existing mechanistic models.

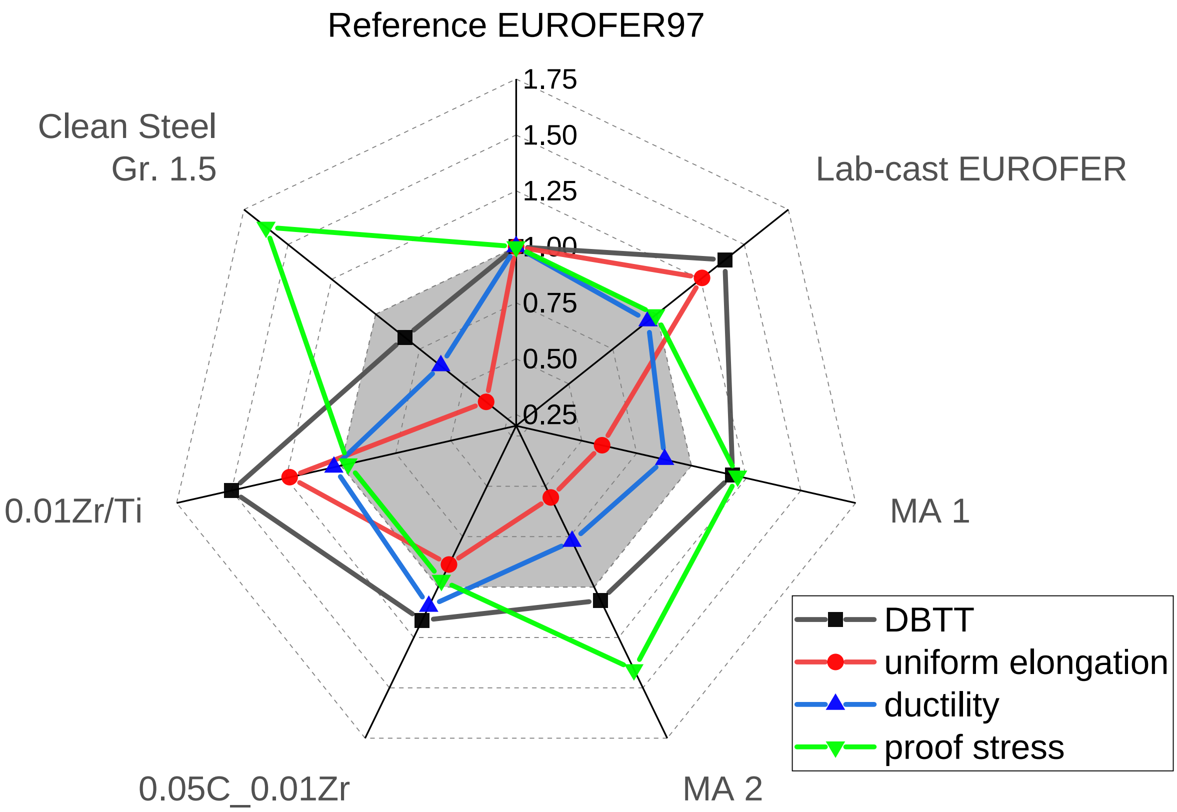

Figure 1. Quantification of improvement of the newly developed grades compared to EUROFER97 in terms of ductile to brittle transition temperature (DBTT), proof stress, uniform elongation and ductility. The displayed properties are normalized relative to the values measured in the EUROFER97 steel. Any point standing outside of the grey hexagon signifies an improvement of a corresponding property.

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