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Materials innovation key to fusion energy

"The results of focused materials research and development will be determinant to the realization of the potential of fusion energy as well as important to the design and construction of nearer term experimental facilities."

Fusion Energy Sciences Advisory Committee Report, 1998

During the last two centuries, innovations in science and technology have been coupled to advances in materials. For instance, the development of steel and reinforced concrete led to skyscrapers rising 100 stories and higher, ceramic tiles were necessary to protect the space shuttle upon reentry into the earth's atmosphere, and high temperature superconductors will revolutionize energy and transportation systems.

Technology with materials innovation are key to fusion's realization as an attractive and cost competitive fusion energy system. Advanced materials research is necessary to push the envelope of stress, temperature, chemical environment, and large fluences of energetic neutrons. It is important to extend the advanced materials technology base to make the challenge of fusion energy more tractable.

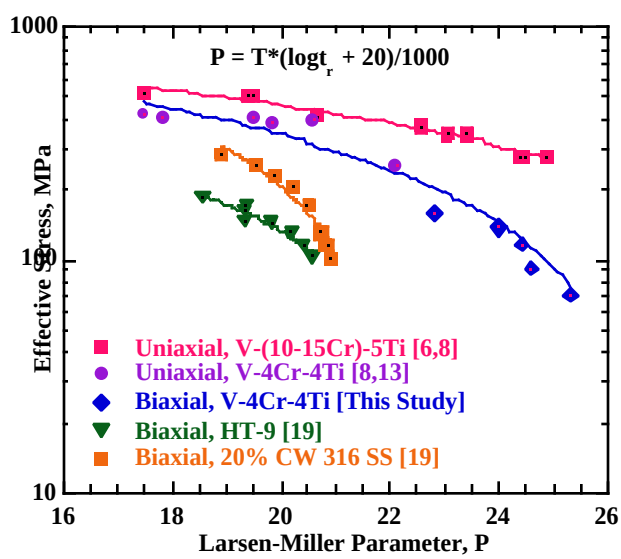
Any cost-effective path to fusion power requires identifying one or more materials to function in a fusion power system. The goal of developing economic, safe, and environmentally attractive fusion power systems has led to three candidate material systems:

- **Vanadium alloys for longevity with potential recycling due to low activation properties.**
- **Silicon carbide composites, although difficult and high risk, promise potential high payoff.**
- **Advanced low activation ferritic steels allow a range of design options.**

Materials science research is focused on developing advanced alloys leading to steels capable of higher operating temperatures. The materials in a fusion reactor can actually be less radioactive than some natural minerals, such as uranium ore.

Vanadium alloys

Vanadium alloys have low-activation properties and are under investigation as a candidate for structures inside the fusion system that are exposed to neutrons produced in the fusion reaction. The potential of recycling fusion structures composed of vanadium alloys can make structural waste manageable.



The Larsen-Miller (L-M) creep curve shows the combined temperature and creep-rupture time for the vanadium alloy. A L-M parameter of ~21 represents a creep-rupture time of ~10000 hr at 600°C.

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"We have labeled civilizations by the main materials which they have used: the Stone Age, the Bronze Age, and the Iron Age . . . a civilization is both developed and limited by the materials at its disposal. Today, man lies on the boundary between the Iron Age and the New Materials Age."

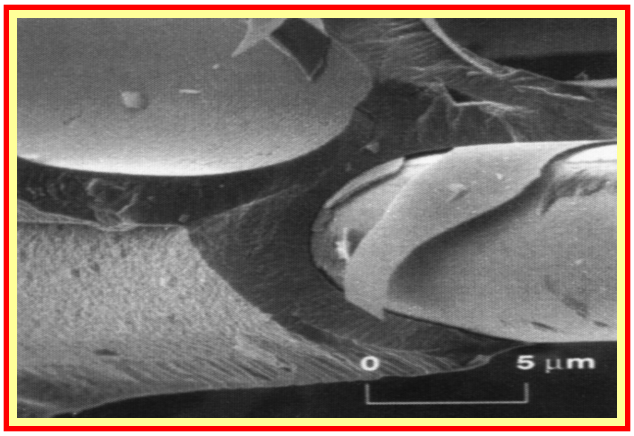
Dr. George P. Thomson, Nobel Laureate in Physics

Silicon carbide composites

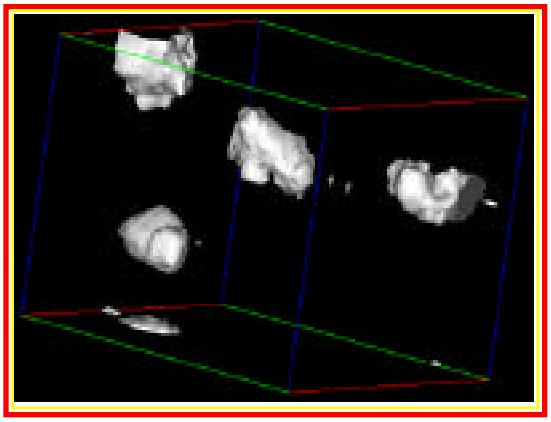
A combination of strengths between U.S. national laboratories and Japanese industry has produced significant progress in the production of a high temperature, low induced radioactivity fusion structural materials. Within a long established collaboration between the U.S. fusion materials program and Japanese universities, silicon carbide fiber composites have been developed and are currently being neutron irradiated to simulate fusion power systems conditions. A patented process has been developed to manufacture silicon carbide fiber composites that can be accomplished within about one day's time.

Unlike ceramics, silicon carbide composites are not brittle and can withstand very high temperatures. Further, silicon carbide is an inherently low activation material, which can satisfy the challenges of waste management.

Conventional steels limit cooling options to water or liquid metals. With new and improved steels other cooling options like helium can enhance the economic and environmental attractiveness of fusion systems.



Silicon carbide composites offer engineerability for extreme environments through tailoring of the fiber, matrix, and interphase structures. Photo courtesy of Oak Ridge National Laboratory.



3-D atom probe image clusters of ~ 100 atoms of Y, Ti and O responsible for high strength of NCF materials

Ferritic steels

The U.S. program on ferritic steels focuses on expansion of the operating temperature window. Micromechanics modeling and associated targeted experiments investigate fracture and embrittlement mechanisms in ferritic-martensitic steels (low temperature embrittlement). Joining issues and the thermal creep and fracture toughness behavior of dispersion strengthened ferritics are assessed for different processing parameters.