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Edited by A. Schrøder Pedersen and J. B. Bilde-Sørensen

Abstract. A presentation (including abstracts) of scientific and technical publications and lectures by the staff of the Metallurgy Department during 1987 is given. The list comprises journal papers, conference papers, reports, lectures and poster presentations in the following categories: Publications, Lectures and Poster Presentations.

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Contents

1. Publications

De nye superledere. (The New Superconducting Materials).

N. Hessel Andersen and J.K. Kjems, Risønyt No. 2 (1987) 1-3.

The recent discovery of superconductivity at liquid nitrogen temperatures is mentioned and discussed in relation to possible technological applications. Risø research activities and the coordinated Danish effort in the field are accounted for.

Fast Ion Conductors.

N. Hessel Andersen, K.N. Clausen and J.K. Kjems, Methods of Experimental Physics 23B (1987) 185-241.

A review of neutron scattering techniques as a probe for studying static and dynamic properties of defect structures in fast ion conductors is given. Basic properties of fast ion conductors, especially the relation between fast ion motion and defect structure, are discussed. The scattering formalism for diffraction, quasielastic diffuse and inelastic neutron scattering studies of defect structures as in fast ion conductors is established. Examples of experimental studies on model systems are presented and discussed.

Superledning - drøm nærmer sig virkelighed. (Superconductivity - Dream Approaches Reality).

N. Hessel Andersen and J.K. Kjems, Naturens Verden No. 7 (1987) 228-232.

The discovery of the new high temperature superconductors are presented. The phenomenon of superconductivity is explained on the basis of a historical summary giving the present level of understanding. The materials properties of the new superconductors are discussed and a number of their prospective technological applications are mentioned. Danish and international research activities in the field are also mentioned.

Synthesis and Physical Characterization of La-Sr-Cu-O, Y-Ba-Cu-0 and Gd-Ba-Cu-O High T_c Superconductors.

J. Als-Nielsen, I. Alstrup, O. Alstrup, N. Hessel Andersen, J.B. Bilde-Sørensen, H. Bohr, B.S. Clausen, K. Flensberg, J.B. Hansen, C.S. Jacobsen, I. Johannesen, F. Kragh, J.G. Larsen, B. Lebech, M.T. Levinsen, K.F. Nielsen, M. Nielsen, K.R. Padmanabhan, N.F. Pedersen, J.L. Skov and O. Sørensen, in Proceedings of the European Workshop on: High T_c Superconductors and Potential Applications, Genova, 1-3 July 1987. Edited by J. Vilain and S. Gregoli. (Commission of the European Communities, Brussels, 1987) 93-94.

Danish research activities in synthesis and physical characterization of high T_c superconductors are presented. Synthesis of powder samples include La-Sr-Cu-O, Y-Ba-Cu-O and Gd-Ba-Cu-O prepared by solid state reactions of carbonates or powder mixtures of oxides and carbonates or from precipitation of oxalates. Thick films of superconducting $YBa_2Cu_3O_7$ have been prepared by plasma spraying. Powder densification studies and thin film preparation by RF-sputtering have been initiated. Phase identification is performed by X-ray diffraction, SEM and TEM. Physical characterisation include dc-conductivity and ac-susceptibility

studies, measurements of Meisner effect, XPS- and Mössbauer (on weakly Co-substituted Y-Ba-Cu/Co-O) studies of the Cu-oxidation state. Dc- and ac-Josephson effects have been observed in point contact junctions of Y-Ba-Cu-O. X-ray crystal structure studies by synchrotron radiation have been performed on twinned single crystals and neutron diffraction on powder samples of $YBa_2Cu_3O_7$. Initiatives also include development and construction of a high resolution neutron powder diffraction facility.

Tynfilmprocesser med RF-sputtering. (Thin Film Processes Using RF-Sputtering).

N. Hessel Andersen, in Metallurgiske processer i dansk industri; Proceedings of Dansk Metallurgisk Selskabs Vintermøde, Sønderborg, 5-7 January 1987. Edited by H. Lilholt et al. (Dansk Metallurgisk Selskab, Copenhagen, 1987) 1-22.

A description of Risø's RF-sputtering system and auxiliary facilities for thin film production and microlithographic processing is given. Principles of the RF-sputtering technique are discussed and characteristic process parameters obtained for a number of metallic and ceramic materials are presented. Examples of experimental studies of thin film metals, ceramics, and interfaces by electron microscopy and impedance spectroscopy are also included.

Thermal Decomposition of (Cerium, Gadolinium)- and (Cerium, Europium)-Carbonates: Compositional and Structural Changes and Kinetics.

J.J. Bentzen, P.L. Husum and O. Toft Sørensen. In: High Tech Ceramics. Proceedings of the World Congress on High Tech Ceramics, the 6th International Meeting on Modern Ceramics Technologies (6th CIMTEC) Milan, 24-28 June 1986. Edited by P. Vincenzini. (Amsterdam, Elsevier, 1987) (Materials Science Monographs, vol. 38A) 385-398.

The existence of a complete solid solution was found for the system $(Ce_{1-x}RE_x)_2O(CO_3)_2{\cdot}H_2O$, RE = Gd, Eu, $0 < x < 1$. The X-ray diffraction patterns of $M_2O(CO_3)_2{\cdot}H_2O$, M = Ce, Gd, Eu, are given. The decomposition of $(Ce_{1-x}RE_x)_2O(CO_3)_2{\cdot}H_2O$ to $Ce_{1-x}RE_xO_{2-x/2}$ took place at one to three different temperature levels depending on x and heat-treatment. The lower decomposition temperature increased with x to a maximum for x = 0.9. For Ce-, Eu-, and Gd-carbonate the rate determining step at low temperature was evaluated as nucleation followed by two-dimensional growth, and that of the second and third temperature levels for the Eu- and Gd-carbonates were estimated as two-dimensional nuclei growth. The oxide crystallites formed were initially ~ 100 Å and grew to cubes and pyramid-cubes reaching sizes of 0.1-0.3 μm at 1000°C. Very high surface area (~ 100 m^2/g) oxide powders could be obtained by calcination at low temperatures.

Nyt elektronmikroskop på Risø. (New Electron Microscope at Risø).

J.B. Bilde-Sørensen, Risønyt No. 2 (1987) 7-7.

The Metallurgy Department at Risø has received a new JEOL 2000 FX transmission electron microscope as a gift from the Villum Kann Rasmussen Foundation. The microscope was officially handed over at a reception held April 24. A short technical description of the microscope is included.

The Structural Basis for Creep Relations.

R.C. Ecob and J.B. Bilde-Sørensen. In: Constitutive Relations and Their Physical Basis. Proceedings of the 8th Risø International Symposium on Metallurgy and Materials Science, Risø, 7-11 September 1987. (Risø National Laboratory, 1987) 67-82.

Constitutive relations for creep are considered in terms of the microstructure of the starting material and the substructure developed during creep deformation. In the dislocation creep regime emphasis is put on the inhomogeneity of the dislocation distribution dividing the material into soft and hard regions. The diffusional creep regime is discussed with emphasis on the grain boundary dislocation structure. Pure and particle-containing materials are considered in both creep regimes.

Fatigue Testing Using Offshore Load Spectrum.

P. Brøndsted, T. Slind and J. Solin. In: Steel in Marine Structures. Proceedings of the 3rd International ECSC Conference on Steel in Marine Structures, Delft, 15-18 June 1987. Edited by C. Noordhoek and J. de Back. (Elsevier, Amsterdam, 1987) 811-819.

A simple algorithm defining a log-linearly distributed load spectrum for simulating the offshore loading conditions is developed. The algorithm generates a cycle by cycle defined sequence of totally 500.000 cycles. It is divided into 9 blocks each having a constant rms amplitude.
The program is implemented on two different computer aided fatigue test systems, namely PDP11 and Olivetti PC controlled servohydraulic testing machines. The reliability of the testing procedures is verified by results from preliminary crack growth tests.

Offshore Load Spectrum and Fatigue Testing.

P. Brøndsted and S. Krenk. In: Constitutive Relations and Their Physical Basis. Proceedings of the 8th Risø International Symposium on Metallurgy and Materials Science, Risø, 7-11 September 1987. Edited by S.I. Andersen et al. (Risø National Laboratory, 1987) 251-257.

The key features involved in the simulation of random stress histories for fatigue testing of offshore structures are discussed. They include sea states and long term statistics, the relation between waves and stresses, and the simulation within a given sea state. The paper also presents an algorithm for the simulation of simplified offshore stress histories, in which the load history is generated on a cycle to cycle basis. The length of the simulated sequence is 500.000, and changes in intensity are accommodated via 9 blocks forming a deterministic pattern of increasing and decreasing intensity. Test results obtained using this algorithm are included.

Fatigue and Creep Properties of Copper-Phosphorus Brazed Copper Joints and of the Brazing Alloys.

J. Christensen and P. Brøndsted. In: High Technology Joining. Proceedings of the BABS 5th International Conference, Brighton, 3-5 November 1987. (British Association for Brazing and Soldering, Oxfordshire, 1987) 20/1-20/10.

Mechanical creep and fatigue properties of copper joints brazed with various silver-copper-phosphorus brazing alloys have been investigated. Joints brazed with the various alloys were all stronger than copper. In fatigue, brazed joints

with only 30% of the normal overlap lengths always fractured in the copper. High silver-bearing brazing alloys can be substituted by the 0-15% silver-copper-phosphorus alloys.

Assessment of Radiographic Image Quality by Visual Examination of Neutron Radiographs of the Calibration Fuel Pin.

J.C. Domanus. In: Neutron Radiography. Proceedings of the Second World Conference on Neutron Radiography, Paris, 16-20 June 1986. Edited by J.P. Barton et al. (D. Reidel Publishing Company, Dordrecht, 1987) 849-855.

