# Nuclear Materials Research at North Carolina State

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## INTRODUCTION

While there exists a plethora of experimental and theoretical studies on the effects of radiation on materials, many first-order problems of both basic and applied interests must still be answered. With this potential in mind, the Nuclear Materials Group was formed at North Carolina State University's Department of Nuclear Engineering in 1982 to conduct research on materials of interest to nuclear power industry. The work is made feasible through research contracts from industry and government agencies.

## EMBRITTLEMENT OF FERRITIC STEELS

The effects of interstitial impurities and neutron irradiation on the mechanical properties of ferritic steels were studied by examining two major classes of materials: low carbon mild steel for basic understanding of the underlying mechanisms and typical nuclear pressure vessel steels for technological applications. The research has since extended to the fracture toughness ($J_{1c}$) of ferritic steels. Much of the work was performed by irradiation of the specimens in the PULSTAR research reactor at NCSU's department of Nuclear Engineering. The investigation determined that radiation exposure is not always detrimental[1] and can sometimes be beneficial.[2] In addition, the effect of dynamic strain aging on the upper shelf fracture behavior was found to result in a distinct drop in fracture toughness. The critical temperature at which the toughness minimum occurs increases with increased deformation (strain) rate.[1] These results possess important implications in understanding radiation embrittlement and pressurized thermal shock (PTS) phenomena.

## PROPERTIES OF ZIRCONIUM ALLOYS

A major investigation has also been conducted on the mechanical anisotropy and SCC susceptibility of zirconium alloys. The research was designated to characterize the effect of cold-reduction and annealing treatment on crystallographic texture, mechanical anisotropy and SCC susceptibility of thick-walled tube shells and TREXs as well as thin-walled tubing (used for cladding the nuclear fuel) of zirconium alloys. New techniques such as impression testing were developed for thick-walled tubing to evaluate mechanical anisotropy and formability characteristics. The burst properties of thin-walled cladding were investigated by internal pressurization. Future studies will emphasize the effects of texture on iodine SCC susceptibility.

## TEXTURED HCP METALS

Under a grant from the National Science Foundation, the Nuclear Materials Group has investigated biaxial creep and deformation of textured hexagonal materials (Ti, Zr, Mg and Zn). Crystallographic textures and their effects on biaxial creep and deformation have been studied. Textures are determined using x-ray techniques from which quantitative formulations are developed through crystallite orientation distribution functions (CODF).[3] Biaxial creep testing has been adapted to thin-walled tubing with the axial load superimposed by internal pressurization while monitoring strains in-situ by laser telemetric extensometer and LVDT. Mathematical descriptions of the preferred orientations, coupled with crystal plasticity, are used to predict the anisotropic creep and deformation of the textured polycrystals.[4]

## COMPUTER MODELING

Studies in computer modeling and simulations have been conducted on Ti and other materials. The modeling and simulation work involves application of molecular dynamics, Monte Carlo, finite difference and finite element methods to the behavior of point defects, dislocations, grain boundaries, surface and phase transformations in nuclear materials. Upcoming research is planned which will complement these studies with experimental investigations.

## FACILITIES

The nuclear materials laboratory at NCSU is well-equipped with up-to-date facilities, including computer-based data acquisition. A closed-loop hydraulic testing machine is equipped with stroke, strain and load control modes along with a high temperature facility and appropriate extensometry for mechanical and fracture toughness ($J_{1c}$) studies. An Apple microcomputer assists with data acquisition while detailed analyses of the acquired data are made on a VAX 11/750. A screw driven tensile testing machine is equipped with furnace and extensometry for impression tests while a creep machine performs impression creep studies. A biaxial creep tester, with a custom-designed high temperature furnace, features laser and LVDT extensometers for in-situ biaxial strain measurements. Dedicated data acquisition is conducted with an IBM XT microcomputer. In addition, a Satec impact tester, a microhardness machine, a dedicated mini-metallography laboratory, and a number of furnaces for heat treatment are available.

Future studies will investigate deformation, fatigue and fracture of surface modified materials through ion-implantation and laser annealing. Plans are being made to develop NMR pulse techniques for studies and mobile dislocations in-situ during the deformation of ceramic and metallic materials.

### References

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4. K.L. Murty, "Application of ODF in Predicting Creep and Formability of Textured Metals," Metals Congress Syposium on "Use of Crystallite Orientation Distributions for Analysis of Texture and Prediction of Properties," ASM Meeting, Toronto, Oct. 16 (1985).

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