

Other scientific publications

10. M.Rogante, G.F. Ceschini, L. Tognarelli, E. Rétfalvi, V.T.Lebedev: SANS-study of nano-defects in the material of NiCrMoV wheel of the axial compressor of a heavy-duty gas turbine (accepted in Int. J. Eng.Design)
11. V.T. Lebedev, V.I. Didenko, A.N. Lapin, D. Orlova, Gy. Török, E. Rétfalvi: SANS investigation of plastically deformed stainless steel, J. Appl. Cryst. (2003). 36, 629-631E. Rétfalvi,L. Almasy, A. Len, Gy. Török, L. Rosta: Small angle neutron spectrometer of Budapest Research Reactor, In Proc of International Workshop on New Opportunities in single Crystal Spectroscopy with Neutrons, Révfülöp, 2001 p77-78.
12. L. Almásy, A. Len, E. Rétfalvi: On the effective neutron wavelength using a mechanical velocity selector (Physica B, beküldve)
13. E. Rétfalvi, M. Rogante, F. Nicolaie, L. Rosta: SANS study of the microstructural evolution of precipitates in Al 4032 car engine pistons (Physica B, előkészületben)D. Posselt, Jens K. Holm, Gy. Garab, L. Kovacs, Zs. Varkonyi, Z. Gombos, L. Rosta, E. Retfalvi: Small angle studies of Thylakoid Membranes and Thylakoid Membranes Lipids,In proc. of the 4th International Conference on Biological Physics, Kyoto, Japan, 2001

Small angle neutron scattering study of radiation damage in steels

PhD thesis

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Premise to the research

Radioactive radiation and high working temperature may induce important changes in the microstructure of metallic components of nuclear reactors changing their macroscopic properties as well. These changes result in weakening of the mechanical properties that have primary influence on the safety and lifetime of nuclear installations. Since the operational cost of a nuclear power plant is negligible as compared to the investment cost, the lifetime prolongation is a primary economical interest. In order to prolong the lifetime, it is necessary to have exact information about the changes appearing in the structure of the most important construction elements. The conventional methods for determining the macroscopic (mainly mechanical) properties are able to measure the net sum effect of the microscopic changes. The method of small angle neutron scattering (SANS) is able to detect the structural changes on the nanometer length scale, more precisely on the scale between 1 and 100 nm. The damage caused by the irradiation can be studied either on model materials[M. Mathon, 1993] or on samples taken from real construction elements[G.Albertini,1992][M.Große, 1994]. Since the irradiation damage depends very sensitively on the concentration of the alloys, the applied technology etc. the measurements on model materials must be followed by measurements on real structural materials. The primary aspect of choosing a sample is that it should represent the status of the whole construction element. Since those structural elements are affected by the high working temperature as well,

Scientific publications connected with the thesis

- 1.E. Rétfalvi, Gy. Török, L. Rosta: Small angle neutron scattering study of radiation damage in reactor vessel materials, *Physica B* 276-278 (2000) 843-844
- 2.E. Rétfalvi, Gy. Török, L. Rosta : Anisotropic small angle neutron scattering analysis of thermally aged reactor vessel materials, *Appl Phys A* 74 (2002) [SupplI], s1415-s1417
3. E. Rétfalvi, L. Rosta: SANS investigation of radiation induced damage of reactor pressure vessel steels, In: *Proc. of Int. Conf. On Experimental Nuclear Physics in Europe*, 1999, Sevilla, Spain
- 4.E. Rétfalvi: Sugárkárosodás vizsgálata neutronszórással (2. Magyar Nukleáris Találkozó Kiadványa, Balatonkenese,1999)
- 5.E. Rétfalvi, Gy. Török, L. Rosta: Small angle neutron scattering study of radiation damage in reactor vessel materials, *ICONE9 Proceedings CD 2001*
- 6.V.T. Lebedev, A.N. Lapin, V.I. Didenko, K.A. Konoplev, D. Orlova, Gy. Török, E. Rétfalvi: Possibilities of strength and damage studies of construction materials by small angle neutron scattering (in Russian); *Proc. 7thInt. Conf. on Materials Issues of Nuclear Power Plant Equipment, St. Petersburg, 17-21 June,2002; Vol 1, pp219-230*
7. Web page about SANS (in Hungarian): www.kfki.hu/~retfalvi\sans.html
8. www.kfki.hu/~retfalvi\disszertacio.pdf (in Hungarian)

one has to be able to determine the effect of that high temperature independently from the irradiation.

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- [G.Albertini,1992] G.Albertini et al.:Study of He-bubble growth in MANET steel by small-angle neutron scattering, J.Nuc.Mat.191-194(1992)1327-1330
- [M.Große, 1994] M.Große,J.Böhmert,H.W.Viehring: Correlation between volume fraction of radiation-induced precipitates and toughness of Cr-Mo-V alloyed VVER pressure vessel steel, J.Nuc.Mat.211(1994)177-180

Objectives

The main goal of the experimental study presented in this thesis was to develop a measurement method for radioactive samples in the SANS setup of the Budapest Research Reactor. Another important purpose was to determine the relation between the measured nanostructural properties and the mechanical features of the studied materials.

Research Methods

The SANS is structure analysing method, which is able to give information of the size, shape, concentration and chemical compound of 1-100 nm sized inhomogeneities. The scattering of the neutrons on the sample is similar to that of the photons, as described by the wave optics of the neutrons. Since the neutron has a spin, they interact with the magnetic moments of the atoms as well. By this effect, the magnetic inhomogeneities, like different phases, precipitates or cavities can be explored in the sample.

New scientific results

1. The precise wavelength calibration of the instrument has a decisive role, because of the measurement error of the scattering vector is proportional to the wavelength uncertainty. The determination of the half width at half maximum (HWHM) of the wavelength distribution is necessary for the correction with respect to the resolution function. The HWHM value that I calculated by taking the effect of the chopper window into account has turned out to be a larger value than the previously calculated one. This new result may be useful for increasing the accuracy of model fits[7].
2. I have shown that the separation of the contributions due to the nuclear and magnetic scattering can be performed in an aware way only. Either the fit of the model function should be checked or a preliminary measurement without a magnetic field is needed to detect the possible anisotropy. I managed to model the anisotropy of the reactor vessel steels due to the shaping process and to show that the value of that anisotropy can vary as a position of sampling. In the future, this fact should be taken into account when determining the position which the sample is taken from, depending on the fact whether one would like to measure the radiation damage with respect to either the average on the reactor wall, or the surface layer of the wall[2].
3. By comparing the nanostructure of the thermally aged and the irradiated samples I have shown that the effect of the annealing is different from that of the irradiation. During the irradiation, small metal-carbide precipitates are produced with a relatively narrow size distribution. As an effect of the

annealing, a separation of relatively large precipitates is happening, with composition similar to that of the Laves phase[1] [3] [5].

4. By measuring samples which had been annealed after irradiation, I have shown that the improvement of the mechanical features is in close correlation with the relaxation of the nanostructure towards the unirradiated state. These results contain important information on choosing the proper temperature for annealing. [8]
5. Last but not least, assuming the Orowan mechanism I succeeded to show a relation between the volume fraction of small sized precipitates and the measured change of the mechanical properties. This result is useful in predicting the status of the steel which has a major importance in safety calculations[6].

To summarize, the results have demonstrated that the SANS method is a powerful tool in the study of the radiation damage, and the determination of the nanostructure is an important step in characterizing the mechanical properties.