Up till now no reliable radiographic image quality standards exist for neutron radiography of nuclear reactor fuel. Under the Euratom Neutron Radiography Working Group (NRWG) Test Program neutron radiographs were produced at different neutron radiography facilities within the European Community of a calibration fuel pin.

The radiographs were made by the direct, transfer and track-etch methods using different film recording materials. These neutron radiographs of the calibration fuel pin were used for the assessment of radiographic image quality. This was done by visual examination of the radiographs and assessing their radiographic image quality on an arbitrary scale.

Can Neutron Beam Component and Radiographic Image Quality be Determined by the Use of Beam Purity and Sensitivity Indicators?

J.C. Domanus. In: Neutron Radiography. Proceedings of the Second World Conference on Neutron Radiography, Paris, 16-20 June 1986. Edited by J.P. Barton et al. (D. Reidel Publishing Company, Dordrecht, 1987) 839-848.

In the Euratom Neutron Radiography Working Group Test Program beam purity and sensitivity indicators, as prescribed by the ASTM E 545-81 were used together with the NRWG beam purity indicator-fuel and calibration fuel pin. They were radiographed together at neutron radiography facilities of the European Community. The direct, transfer and track-etch methods using different film recording materials were used. Neutron beam components were calculated from film density measurements under the beam purity indicators and radiographic image quality was assessed by visual examination of the sensitivity indicator. Results obtained under the NRWG Test Program are summarized and compared.

Collimators for Thermal Neutron Radiography.

J.C. Domanus. Edited by J.F.W. Markgraf. (D. Reidel Publishing Company, Dordrecht, 1987) (EUR-10859) 103 pp.

The purpose of this survey is to review the design and construction of collimators used for thermal neutron radiography. To this end handbooks and general publications in the field of neutron radiography have been reviewed. Conference papers related to non-destructive testing and neutron radiography were also considered. As the resultant information was rather sparse and incomplete, the author attempted to extract information concerning collimators from other sources, particularly the numerous papers describing neutron radiography facilities in different countries. For practical reasons it was not possible to review all the papers available on the subject. A concise overview is presented concerning the basic data concerning the design and construction of collimators used for thermal neutron radiography.

Euratom Neutron Radiography Working Group.

J.C. Domanus. In: Neutron Radiography. Proceedings of the Second World Conference on Neutron Radiography, Paris, 16-20 June 1986. Edited by J.P. Barton et al. (D. Reidel Publishing Company, Dordrecht, 1987) 339-347.

In 1979 a Neutron Radiography Working Group (NRWG) was constituted within Euratom with the participation of all centers within the European Community at which neutron facilities were available. The main purpose of NRWG was to standardize methods and procedures used in neutron radiography of nuclear reactor fuel and establish standards for radiographic image quality of neutron radiographs. The NRWG meets once a year in each of the neutron radiography centers to review the progress made and draw plans for the future. Besides, ad-hoc sub-groups on different topics within the field of neutron radiography are constituted. This paper reviews the activities and achievements of the NRWG and its sub-groups.

International Neutron Radiography Newsletter.

J.C. Domanus. In: Neutron Radiography. Proceedings of the Second World Conference on Neutron Radiography, Paris, 16-20 June 1986. Edited by J.P. Barton et al. (D. Reidel Publishing Company, Dordrecht, 1987) 55-58.

At the first World Conference on Neutron Radiography it was decided to continue the "Neutron Radiography Newsletter", published previously by J.P. Barton, as the "International Neutron Radiography Newsletter" (INRNL), with J.C. Domanus as editor. The British Journal of Non-Destructive Testing (BJNDT) has agreed to publish the INRNL in its column "NDT Bookcase". The Revue Pratique de Control Industriel has also agreed to publish the French version of the INRNL. Up till now 12 issues of the INRNL were published in the BJNDT. They are reviewed below.

Neutron Radiography. Techniques and Applications.

J.C. Domanus. Risø-M-2672 (Risø National Laboratory, 1987). 32 pp.

After describing the principles of the "in pool" and "dry" installations, techniques used in neutron radiography are reviewed. Use of converter foils with silver halide films for the direct and transfer methods is described. Advantages of the use of nitrocellulose film for radiographying radioactive objects are discussed. Dynamic imaging is shortly reviewed. Standardization in the field of neutron radiography (ASTM and Euratom Neutron Radiography Working Group) is described. The paper reviews main fields of use of neutron radiography. Possibilities of use of neutron radiography at research reactors in various scientific, industrial and other fields are mentioned. Examples are given of application of neutron radiography in industry and the nuclear field.

Recording Radiographic Images on Nitrocellulose Film in Neutron Radiography of Nuclear Reactor Fuel.

J.C. Domanus. Risø-M-2654 (Risø National Laboratory, 1987). 19 pp.

Nitrocellulose film, insensitive to X- and gamma-rays (as well as visible light), is especially suitable for neutron radiography of spent nuclear reactor fuel, which itself is a source of high-intensity gamma-radiation. As nitrocellulose film is also insensitive to neutrons a converter is necessary to convert neutrons to alpha

particles, which in turn are able to produce a radiographic image on the film. This image, in the form of minute pits in the film, must thereafter be made visible by etching the nitrocellulose film to thereby enlarge the pits so much as to produce a visible image on the film. After a short description of neutron radiography facilities at various reactor types three methods of producing neutron radiographs are explained (direct, transfer and track-etch). Nitrocellulose film and neutron-to-alpha converters used with it are described. Radiographic image quality of this film is compared with that of silver halide film. A similar comparison is made of the accuracy of dimensional measurements from neutron radiographs.

Reference Neutron Radiographs of Nuclear Reactor Fuel.

J.C. Domanus. In: Neutron Radiography. Proceedings of the Second World Conference on Neutron Radiography, Paris, 16-20 June 1986. Edited by J.P. Barton et al. (D. Reidel Publishing Company, Dordrecht, 1987) 375-379.

Reference neutron radiographs of nuclear reactor fuel were produced by the Euratom Neutron Radiography Working Group and published in 1984 by the Reidel Publishing Company.
In this collection a classification is given of the various neutron radiographic findings, that can occur in different parts of pelletized, annular and vibro-compacted nuclear fuel pins. Those parts of the pins are shown where changes of appearance differ from those for the parts as fabricated. Also radiographs of those as fabricated parts are included. The collection contains 158 neutron radiographs, reproduced on photographic paper (twice enlarged) and on duplicating film (original size).

Standardization Problems in Neutron Radiography of Nuclear Reactor Fuel.

J.C. Domanus. In: 8th International Conference on NDE in the Nuclear Industry. Proceeding of the conference, Kissimee, 17-20 November 1986. Edited by D. Stahl. (ASM International, 1987) 565-570.

Reference neutron radiographs, radiographic image quality, determining the L/D ratio and standard practices are the main topics for standardization in the field of neutron radiography of nuclear reactor fuel.
As the standards for neutron radiography issued up till now by the ASTM do not cover that particular field the Euratom Neutron Radiography Working Group has started standardization work of its own. The results, status and plans for this work are reviewed in this paper.

Application of the Positron Annihilation Technique in Studies of the Defects in Solids.

M. Eldrup. In: Defects in Solids. Proceedings of the NATO Advanced Study Institute, Cetraro, 16-27 September 1985. Edited by A.V. Chadwick and M. Terenzi. (Plenum Publishing Corporation, 1986) 145-178.

The basic principles of positron annihilation physics are discussed and the four most important experimental techniques are described (i.e. the positron lifetime, the angular correlation, the Doppler broadening, and the low-energy-positron beam techniques). Several examples are discussed, in particular for metals and molecular crystals, which illustrate the sensitivity of the positron annihilation techniques to vacancy type defects. For example it is shown how information can be obtained about vacancy formation energies, vacancy migration and clustering,

vacancy-impurity interactions, densities of rare gasses in bubbles in metals, and defect density profiles in near-surface regions.

Positron Trapping Rates into Cavities in Al: Temperature and Size Effects.

M. Eldrup and K.O. Jensen. Phys. Stat. Sol. 102 (1987) 145-152.

Positron specific trapping rates into voids and helium bubbles are measured as functions of temperature and cavity size. Qualitatively the data show the behaviour expected from a model similar to that of Nieminen et al., but quantitatively the agreement fails. If trapping into shallow traps at low temperatures is assumed, the disagreement is removed. For cavities of radii larger than 5 nm diffusion limited trapping is observed at room temperature. The positron diffusion constant is found to agree with earlier determinations, if a time dependence of the trapping rate is taken into account.

Effect of Metallurgical Parameters on Texture and Microstructure in Cold Deformed Aluminium and Aluminium Alloys.

N. Hansen and D. Juul Jensen. In: Formability and Metallurgical Structure. Proceedings of a symposium, Orlando, 5-9 October 1986. Edited by A.K. Sachde and J.D. Embury. (The Metallurgical Society Inc., Warrendale, 1987) 119-136.

The effects of metallurgical parameters on the textural and microstructural development during cold deformation are described with special emphasis on aluminium and aluminium alloys. The parameters are the grain size and the size and volume fraction of hard particles. It is generally observed that these parameters affect the strength of the deformation texture and thereby the formability of the metal in the cold-worked state. The grain size effect relates specially to the rate of texture development which decreases when the grain size is increased. The presence of large particles causes a weakening of the texture and this effect becomes pronounced for large volume concentrations of particles having as size larger than approximately 1 μm. A weakening of the texture is also observed when small particles (< 0.1 μm) are present in large volume concentrations, whereas the effect of such particles in small concentrations is inconclusive. The experimental observations are discussed in terms of the effect of the metallurgical parameters on the deformation pattern during cold-working.

Evaluation of the Community's Research Programme "Nuclear Measurements and Reference Materials" (1980-1985). Research Evaluation - Report No. 20.

