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Commentary

Thermal Spray Opportunities in Thermonuclear Energy Generation

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In the past, the designers were more or less forced to use materials directly available on the market for their new creations. This had to be done while making allowances for the safety factor, giving up ambitions regarding weight, sometimes appearance, and so forth. The past several decades are witnessing a different approach, where design engineers and analysts work closely with material engineers to prepare materials tailored for a given design. One of the important tools in materials tailoring is thermal spray. Today, students taking basic courses in materials engineering learn about ductile cores and hard surfaces of parts, about composite layered materials, and so forth. In many fields, such as aircraft, or in general aerospace industry, automotive industry, pulp and paper production, chemical plants, and many others, coating technologies are routinely used to attain desired properties of manufactured tools and/or products.

An extreme challenge for all of us involved in development of thermal spray coatings has come with the signature of a international agreement to build a new and large fusion device called ITER (standing originally for the International Thermonuclear Experimental Reactor, now having rather the meaning of the Latin expression for "The Road").

Let me briefly recapitulate the story for those not directly involved in plasma physics. The idea for ITER originated from the Geneva superpower summit in November 1985, where Premier Gorbachov, following discussions with President Mitterrand of France, proposed to President Reagan that an international project be set up to develop fusion energy for peaceful purposes. The ITER project subsequently began as collaboration between the former Soviet Union, the United States, the European Union (via Euratom), and Japan. In 1988 the conceptual design work was started, followed in 1992 by engineering design. On July 21, 2001, the ITER engineering design activities were successfully completed, and the final design report was made available to the ITER parties. ITER consortium now consists of EU, United States, Russia, Japan, China, S. Korea, and India. In June 2005, an accord had been reached on the actual location of the device at Cadarache in Southern France; later the Director General was appointed, and now the international agreement on ITER is in the process of ratification. Construction should start in 2007.

The official objective of ITER is to "demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes." The activation energy for fusion is so high because the protons in each nucleus tend to strongly repel one another, as they each have the same positive charge. Estimation shows that nuclei must be able to get within 1 femtometer (1×10^{-15}–m) of each other to allow them to fuse. In ITER, this distance of approach is made possible by the high temperature and magnetic confinement of the plasma. While in fact nearly all stable isotopes lower on the periodic table than iron will fuse with some other isotope and release energy, deuterium and tritium are by far the most attractive for energy generation, as they require the lowest temperature to do so en masse. In terms of fuel efficiency, the deuterium-tritium fusion process releases roughly three times as much energy as a uranium-235 fission event, and millions of times more energy than a chemical reaction such as the burning of coal. It is the goal of a fusion power plant to harness this energy to produce electricity.

A successful reactor would need to contain the particles in a small enough volume for long enough for much of the plasma particles to fuse. In ITER, the plasma, a gas of charged particles, is confined using magnetic fields. A solid confinement vessel is needed, both to shield the magnets and other equipment from high temperatures and energetic photons and particles, and to maintain a near-vacuum condition for the plasma to populate. The containment vessel is subject to a barrage of very energetic particles, where electrons, ions, photons, alpha particles, and neutrons constantly bombard the surface and degrade the structure. The material must be designed to stand up to this environment long enough for the entire power plant to be economical. A distinction is made between "structural materials," "breeding materials," "plasma facing materials," and other materials for specific applications. Several possible solutions for the ITER's first wall ("plasma facing materials") are under consideration, including special steels, carbon fiber reinforced carbon composites, beryllium, tungsten, liquid walls, and so forth.

Beyond the inner wall of the containment vessel, which must resist even limited radioactive activation, one of several blanket modules are to be placed. These modules are designed to slow down and absorb neutrons in a reliable and efficient manner, limiting damage to the rest of the structure, and to breed tritium from lithium and the incoming neutrons for fuel. Energy absorbed from the fast neutrons is extracted and passed onto the primary coolant. This energy would then be used to power an electricity-generating turbine in a real power plant.

It is clearly evident that materials issues are of vital concern for the construction of ITER. Readers of JTST may legitimately ask the question: "Is there any niche for thermal spray?" The answer is yes. For instance, the divertor surface is proposed to be made of tungsten. Three technologies are under development and assessment: bulk tungsten wires, rather thin tungsten deposits made by any of the large variety of PVD methods, and finally plasma sprayed tungsten coatings of several hundreds of microns thick. Other possible applications include plasma sprayed low Z composite material for the wave guides, ceramic coatings for electrical insulation, and so forth.

There is currently a huge worldwide effort, in Europe orchestrated by EFDA (European Fusion Development Agreement), to tailor a variety of materials for different parts of the ITER device. However, besides the evolutionary process of materials and technology development, a major advancement in basic research in the field of materials science is urgently needed, done hand in hand by fusion physicists and materials scientists.

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