Low activation steels reinforced by nano-oxides particles

Oriana TASSA, CSM, Castel Romano, Roma

Reduced activation ferritic/martensitic (RAFM) steels are currently the most technologically mature option for the structural material of proposed fusion energy reactors. Although RAFM steels have numerous advantageous features including well-established large-scale industrial fabrication capability (leveraging the worldwide steel industries) and overall good thermomechanical properties and resistance to neutron irradiation-induced property, the extremely challenging operating environment of fusion reactors requests the development of even higher performance steels. As a consequence, RAFM steels are considered to have a rather limited operating temperature range in nuclear energy systems to avoid both radiation embrittlement, thermal aging instabilities and creep rupture failure, being the upper viable operational temperature lower than 550°C.

Two main strategies for developing improved steels for fusion energy applications have been investigated. The first, more conventional, approach is based on the chemical composition and process condition optimization by using computational thermodynamics modelling and modified thermomechanical treatments (TMT) to produce higher performance reduced activation ferritic/martensitic (RAFM) steels. The second, more innovative, strategy is based on powder metallurgy techniques to produce very high strength oxide dispersion strengthened (ODS) steels capable of operating at very high temperatures and with potentially very high resistance to fusion neutron-induced property degradation. These advanced alloys present an excellent combination of properties including favorable resistance against corrosion, creep and swelling, as well as good irradiation damage tolerance due to a reinforcement by the homogenous dispersion of hard nano-sized ceramic.

The process for producing ODS steels has been investigated since many years and a large literature is available. The present paper is aimed to describe both fabrication issues and nano-microstructurally based understanding of the resulting properties. Batches of blended micrometric 14Cr steel powders and Y_2O_3 nanostructured particles were prepared by mechanical alloying: milling speed and times were systematically varied in order to study the effect of the milling conditions on the milled powders or compacts. Two consolidation methods were employed, namely hot isostatic pressing (HIP) and hot extrusion to produce (HE) to produce ODS rods and the effect of process parameter variations were investigated. Hot extrusion was successfully applied to produce a batch of about 10 kg of ODS steel. Tensile tests were performed from room temperature up to 800 °C. Mechanically alloyed samples were characterized by means of TEM, revealing the in-situ precipitation of nano-sized particles with a complex structure of a Y-Si-Ti oxide. Such particles are stable after annealing at 800 °C for 24 h while the matrix hardness remaining around 400 HV. Ultimate tensile stress higher than 1350 MPa have been obtained in the as-extruded material and higher than 1100 MPa in samples annealed for 4 hours at 800 °C.