N. Hansen, H.J. Ache, P. Brown, A. Michaudon and J. Yoccoz. (Commission of the European Communities, Brussels, 1986). (EUR-10761) 64 pp.

A panel has evaluated the research programme "Nuclear Measurements and Reference Materials" as a part of the Commission's ongoing evaluation. The themes considered in the report are the following: Formulation of objectives, definition of tasks, the present programme, staff, major facilities, international collaboration, collaboration within JRC and future orientation of the programme.

The Effect of Small Particles on the Flow Stress-Strain Behaviour of Aluminium.

N. Hansen and D. Juul Jensen. In: Constitutive Relations and Their Physical Basis. Proceedings of the 8th Risø International Symposium on Metallurgy and Materials Science, Risø, 7-11 September 1987. Edited by

S.I. Andersen et al. (Risø National Laboratory, 1987) 331-336.

The work hardening behaviour of commercial purity aluminium (99.5%) and two aluminium-aluminium oxide materials has been examined by measuring the flow stress (0.2% offset) at room temperature after cold drawing in the strain range 0.2-3.2. The changes in the work hardening rate as a function of strain are related to the microstructural and textural changes during deformation. It is found that the work hardening rate at large strain is affected by the presence of dispersed particles and it is shown that the flow stress can be correlated with the dislocation cell size.

Void Hyperlattices in High-Purity Aluminium Irradiated with Fast Neutrons.

A. Horsewell and B.N. Singh. Radiation Effects 102 (1987) 1-5.

Void hyperlattices have been observed in high purity aluminium irradiated with fast neutrons at 323 K to a dose level of 2×10^{26} n/m^2. Void ordering is found to occur at a much lower void density and with a void lattice-spacing considerably larger than hitherto reported in the literature. In spite of void ordering, voids appear to maintain a healthy growth rate. Implications of these observations are briefly discussed.

Computer Controlled Forced Stepwise Isothermal Analysis.

P.L. Hansen and O. Toft Sørensen. Thermochim. Acta 114 (1987) 131-138.

A new version of the Stepwise Isothermal Analysis technique is described in which the temperature is forced to increase in predetermined steps during the reaction. Data obtained by this technique can be used to determine not only the controlling mechanism but also the activation energy and the pre-exponential factor in the Arrhenius equation. As a demonstration of the advantages of this technique the results obtained in a kinetic study of the thermal decomposition of cerium carbonate in different atmospheres is described.

Development of Deformation Textures in Polycrystalline Copper. Experiments and Model Predictions.

N. Naaman, R. Talreja, D. Juul Jensen and N. Hansen. Textures and Microstructures 7 (1987) 149-170.

The textural development and flow stress have been determined in compression and tension of copper (99.999%). For strains below 1.4 (compression) and 1.0 (tension) the textural development is in qualitative agreement with Taylor-model predictions, i.e. a maximum concentration at the <110> and <111> + <100> orientations for compression and tension, respectively. The grain size (23 and 125 μm) has only a relatively small effect on the textural development. For large strains 1.4-2.9 (compression) the textural development is in broad agreement with relaxed-constraints (RC) model predictions. In the strain range where the Taylor-model is prevalent the textural development has only a small effect on the M-factor, i.e. on the flow stress-strain relationship.

New Neutron Scattering Instruments at Risø National Laboratory: A Multipurpose Spectrometer and the SANS Facility.

B. Lebech, T. Freltoft, D. Juul Jensen, C. Broholm, K. Clausen, L.G. Jensen, J.K. Kjems and K. Mortensen. In: Research Reactor Activities in

Support of National Nuclear Programs. Proceedings of an IAEA conference, Copenhagen, 9-13 September 1987. (IAEA, Vienna, 1987) (IAEA-TECDOC-409) 281-297.

Two neutron scattering instruments recently installed at the DR 3 reactor at Risø National Laboratory is described and examples of experimental results are given.

One instrument is a multipurpose instrument TAS3 which can be operated in four different modes:

1) *TAS-MODE: In this mode the detector system consists of a complete analyser-detector system, and the instrument is a conventional neutron triple-axis-spectrometer used for inelastic neutron scattering.*
2) *DAS-MODE: In this mode the detector system consists of a detector system, which can be rotated around the vertical sample axis and in addition by means of an automated mechanical tilt can be tilted from 5° below to 25° above the horizontal plane. The spectrometer is used for elastic neutron scattering.*
3) *DPS-MODE: In this mode the detector system is a linear position sensitive detector which is mounted vertically in the mechanical tilt device used in the DAS-mode. The DPS-mode supplements the DAS-mode and has proven to be useful in single crystal structural studies when searching for satellite Bragg peaks in odd directions of reciprocal space.*
4) *TEX-MODE: This mode is used for measuring texture of polycrystalline materials, both statistical and dynamical. An Eulerian craddle is mounted on the sample table, and the detector system consists of a linear position sensitive detector mounted as in the DPS-mode.*

The other facility to be described is the six meter Small Angle Neutron Scattering facility SANS. It is situated at a cold source beam outside the DR 3 reactor confinement at the end of a 20 m long neutron guide. A mechanical velocity selector with variable tilt provides the monochromatization with $\Delta\lambda/\lambda$ in the range 0.05 to 0.20. As a novel feature the sample is placed in high vacuum, ($< 10^{-6}$ mbar), without windows between the entrance slit and the 40 cm $\times$ 40 cm area-sensitive detector. The sample can be rotated and translated automatically in the vacuum, which allows the use of cryostats, cryomagnets and furnaces without introduction of extra windows. The instrument uses neutron wavelengths in the range 4 Å to 24 Å with momentum transfers in the range 0.2 $Å^{-1}$ to 0.003 $Å^{-1}$.

Relations Between Texture and Flow Stress in Commercially Pure Aluminium.

D. Juul Jensen and N. Hansen. In: Constitutive Relations and Their Physical Basis. Proceedings of the 8th Risø International Symposium on Metallurgy and Materials Science, Risø, 7-11 September 1987. Edited by S.I. Andersen et al. (Risø National Laboratory, 1987) 353-360.

The plastic anisotropy of commercially pure aluminium deformed by cold rolling at strains up to 2.3 has been investigated. The flow stresses (0.2% offset) measured at room temperature are related to M-values which are calculated on the basis of the Taylor theory from experimentally determined texture data. It is found that the flow stress varies significantly with orientation at low and high strains, while weak anisotropy effects are found at medium strain. It is shown that the measured anisotropy is in reasonable agreement with the calculated M-values at high strain, whereas the anisotropy at low strain cannot be related to the texture.

Characterization of Vacancy and Vacancy-Gas Aggiomerates in Aluminium Irradiated with Medium Energy Protons by Positron Annihilation.

K.O. Jensen, M. Eldrup, B.N. Singh, A. Horsewell, M. Victoria and W.F. Sommer, Materials Science Forum 15-18 (1987) 913-918.

Positron annihilation and electron microscopy investigations of aluminium samples irradiated with 600 or 800 MeV protons or with neutrons have been carried out. The samples contain helium bubbles or voids of various sizes. This was used to determine the positron specific trapping rate into the cavities as a function of radius. Using this function and a theoretical estimate of the helium density in the bubbles based on the trapped-positron lifetime it is shown how the average bubble size and density can be derived from the positron lifetime data. Finally, the shapes of the angular correlation curves for positrons trapped in bubbles are derived and correlated with the He density in the bubbles.

Helium Bubbles in Metals: Molecular-Dynamics Simulations and Positron States.

K.O. Jensen and R.M. Nieminen, Phys. Rev. B35 (1987) 2087-2090.

By combining molecular-dynamics results for the aluminium-helium interface with positron-state calculations it is demonstrated that a positron is trapped at the surface of a He bubble in Al. The annihilation rate with Al electrons is similar to that at a clean surface, while simultaneously there is a significant annihilation rate with He electrons. This enables one to obtain a useful relation between the positron lifetime and helium densities in bubbles.

Noble Gas Bubbles in Metals: Molecular Dynamics Simulations and Positron States.

K.O. Jensen and R.M. Nieminen, Phys. Rev. B36 (1987) 8219-8232.

A theoretical treatment of atomic structure and positron states in noble gas bubbles in metals is presented. The Al-He and Cu-Kr systems are considered as specific examples. For large bubbles (radii above a few tens of Å) a calculational scheme is developed combining molecular dynamics results for the metal-noble gas interface with positron calculations. It is demonstrated that a positron is trapped at the surface of a noble gas bubble, i.e. at the metal-gas interface. The annihilation rate with metal electrons is similar to that at a clean surface, while simultaneously there is a significant annihilation rate with gas-atom electrons. This enables relationships between gas density and positron lifetime to be obtained for the systems considered. Experimental evidence supports the theoretical relations. In the molecular dynamics simulations a trend towards layer-by-layer ordering of the gas atoms close to the metal-gas interface is found even in the cases, where the bulk gas is in a fluid phase. The positron state calculations also cover the case of adsorbed noble gas layers at surfaces. For small vacancy-noble gas clusters complementary positron results obtained with the calculational method developed by Puska and Nieminen are presented.

Testing of Power Reactor Fuel Types in the DR 3 Reactor at Risø.

P. Knudsen and I. Misfeldt. In: Research Reactor Activities in Support of National Nuclear Programmes. Proceedings of a Technical Committee meeting on Research Reactor Activities in Support of National Nuclear Programmes, Budapest 10-13 December 1985, and selected papers from a Seminar on Applied Research and Service Activities for Research Reactor

Operations, Copenhagen, 9-13 September 1985. IAEA-TECDOC-409 (IAEA, Vienna, 1987) 251-261.

From the beginning of the Danish Fuels Development Program, it has been important to test UO_2-Zr fuel pins under realistic conditions, i.e. at temperature and coolant conditions as in a power reactor. This is possible with the high-pressure rigs simulating BWR and PWR conditions.

More than 200 test fuel pins have been irradiated at DR 3 to burnups up to 70,000 MWD/tU. This program comprises standard BWR and PWR designs, advanced fuel designs such as LOWI (low interaction), i.e. a special duplex pellet, power ramp tests at significant burnup levels etc.

Significant use of the DR 3 facilities is also being made in the current, internationally sponsored RISØ Transient Fission Gas Release Project, with the objective to study the kinetics of fission gas release in high-burnup fuel. Segments from previously irradiated UO_2-Zr fuel pins are refabricated in the hot cells and mounted with pressure transducers. During transient testing in the DR 3 reactor at RISØ, the change in internal pin pressure is monitored continuously. Before and after the transient testing, the fuel is characterized extensively in the hot cells, as a supplement to the observations during the irradiation.

The pressure transducer of a test fuel pin is connected to a fully computerized measuring and data acquisition system. This system allows measuring of power and pressure in the experiments with high accuracy. Techniques have been developed for the derivation of gas release in fractions of the produced fission gas with overall accuracies better than 1% of the gas inventory. Releases down to 0.1% can be followed with a resolution in time of less than 1 minute.

The DR 3 facilities are well suited for both general fuel performance evaluation and special projects, because they are simple in design and reliable in operation. Also, the DR 3 reactor and RISØ's Metallurgy Department, including the hot cells, are close to each other. This enables a quick feedback of test results as input to the planning of new investigations.

Konstitutive modeller for metallers plastiske deformation. (Constitutive Models for the Plastic Deformation of Metals).

T. Leffers and O.B. Pedersen. In: Metallurgiske processer i dansk industri. Proceedings of Dansk Metallurgisk Selskabs Vintermøde, Sønderborg, 5-7 January 1987. (Dansk Metallurgisk Selskab, Copenhagen, 1987) 195-205.

Constitutive models for texture evolution, work hardening and elastic-plastic transition are discussed with special consideration of the rate of plastically heterogeneous deformation.

Measurement of Internal Stresses by Neutron Diffraction Using a Position Sensitive Detector.

T. Leffers, T. Lorentzen, D. Juul Jensen and J.K. Kjems. In: Residual Stresses in Science and Technology. Proceedings of the International Conference on Residual Stresses, Garmisch-Partenkirchen, 15-17 October 1986. Edited by E. Macherauch and V. Hauk. (DGM Informationsgesellschaft, Oberursel, 1987) 143-150.

The abstract appeared in the progress report for 1986.

Polycrystal Calculations with a 'Universal' Elastic-Plastic Model.

T. Leffers and O.B. Pedersen. In: Constitutive Relations and Their Physical Basis. Proceedings of the 8th Risø International Symposium on Metallurgy and Materials Science, Risø, 7-11 September 1987. Edited by S.I. Andersen et al. (Risø National Laboratory, 1987) 401-408.

An elastic-plastic model, which includes texture development and work hardening of the individual grains is used in calculations on tensile deformation of f.c.c. polycrystals. The output is the stress-strain curve and the variation in M factor, stored energy and deformation heterogeneity with strain.

Creep Behaviour of the Metal Matrix Composite Al 2124 with SiC Fibres.

H. Lilholt and M. Taya. In: Proceedings of the ICCM6/ECCM2 Conference, London, 20-24 July 1987. Edited by F.L. Matthews et al. (Elsevier Applied Science, London, 1987) 2.234-2.244.

The creep deformation of the metal matrix composite Al 2124 with SiC fibres is studied at 300°C. The strain vs. time curves show three stages, with a fairly long stage I, a well-developed stage II and an extremely short stage III. The creep rates vs. applied stress demonstrate improvements in creep strength, but less than predicted by (simple) models for aligned fibre composites. The stress sensitivity of the creep rate is larger for the composite than for the matrix alloy; this is interpreted to indicate possibly complex interactions between fibres and the precipitation process.

Fremstilling af kompositmaterialer med metallisk matrix og keramiske fibre (Fabrication of Composite Materials with Metallic Matrix and Ceramic Fibres).

H. Lilholt. In: Metallurgiske processer i dansk industri. Proceedings of Dansk Metallurgisk Selskabs Vintermøde, Sønderborg, 5-7 January 1987. (Dansk Metallurgisk Selskab, Copenhagen, 1987) 207-229.

Fabrication methods for metal matrix composite materials were reviewed. Metallurgical and chemical problems related to the process condition were discussed and processes were grouped according to the process conditions.

Internal Stresses Measured by Neutron Diffraction in Metal Matrix Composites Exposed to Thermal Treatments.

H. Lilholt and D. Juul Jensen. In: Composites Evaluation. Conference Proceedings TEQC 87, University of Surrey, 22-24 September 1987. Edited by J. Herriot. (Butterworths, Sevenoaks, 1987). 156-161.

Internal stresses in inhomogeneous materials are of great importance for engineering properties. These internal stresses can be measured in bulk specimens by neutron diffraction penetrating centimeters into the material. The technique is illustrated for a metal matrix composite of Al reinforced with SiC-fibres. The material is exposed to several thermal treatments and the internal strains are measured after various times of relaxation. A simple model for the internal strains, based on a stress balance, is included in the analysis of the experiments. The neutron diffraction technique has proved useful for these studies of internal strains. The kinetic studies indicate slow relaxation processes, and the existence of internal strains at all temperatures, i.e. the relaxation is not complete.

Metallurgiske processer i dansk industri (Metallurgical Processes in the Danish Industry).

H. Lilholt, P.H. Gundel and G. Skjelsager (editors). Proceedings of Dansk Metallurgisk Selskabs Vintermøde, Sønderborg, 5-7 January, 1987. (Dansk Metallurgisk Selskab, Copenhagen, 1987). 313 pp.

Metallurgical processes, existing and potential methods, were presented in 17 lectures.

Nye materialer - ny udvikling (New Materials - New Developments).

H. Lilholt. In: Fremtidens byer, boliger og byggeri. Proceedings from the meeting on the 40-years anniversary of SBI, Lyngby, 20 May 1987. Edited by J. Kristensen. (SBI, Hørsholm, 1987) 59-65.

A brief presentation of composite materials, both on polymer and on cement basis, was given. Special reference was made to the building sector.

Effect of Orientation on the High Temperature Fatigue of Copper Single Crystals.

L.L. Lisiecki and J.R. Weertman. In: Constitutive Relations and Their Physical Basis. Proceedings of the 8th Risø International Symposium on Metallurgy and Materials Science, Risø, 7-11 September 1987. Edited by S.I. Andersen et al. (Risø National Laboratory, 1987) 415-420.

The effect of orientation on the elevated temperature fatigue of copper single crystals has been studied with crystals grown so that the stress is applied near one of the 3 double slip orientations. Reactions between dislocations on the primary and secondary slip systems in the 3 types of crystals lead to the production of sessile jogs, Lomer-Cottrell locks or cells formed by coplanar slip. These reaction products vary markedly in their response to increasing temperature. At 523 K, a plateau in the saturation stress for the [211] and [210] orientations is present at approximately 14 MPa. No plateau or TEM evidence of persistent slip band formation has been seen at 678 K.

Nye plastbaserede kompositmaterialer (New Fibre Reinforced Polymer Materials).

Aa. Lystrup, M. Wahlberg, J. Honoré and J. Ejlsted. Informationshæfte nr. 2, ISBN 87-7511-699-5, (TI-Tryk, Teknologisk Institut, 1986). 43 pp.

A part of a Danish information campaign about new materials consists of a series of 4 booklets. The present is No. 2 about fibre reinforced polymer materials. A survey of materials, properties, and fabrication methods is given.

Fission Gas Release Mechanisms Operating in Water Reactor Fuel in Power Transients.

M. Mogensen, P. Knudsen and C.T. Walker. In: Improvements in Water Reactor Fuel Technology and Utilization. Proceedings of an international symposium, Stockholm, 15-19 September 1986. Edited by P.H. Kitto, IAEA. STI/PUB/721 (IAEA, Vienna, 1987) 291-303.

Local Xe concentrations in grains and grain boundary porosities were obtained as a function of the relative radius on pellets of transient tested, high burnup BWR and PWR fuels. The technique used were X-ray fluorescence analysis and electron probe microanalysis (EPMA). The PWR fuel had a burnup of 3.4%

fissions of initial metal atoms (FIMA) (31 GW·d/t U) and was held for 28 h at a transient terminal level of 32 kW/m. The BWR fuel with 4.3% FIMA (39 GW·d/t U) was held at a terminal level of 42 kW/m for 14 h. Considerable amounts of gas in the grain boundary porosities were found at certain radial positions, up to 40% of the Xe generated for the PWR and up to 20% for the BWR fuel. The Xe distribution within single grains in the PWR fuel was measured by EPMA. On the basis of these observations, the mechanisms of transient fission gas release from high burnup fuel are discussed. It is shown that for both types the gas release is limited by the tunnel formation process and not by diffusion of gas from the grain interior to the grain boundary.

Kinetics of LiCl Film Formation on Anodes in $SOCl_2$.

M. Mogensen, Risø-M-2619 (Risø National Laboratory, 1987). 29 pp.

The report summarizes the results of a study of LiCl film formation on lithium anodes in thionyl chloride batteries. The film formation was monitored by ac impedance measurements in up to 4 years and the resulting morphology was studied by scanning electron microscopy. A film formation model capable of explaining the experimental results including observations which have puzzled workers through years is established. The new key-concept is that nucleation and growth is rate determining in the early stages of Li passivation. A summary of the experimental results obtained is given and an outline of future work is described. Methods of controlling the passivation rate are proposed. Reprints of 7 publications are included in the report.

Nucleation and Growth of LiCl Passivating Layers on Electrodes in Thionyl Chloride.

M. Mogensen. In: Power Sources 11. Proceedings of the 15th International Power Sources Symposium, Brighton, 8-11 September 1986. Edited by L.J. Pearce. (International Power Sources Symposium Committee, Leatherhead, 1987) 455-462.

The kinetics of LiCl layer formation on lithium and stainless steel electrodes were studied by means of ac-impedance. Li electrodes were followed from a few minutes to years of exposure in $SOCl_2$ solutions of 1.8 M $LiAlCl_4$ and 1.2 M $LiAlCl_4$ + 0.6 M SO_2AlCl_3. A stainless steel electrode was polarised 3.68 V to the free potential of Li using a potentiostat in order to get the current as a function of time. Also the ac-impedance of this electrode was measured. The results indicate that the LiCl film growth on Li in the early stages is controlled by a nucleation and growth type of mechanism whereas the LiCl production (electronic conductivity) is the rate determining step after about 2 days.

On the Rate Determining Step in Fission Gas Release From High Burn-Up Water Reactor Fuel During Power Transients.

C.T. Walker and **M. Mogensen,** J. Nucl. Mater. 149 (1987) 121-131.

The radial distribution of grain boundary gas in a PWR and a BWR fuel is reported. The measurements were made using a new approach involving X-ray fluorescence analysis and electron probe microanalysis. In both fuels the concentration of grain boundary gas was much higher than hitherto suspected. The gas was mainly contained in the bubble/pore structure. The factors that determined the fraction of gas released from the grains and the level of gas retention on the grain boundaries are identified and discussed. The variables involved are the local fuel stoichiometry, the amount of open porosity, the magnitude of the local

compressive hydrostatic stress and the interaction of metallic precipitates with gas bubbles on the grain faces. It is concluded that under transient conditions the interlinkage of gas bubbles on the grain faces and the subsequent formation of grain edge tunnels is the rate determining step for gas release; at least when high burn-up fuel is involved.

Properties of LiCl Layers Formed on Lithium in Various $SOCl_2$ Solutions.

M. Mogensen, J. Power Sources 20 (1987) 53-59.

The growth rate of LiCl solid electrolyte layers on Li was studied in neutral and acid $LiAlCl_4$-$SOCl_2$ solutions over periods of years. For SO_2-containing acid solutions, a small anodic load resulting from the coupling of lithium to stainless steel proved to be more important than the acidity.

The ionic and electronic conductivities of the layers were derived from impedance measurements and passivation rates, respectively. In neutral solutions, the Li^+ conductivity decreased with increase in the layer thickness; this effect was not observed in acid SO_2-containing solutions.

Factors influencing the growth rate of the LiCl layer are briefly analysed. It is concluded that increasing the ratio of ionic to electronic conductivity would be the most efficient way of improving the performance of the solid electrolyte.

Metallurgy Department Progress Report for the Period 1 January to 31 December 1986.

A. Schrøder Pedersen and **J.B. Bilde-Sørensen** (editors). **Risø-R-547 (Risø National Laboratory, 1987) 96 pp.**

The activities of the Metallurgy Department at Risø during 1986 are described. The work is presented in four chapters: General Materials Research, Technology and Materials Development, Chemical and Electrochemical Energy Research and Development, and Fuel Elements. A survey is given of the Department's participation in international collaboration and of its activities within education and training. A list (with abstracts) of publications and lectures by the staff during 1986 is included.

The Effect of Cycling in Impure Hydrogen on the Hydrogen Capacity of Magnesium Powder.

A. Schrøder Pedersen, B. Vigeholm, J. Kjøller and **B. Larsen,** Int. J. Hydrogen Energy 12 (1987) 765-771.

In a series of continuous cycling experiments magnesium powder with average particle diameter around 65 μm was exposed to hydrogen gases containing oxygen and nitrogen. The absorption and the desorption were measured over approx. 17 min each at a temperature of 375°C with small variations caused by the heat of reaction. The hydrogen gases used were N57 (99.9997%), H_2 + approx. 0.5% O_2 and H_2 + approx. 0.5% N_2. In pure hydrogen approx. 95% of the magnesium reacted within the absorption period to form MgH_2. When 0.5% O_2 or N_2 was added a prompt drop took place. When the Mg powder was exposed to 0.5% N_2 from the start, the uptake of hydrogen gradually rose to 35% over 50 cycles. The sample exposed to 0.5% O_2 suffered a permanent loss of approximately 20% of the initial capacity. The effect of 0.5% N_2 was similar but less pronounced. The temporary and permanent effects of the impurities are discussed.

The Formation of Hydrides in Pure Magnesium Foils.

A. Schrøder Pedersen, K. Jensen, B. Larsen and B. Vigeholm, J. Less-Common Met. 131 (1987) 31-40.

Formerly the hydriding of magnesium was considered to be a very slow, incomplete process. During the last ten years, however, it has been demonstrated that magnesium in the form of finely comminuted powder (50 μm or less) readily reacts with hydrogen to form the stoichiometric compound MgH_2 completely. Attempts have been made to describe theoretically the formation of hydride in more or less spherical magnesium particles. However, very few studies have been done on the hydriding of magnesium foils. In our study pure magnesium was rolled to foil thicknesses down to 20 μm. The foils were exposed to hydrogen in the pressure range 1-3 MPa and temperatures between 650 and 700 K. The hydride formation was followed by gravimetry and by microscopy. The effect of foil thickness on the hydride formation is described and the mechanism and kinetics of hydride formation are discussed. It is concluded that the chemical reaction between magnesium and hydrogen is the rate-limiting step for the growth of the nuclei and that the transport processes are fast.

Composite Models and Mapping of Fatigue.

O.B. Pedersen. In: Constitutive Relations and Their Physical Basis. Proceedings of the 8th Risø International Symposium on Metallurgy and Materials Science, Risø, 7-11 September 1987. Edited by S.I. Andersen et al. (Risø National Laboratory, 1987) 471-478.

Dislocation mechanisms of flow, structural change and cracking in simple histories of low-temperature cyclic and monotonic deformation are reviewed briefly in the light of composite models. The range of control of each mechanism appears as a field in a fatigue diagram, a plot of plastic strain amplitude versus cycle number. An ideal set of constitutive equations would predict the pattern of fields in the fatigue diagram; but in most cases the field boundaries still remain empirical observations, unsupported by theory.

Modelling of Plastic Heterogeneity in Deformation of Single-Phase Materials.

O.B. Pedersen and T. Leffers. In: Constitutive Relations and Their Physical Basis. Proceedings of the 8th Risø International Symposium on Metallurgy and Materials Science, Risø, 7-11 September 1987. Edited by S.I. Andersen et al. (Risø National Laboratory, 1987) 147-172.

Ideas for modelling the role of heterogeneity in low-temperature deformation of single-phase crystalline materials are discussed. The heterogeneity in isolated grains (single crystals) is discussed in terms of composite models. Work hardening may be described with a two parameter model if a coupling is introduced between thermal flow stress and structure evolution. The heterogeneity in aggregates of grains (polycrystals) is discussed in terms of two bounds: the elastic-plastic Taylor model forms a lower bound for the heterogeneity, while the Sachs model with appropriate modifications forms an upper bound. The problem of the interdependence of the heterogeneous deformation of aggregates of grains and the work hardening of individual grains remains open.

The Flow Stress of Copper.

O.B. Pedersen, Acta Metall. 35 (1987) 2567-2581.

The reverse microflow associated with the Bauschinger effect in copper strained into stage II is characterized experimentally and analyzed in terms of obstacle-controlled flow and established composite theory. The results are discussed in the light of observations by electron microscopy, deformation calorimetry and X-ray diffraction. It is suggested that the overall flow resistance arises from an interplay of two modes of obstacle controlled glide, none of which dominate the flow stress. One mode occurs inside regions of high local dislocation density (inclusions) where individual forest dislocations oppose glide on the primary slip system. The second mode is bowing of dislocations between the inclusions.

The Effect of Different Internal Surfaces in Composite Lithium Electrolytes.

F.W. Poulsen, J. Power Sources 20 (1987) 317-325.

A linear increase in the conductivity of LiI-alumina composite electrolytes with increasing specific surface area (2.4-260 $m^2\ g^{-1}$) of the alumina is demonstrated. Part of the enhanced conductivity is probably due to normal doping of the LiI by the alumina. Replacing 25% of the LiI by LiBr does not change the conductivity. Replacing part of the LiI by Li_3N has a detrimental effect.

Diffusion Mechanisms for Enhanced Vacancy Accumulation Near Planar Sinks.

A.J.E. Foreman, B.N. Singh and A. Horsewell, Materials Science Forum 15-18 (1987) 895-900.

Both the nucleation and growth of cavities are appreciably enhanced in a relatively wide (of the order of 20 cavity spacings) band near planar sinks, e.g. grain boundaries. The vacancy accumulation peaks at a distance of about 10 cavity spacings from the boundaries. We speculate here on the nature of the cavity enhancement arising from various modes of interstitial transport. We consider the conventional three-dimensional and the anisotropic diffusion of self-interstitials, and dynamic transport of atoms into boundaries by replacement sequences or long range channelling. Predictions of these calculations are compared with experimental results.

Helium Flux to Grain Boundaries During Irradiation.

A.J.E. Foreman and B.N. Singh, J. Nucl. Mater. 149 (1987) 266-268.

A comparison is made between the measured and calculated values for the helium flux to grain boundaries. There is good agreement between the measured and calculated accumulation of helium on grain boundaries for a range of materials, helium production rates and irradiation conditions. It is concluded that the helium flux to grain boundaries can be reliably calculated provided the cavity sink strength within the grains is known.

Implications of the Variation in Microstructure Caused by Changes in Helium Generation Rate and Other Irradiation Parameters.

B.N. Singh and T. Leffers, Radiation Effects 101 (1987) 73-90.

The effect of changes in helium generation rate on void and bubble nucleation, growth and distribution observed mainly in high-purity aluminium are summari-

sed. It is shown that at a given irradiation temperature, the cavity microstructure may be composed of voids only, voids and bubbles or bubbles only, depending on helium generation rate. The accumulation of helium (generated during irradiation) on grain boundaries is considered; the helium generation rate is found to control the flux of helium to grain boundaries and therefore may also determine the rupture lifetime. The influence of materials variables on the flux to the boundaries is also considered. Changes in recoil energy and/or damage rate may have strong influence on precipitation and precipitate stability - and hence on helium flux to grain boundaries and mechanical properties. The implications of the effects of changes in irradiation parameters and materials variables are discussed.

Microstructure and Mechanical Properties of Medium Energy (600-800 MeV) Proton Irradiated Commercial Aluminium Alloys.

W. Lohmann, A. Ribbons, W.F. Sommer and B.N. Singh, Radiation Effects 101 (1987) 283-299.

Commercial AlMg- and AlMgSi-alloys were irradiated with medium energy (600-800 MeV) protons to a nominal fluence of 3.2 × 10^{24} p/m^2 which yields by calculation a displacement damage of 0.2 dpa and helium and hydrogen generation of 67 and 275 appm, respectively. Post-irradiation tensile testing revealed a very marked degree of irradiation-induced softening in the cold-worked AlMg-alloy as well as in the precipitation-hardened AlMgSi-alloy. The TEM examination of the irradiated specimens showed that neither the cold-work microstructure in the AlMg-alloy nor the G.P. zone type precipitates in the AlMgSi-alloy survive under the irradiation conditions used in the present experiment. Results of complimentary investigations (i.e., hardness measurements, optical microscopy and SEM-fractography) are also presented.

The Relations Between Mechanical Properties and Microstructure Under Fusion Irradiation Conditions.

B.N. Singh, T. Leffers, M. Victoria and W.V. Green (Guest Editors), Radiation Effects 101 (1987) 1-304.

The radiation conditions for the materials in a fusion reactor will differ significantly from those in a fission reactor in a number of ways. The effect of these irradiation conditions (e.g., high production rate of gaseous and solid impurities, modified cascade structure) on microstructural evolution and mechanical properties was the theme of the present workshop. Special consideration was given to the effect of the high helium production rate. As background for the fusion-specific papers the workshop also included some more general papers on radiation effects on microstructure and mechanical properties.

In hindsight we must admit that the title of the workshop "The Relation between Mechanical Properties and Microstructure under Fusion Irradiation Conditions" was rather ambitious. The investigations of irradiation effects under fusion conditions are still at a rather early stage, and the number of experimental investigations of the relation between mechanical properties and microstructure is indeed limited. "Mechanical properties and Microstructures ..." might have been a more appropriate title.

The present workshop was the follow-up of a workshop on "Evaluation of Simulation Techniques for Radiation Damage in the Bulk of Fusion First Wall Materials" held at Interlaken in 1983 [overviewed in Radiation Effects 83 (1984) 1]. The problem of simulation of fusion irradiation conditions is so

fundamental that it turned out also to be one of the major items of this workshop.

In the present proceedings the papers appear in the order in which they were presented at the workshop. The workshop finished with a general discussion which is summarized for the proceedings by John Brimhall and Helmut Trinkaus.

Progress in the Thermal Analysis of Oxides and Refractories.

O. Toft Sørensen, Thermochim. Acta 110 (1987) 449-51.

Selected papers dealing with catalysts, electrode materials, solid electrolytes and non-stoichiometric oxides are reviewed and discussed.

Report on the Workshop: Thermal Characterization of Non-Stoichiometric Oxides and Similar Compounds and Their Application in Energy Storage and Conversion.

O. Toft Sørensen and D. Jakes, Thermochim. Acta 110 (1987) 395-405.

Report of a workshop arranged in connection with 8th International Conference on Thermal Analysis, Bratislava, Czechoslovakia 19-23 August 1985.

Hydride Formation Mechanisms in Nearly Spherical Magnesium Powder Particles.

B. Vigeholm, K. Jensen, B. Larsen and **A. Schrøder Pedersen**, J. Less-Common Met. 131 (1987) 133-141.

Experiments on a large number of magnesium powders varying in particle size, morphology, purity and surface oxidation have shown that most of these parameters influence the kinetics of the hydride formation. Although no single step in the reaction will in general be rate determining we have in a previous investigation been able to assign a nucleation and growth model to the initial hydriding of an atomized powder. This powder of nearly spherical particles ($d \sim 90$ μm) with a thin oxide coating has also been used in this investigation of the nucleation and growth mechanisms. It is found that the nucleation is rate determining in the initial hydriding only and that the growth takes place entirely by interface migration of hydrogen from the particle surface. The pressure-nucleation relation and impurity effects on the ultimate degree of reaction are discussed.

Energy Storage Applications of Magnesium.

B. Vigeholm. In: Magnesium Technology. Proceedings of a conference, London, 3-4 November 1986. Book 396, 1987, The Institute of Metals (The Institute of Metals, London, 1987) 97-102.

This paper outlines the concept of energy storage in metal hydride with emphasis on the magnesium/magnesium hydride system. An attempt is made to survey the magnesium and magnesium alloy hydride application as it may be inferred from operating, planned and intended programmes mainly involving other hydrides. The overview includes hydrogen storage, heat storage, heat pumps, hydrogen recovery and refining.

Flydning i limfuger samt udformning af zoner med konstante elastiske forskydningsspændinger (Yields in Adhesive Joints and Design of Zones with Constant Elastic Shear Stresses.

G. Waagepetersen, Risø-M-2643 (Risø National Laboratory, 1987) 39 pp.

A method is given which based on a simple elastic-plastic model shows the distribution of shear stresses in the adhesive and gives a total picture of the development of the length of the yield zones and their strain as a function of load. Methods are given for the design of adhesive joints with constant elastic shear stresses in the ends of the adhesive or throughout the whole length of the adhesive, obtained by varying the thickness of the adherends or of the adhesive or a combination of both. The characteristic yield properties of such designs are being determined. Internal stresses after yield and unloading are determined, and modified stress-distribution for new load is found. The constant elastic shear stress zones can be designed taking all relevant factors into consideration including various temperature stresses, bending moments in the adherends etc. Thereby zones with constant stresses will be general usable also for single lap joints.

The Evaluation of Internal Stresses in a Short Fibre Metal Matrix Composite by Neutron Diffraction.

P.J. Withers, D. Juul Jensen, H. Lilholt and W.M. Stobbs. In: Proceedings of the ICCM6/ECCM2 Conference, London, 20-24 July 1987. Edited by F.L. Matthews et al. (Elsevier Applied Science, London, 1987) 2.255-2.264.

The use of neutron diffraction is described for the evaluation of the mean matrix and fibre strains in a short fibre metal matrix composite as a function of its thermal history. The data obtained are analysed in terms of a developed Eshelby based model for the stresses generated as a result of the different thermal expansion coefficients and compliances of the two phases. The results are discussed in terms of the partial diffusional relaxation which can occur as a function of temperature.

2. Lectures

De nye højtemperatur superledere. (The New High Temperature Superconductors).

N. Hessel Andersen, presented to Danmarks Naturvidenskabelige Samfund, Danmarks Tekniske Højskole, 3 December 1987.

De nye superledere. (The New Superconductors).

N. Hessel Andersen, presented to Folkeuniversitetet i Roskilde, 2 November 1987.

De nye superledere - nye materialer med revolutionerende egenskaber. (The New Superconductors - New Materials with Revolutionizing Properties)

N. Hessel Andersen, presented at Roskilde Efterskole, 5 November 1987.

Højtemperatur superledere - deres egenskaber og mulige anvendelser. (High Temperature Superconductors - Their Properties and Possible Applications).

N. Hessel Andersen, presented at Den Kongelige Veterinær- og Landbohøjskole, 12 November 1987.

Materialeforskning til brændselsceller baseret på iltionledende faststofelektrolytter. (Materials Research for Fuel Cells Based on Oxide Ion Conducting Solid Electrolytes).

N. Hessel Andersen, presented to Elektro-Kemisk Forening, Danmarks Tekniske Højskole, 30 April 1987.

Superconducting Ceramics.

N. Hessel Andersen, presented at a conference and exhibition on technical ceramics, Danmarks Tekniske Højskole, 25 September 1987.

Superledning i keramiske materialer. (Superconductivity in Ceramic Materials).

N. Hessel Andersen, presented to Dansk Metallurgisk Selskab, Danmarks Tekniske Højskole, 8 December 1987.

Effect of Ply Configuration and Specimen Geometry for Angle-Ply Carbon Fibre Reinforced Plastics.

S.I. Andersen, presented at the European Symposium on Damage Development and Failure Processes in Composite Materials, Leuven, Belgium, 4-6 May 1987.

The boundary layer zones in rectangular angle ply specimens are modelled by linear elastic finite element technique. Different ply angles and specimen widths are treated, and it is shown that both the width and the stresses in the boundary layer zone is dependent of the fibre angle and of the stacking sequence. Good correlation with experimental results are shown at moderate fibre angles, i.e. angles less than approximately 30°. For higher fibre angles, non-linearity seems to invalidate the analytical results.

Fatigue Properties of Glass Fibre Polyester.

S.I. Andersen, H. Lilholt and Aa. Lystrup, presented at the 2nd Meeting of the EEC Wind Programme, Brussels, 23 November 1987. Proceedings to be published.

Within the WT design basis, fatigue properties form a subaction; one part of this subaction is fatigue of glass-fibre reinforced polyester. The subaction programme will study selected materials and properties, which are representative for current materials and loadings on windturbine rotorblades. The new aspects of the programme are the relatively new materials, which are now widely used by the European windturbine industry, the need for performance data at more than 10^8 fatigue cycles, and the establishment of design criteria, e.g. based on sufficient stiffness or sufficient strength during the lifetime of the rotorblades.

This report contains activities and results obtained since the start of the project:

- *Glassfibre reinforced polyester materials have been designed to have well-defined fibre orientations and to be transparent, for easy observation of damage; the necessary fabrication methods have been developed.*
- *Materials with fibre orientation 0° have been fabricated, and materials with ±10° fibres are in progress. The materials have been tested in fatigue, both at Risø Laboratory and at Ghent University.*
- *Fatigue results for 0°-material are completed, and for ±10°-material testing is in progress. The results compare well, and are also consistent with existing data on ±5°-material.*
- *The analysis of the results, in particular the stiffness reduction during fatigue, is in progress, and indicates possible ways to normalize the data.*
- *Damage or cracks forming during fatigue are important, and equipment (video camera) have been installed to give a continuous and permanent recording of the damage development during fatigue testing.*

Overview of Fracture Mechanics Related Work in Progress at Risø National Laboratory.

S.I. Andersen, presented at the 15th Plenary Meeting of EGF Task Group No. 1: Elasto Plastic Fracture Mechanics Work, Risø National Laboratory, 29-30 October 1987.

A short review of background and activities of fracture mechanics related work at Risø is given. Both theoretical work (structural mechanics and probabilistic mechanics) and experimental work are covered, and materials are steel and to a minor extent ceramics.

Brændselceller og iltsensorer baseret på keramik. (Full Cells and Oxygen Sensors Based on Ceramics).

J.J. Bentzen, presented at Dansk Forening for Materialografi's November-seminar, Kolding, 19-21 November 1987.

Fundamentals of oxygen ion conducting ceramics with the fluorite structure were presented along with some examples of their application.

Ceria and Zirconia Based Oxygen Conducting Ceramics: Preparation, Characterization and Application.

J.J. Bentzen and O. Toft Sørensen, presented at the conference Ceramic Materials '87, Chalmers Tekniske Højskole, Göteborg, 2-3 June 1987.

Doped ceria and zirconia ceramics are important oxygen ion conductors for application in fuel cells, sensors and electrolysers. Ceria and zirconia based oxygen ion conductors doped with gadolinia, europia and/or yttria prepared in different ways including homogeneous precipitation and hydrothermal methods characterized by various methods such as a.c. impedance spectroscopy and SEM are discussed in this paper.

Ionlederkeramik. (Oxygen Ion Conducting Ceramics).

J.J. Bentzen, presented at the conference Teknisk Keramik '87, Danmarks Tekniske Højskole 24-25 September 1987.

Fundamentals of oxygen ion conducting ceramics with the fluorite structure were presented along with some examples of their application.

Strukturanalyse med elektronmikroskopi. (Application of Electron Microscopy to Microstructural Analysis).

J.B.Bilde-Sørensen, presented at Metallurgiafdelingens Industrimøde, Risø National Laboratory, 17 June 1987.

A survey was given of the techniques that can be used in scanning and transmission electron microscopy with emphasis on the techniques that are most relevant to industrial customers. Techniques for elemental analysis (EDS and EELS) were included. Examples of the application of various techniques to actual problems were given.

Fatigue Crack Growth Studies Based on Fracture Mechanics.

P. Brøndsted, presented at the "European Group of Fracture"-Meeting, Risø National Laboratory, 29-30 October 1987.

The behaviour of fatigue cracks can be described based on studies of the structural response on reverse straining of the material, the crack initiation, the short crack growth, the threshold range and the crack growth.

Characteristic dislocation structures are build up in a metal when it is exposed to reverse straining. Due to extrusions and intrusions this will result in microstructural crack initiation at the surface. The initiated cracks will then behave as short cracks. Normally this crack growth will be impeded by the microstructures and this leads to definition of a threshold value in fatigue crack studies. At increasing stress intensities the crack will grow according to an exponential correlation between crack growth rates and stress intensities.

In the talk this simplified modelling of fatigue behaviour is presented and methods for studying the different steps in the fatigue crack development are described based on ongoing work in the Metallurgy Department at Risø National Laboratory.

Mechanical Testing of High Temperature Materials.

P. Brøndsted and **J.B. Bilde-Sørensen**, presented at the NKA-Meeting on High Temperature Materials in Fossil Fired Plants, Risø National Laboratory, 25 November 1987.

A description of the creep behaviour of metallic materials is given using the "θ-projection concept". This concept can be used for extrapolating short time creep test results to give reliable long time predictions.

The traditional experimental techniques used in extrapolation are reviewed and actual results from tests performed at Risø are presented. Errors introduced

introduced during tests using small test specimens are discussed and comparisons between tests on X20CrMoV 12 and 14MoV 6 3-steels are made to discuss influences from oxidation of test specimens at elevated temperature. Finally the facilities for creep testing at Risø are shown.

Defects in Molecular Crystals Studied by Positron Annihilation.

M. Eldrup, presented to the Department of Physics, University of Jyväskylä, Finland, 13 November 1987.

Positronium as a Probe of Molecular Environment.

M. Eldrup, presented at the International Symposium on Positron Annihilation Studies of Fluids, Fort Worth, Texas, 8-12 June 1987.

In many condensed molecular substances a certain fraction of injected positrons will form positronium (Ps). The Ps wavefunction may be strongly influenced by the surrounding medium and the Ps state is therefore sometime referred to as quasi-Ps (as opposed to Ps in vacuum). Once formed, Ps may react chemically with surrounding impurity molecules (Ps quenching). Surrounded by non-reacting molecules the main interaction will be repulsive exchange interaction between the Ps electron and molecular electrons. These electrons will also to some extent screen the Ps positron from its electron. Because of the repulsion between Ps and the surrounding molecules, Ps may become localized in cavities, either pre-existing or induced by the presence of the Ps atom. Examples of the latter are Ps bubbles in liquids. The present talk will mainly concentrate on Ps interactions in molecular solids.

In crystals with low defect concentration (ppm or less) Ps is in a delocalized Bloch state as has been demonstrated experimentally in a few cases by the presence of narrow p-Ps peaks in angular correlation curves. Localization of Ps into molecular vacancies and clusters of these are observed for concentrations above the ppm level. The o-Ps lifetime depends on the size of the free volume in the defect and the quantitative correlation between these two parameters has been established experimentally for "spherical" and recently also for elongated molecules. Using Ps as a probe for vacancies the formation energy of these defects has been determined for several crystals.

In most molecular crystals Ps is only observed in localized states, probably because of an inherently high defect concentration. Still the Ps state has been found to be influenced by impurity molecules and temperature. Experimentally the correlation between o-Ps lifetime and molecular packing density has been obtained and the influence of molecular shape has been studied. Also the effect of the size of impurity molecules on the measured annihilation characteristics has been established.

In the talk the above mentioned topics will be critically discussed. Emphasis will be put on open questions and possible future research.

Positronium in Solids and Molecular Crystals.

M. Eldrup, presented at Spanish School of Positron Annihilation Spectroscopy in Materials Science, San Lorenzo de El Escorial, Spain, 1-6 September 1987.

The characteristics of positronium and its behaviour in molecular crystals are briefly discussed. Results from the literature are presented for a number of crystals and the possibility to study defect properties is illustrated by examples.

Ultrasonic Examination of Ceramics and Composites for Porosities in an Automatic Scanning System.

H.E. Gundtoft, presented at the 4th European Conference on Non-Destructive Testing, London, 13-17 September 1987.

Using a very precise scanning system and computer evaluation, we can get quantitative results from automatic ultrasonic examination. In this paper two examples dealing with nonmetallic materials are presented.

In a ceramic plate (>1 inch thick) small spherical porosities (down to 0.1 mm) would harm the final product. Several artificial defects made in the plate were used for calibration and optimisation of the technique. Areas with natural defects were viewed with a microscope. Good agreement with the predicted values from the ultrasonic examination was found. From the NDT-examination the exact position of a porosity is known in all 3 coordinates (x, y, and z). The size of the defect can also be measured. A single porosity with a diameter of 0.1 mm can be detected.

Carbon-reinforced composites were examined. 8 prepregs were stacked and hardened in an autoclave to form a sheet (1 mm thick). Air trapped in the material resulted in porosities in the final product. A double trough-transmission-scanning technique was used for the examination. The porosity percentages were determined by the NDT-technique, and agreement with destructively determined values on samples from the same sheet was found.

Microstructures, Textures and Mechanical Properties After Large Strains.

N. Hansen and T. Leffers, presented at the Europhysics Study Conference on Mechanisms and Mechanics of Plasticity, Aussois, France, 1-10 April 1987. To appear in Revue de Physique Appliquee.

Microstructure, texture and mechanical properties of polycrystalline materials after medium and large strains are reviewed. The existing deformation models are discussed on the basis of the evidence presented, and mechanical properties and microstructure are correlated. Finally anisotropy and constitutive relations are discussed briefly.

Research Evaluation - Truth or Trickery.

N. Hansen, presented to Senior Advisers to ECE Governments on Science and Technology, Helsinki, 22-26 June 1987.

The principles of research evaluation are discussed with special reference to the author's own experience as a reviewer and as the one being reviewed.

Texture and Microstructure Development During Grain Growth in Copper.

E.M. Grant, N. Hansen, D. Juul Jensen, B. Ralph and M. Stobbs, presented at the International Conference on Texture of Materials, Santa Fe, USA, 20-25 September 1987. Proceedings to be published.

Grain growth in copper has been investigated by texture measurements and microstructural observations. Neutron diffraction techniques have been used to study bulk texture changes during grain growth and backscattered selected area channelling patterns have been used to obtain information about local texture changes. The microstructural development during grain growth has been studied by transmission electron microscopy (TEM). The observed texture changes are related to the change in the grain size distribution, which is discussed on the basis of the local texture measurements. Also the grain growth characteristics are

considered on basis of the TEM observations of the microstructural development during grain growth.

Atomic Collisions, Defect Diffusion and Defect Accumulation in Irradiated Materials.

A. Horsewell, presented at a seminar at the Department of Physics, Ecole Polytechnique Fédérale de Lausanne, Switzerland, 9 February 1987.

Irradiation of metals with energetic particles (fast neutrons, high energy electrons, high energy protons, ions) results in direct atomic displacement producing Frenkel defect pairs (vacancies and interstitials).

Conventionally, the created vacancies and interstitials are treated as diffusing randomly. The separation of vacancies and interstitial defects and continued clustering to produce voids and dislocation loops is seen as a consequence of a slight bias of the dislocations for interstitials.

Electron microscopy of fast neutron and high energy proton irradiated pure aluminium and copper shows void microstructures which cannot be interpreted entirely within this framework. Large scale inhomogeneities and enhanced void growth near grain boundaries are observed over several microns: void hyperlattices in aluminium have a lattice parameter of 150 nm. These results are interpreted with reference to long-range dynamic transport of interstitials and related back to atomic collision processes following the initial atomic displacement events.

The Application of Transmission Electron Microscopy Techniques in Materials Research in Denmark.

A. Horsewell and **J.B. Bilde-Sørensen**, presented to the Danish Society for Materials Testing, Lyngby, 16 September 1987.

Denmarks TEM capabilities were reviewed. Recent research at Risø Metallurgy Department was used to illustrate the strength of combining microstructural information, microdiffraction and microchemical information, which can be obtained from "new-generation" analytical electron microscopes.

Effect of Metallurgical Parameters on the Textural Development in FCC Metals and Alloys.

D. Juul Jensen, N. Hansen and F.J. Humphreys, presented at the 8th International Conference on Textures of Materials, Santa Fe, USA, 20-25 September 1987. Proceedings to be published.

The textural development during cold deformation and recrystallization is strongly related to metallurgical parameters such as initial grain size and size and volume fraction of second phase particles. Such relationships are described with reference to the microstructural changes for medium and high stacking fault energy fcc metals.

Deformation textures depend strongly on the deformation mode and the degree of deformation. The present paper is mainly concerned with deformation by rolling to strains in the range 0.2-3.0. The textural development is discussed on the basis of microstructural observations and is compared with predictions based on different deformation models. In general the effect of varying the initial grain size or introducing second phase particles is to change the strength of the deformation texture and this finding is related to effects of the metallurgical parameters on the deformation pattern.

Recrystallization textures depend on the mechanisms for nucleation and growth. The formation of recrystallization textures (e.g. the cube texture) in pure

metals is not reviewed whereas the behaviour of particle containing materials is discussed in detail based on recent experimental observations. Parameters in these experiments were the volume fraction of large (>0.1-1 μm) and small particles (< 0.1 μm). The observed textural changes are related to the formation and growth of recrystallization nuclei and the relationships between the development in texture and microstructure are discussed.

Local Features Related to Fission Gas Release in Transient-Tested High-Burnup Fuel.

P. Knudsen, presented at Seminar on High-Burnup Fuel Performance Topics, Frederiksstad, Norway, 12-15 May 1987.

High-burn UO_2-Zr fuels were submitted to power transients and examined by a series of special hot cell techniques, including: x-ray fluorescence analysis, electron probe micro analysis, optical microscopy, scanning electron microscopy, and x-ray diffraction. This provided detailed, local data on: grain boundary gas distribution, porosity distribution and morphology, and fuel stoichiometry; evaluation of these data show that the rate-determining step for fission gas release in these fuels is interlinkage of gas bubbles on the grain faces and the formation of grain edge tunnels.

Early-Stage Differences Between the Copper-Type and the Brass-Type Texture.

T. Leffers, D. Juul Jensen and **B. Major**, presented at the 8th International Conference on Textures of Materials, Santa Fe, USA, 20-25 September 1987. Proceedings to be published.

It is demonstrated that the development of the copper-type and the brass type textures (represented by pure copper and brass with 15% zinc) are different from the very early stage and that the difference is not due to the initial textures. On the basis of this observation (supplemented by TEM observations) it is argued that, at present, there appears to be no alternative to the Sachs model for describing the development of the brass-type texture.

Fast Texture Measurements by Neutron Diffraction Using a Position Sensitive Detector.

T. Leffers and **D. Juul Jensen**, presented to Deutsche Gesellschaft für Metallkunde, GKSS Forschungszentrum, Geesthacht, 26 June 1987. To appear in a GKSS report.

The general advantages of neutron diffraction for texture measurement and the special advantages in the Risø set-up are described together with various results obtained.

Various Effects of Grain Size on FCC Rolling Textures.

T. Leffers, D. Juul Jensen and **N. Hansen**, presented at the 8th International Conference on Texture of Materials, Santa Fe, USA, 20-25 September 1987. Proceedings to be published.

In the literature there are various references to grain-size effects on the development of deformation texture. The concept of such an effect is alien to most standard models for texture formation, which means that, apart from the possible practical importance, the effect has interesting theoretical implications.

In the present work we perform a critical examination of the reported cases of grain-size effects on the development of rolling textures in f.c.c. materials, all referring to differences in texture development between coarse-grained materials and "normal" fine-grained materials. Special emphasis is given to the question whether the apparent grain-size effect may actually be an effect of the difference in initial texture which normally accompanies a difference in grain size.

Fiberforstærkede plastmaterialer. (Fibre Reinforced Plastics).

H. Lilholt and Aa. Lystrup, presented at a symposium at Center for Konstruktion og Udvikling, Risø National Laboratory, 26 February 1987.

A survey of materials, mechanisms, properties, fabrication methods, and applications was given, with special emphasis on continuous fibre composites.

Kompositmaterialer. (Composite Materials).

H. Lilholt, presented at the meeting Danmark i Materialealderen, Dansk Ingeniør Forening, Copenhagen, 31 August - 2 September 1987.

A brief presentation was given of composite materials and the organisation of the work on national and international level.

Kompositmaterialer. (Composite Materials).

H. Lilholt, presented at Horsens Teknikum, Horsens, 4 November 1987.

A presentation was given of fibres, matrices and composite materials with special emphasis on mechanical behaviour.

Kompositmaterialer - lette materialer med skræddersyede egenskaber. (Composite Materials - Light Materials with Tailormade Properties).

H. Lilholt, presented at Århus Teknikum, Århus, 18 November 1987.

A presentation was given of fibres, matrices and composite materials, with special emphasis on mechanical behaviour.

Metallkompositter. (Metal Matrix Composites).

H. Lilholt, presented at Statens Teknologiske Institutt, Fornebu, Norway, 18 June 1987.

A brief presentation of properties and fabrication of metal matrix composites was given.

Organisation of Composites in Scandinavia.

H. Lilholt, presented to European Composite Forum, Cambridge, 8-11 July 1987.

A brief presentation was given of the work and programmes on composite materials, primarily in Denmark.
Performance of Metal Matrix Composites.

H. Lilholt, presented at Composite Materials Technology Course, University of Surrey, England, 13-17 July 1987.

A presentation was given of the performance during long term loading of metal matrix composite materials; emphasis was placed on creep properties.

Report on the Twinning Material Carbon Fibre (IM6) Reinforced Epoxy (6376).

H. Lilholt and co-authors, presented at lst Leuven Symposium, Leuven, Belgium, 4-6 May 1987.

A review and discussion was given on the C/epoxy material which was used by five laboratories in studies on the effect on damage in composite laminates under static and fatigue loadings. A comparison of test methods and results was given.

Udmattelsesegenskaber af glasfiberforstærket polyester. (Fatigue Behaviour of Glass Fibre Reinforced Polyester).

H. Lilholt, presented to Polymerteknisk Selskab (Dansk Ingeniør Forening), Copenhagen, 24 November 1987.

The use of glassfibre reinforced polyester as a material for wingblades on wind turbines requires information on the long term fatigue properties. The materials data and research was reviewed.

Utmatningsprøver på vindmøllevinger. (Fatigue Testing of Wind Turbine Blades).

H.Lilholt, presented at a meeting at Statens Teknologiske Institutt, Fornebu, Norway, 18 June 1987.

A brief presentation was given of fatigue properties of glassfibre reinforced polyester and of fatigue testing of wingblades.

Måling af indre spændinger med neutrondiffraktion. (Measurement of Internal Stresses by Neutron Diffraction).

T. Lorentzen, presented at the meeting Eksperimentel Mekanikdag, Aalborg Universitetscenter, 1 December 1987.

Stress states caused by external loadings can in principal be determined analytically or they can be calculated numerically. However residual stresses produced during fabrication can exist and are often neglected because they can only be calculated in very rare cases, and because measurements are often difficult and time consuming. Often these stresses are caused by thermal loadings or by plastic deformation, and it can be of great importance to know these stresses in order to determine the absolute stress level.

A relatively new non-destructive method for experimental determination of these types of stresses, is stress determination by neutron diffraction, and the equipment needed for applying this method has now been implemented at Risø through a three year FTU grant. The oral presentation will describe the technique, as well as the principal problems inherent. The equipment, now installed at the Risø neutron radiation facility - DR3, will be described, examples are given on the use of this method, and test measurements will be shown.

Fabrikation af polymerbaserede kompositmaterialer. (Fabrication of Fibre Composites with Polymer Matrix).

Aa. Lystrup, presented to Polymerteknisk Selskab (Dansk Ingeniør Forening), Copenhagen, 24 November 1987.

A survey of fabrication methods for fibre reinforced polymer materials was given. Special emphasis was put on the use of different matrix materials, and both thermosets and thermoplastics were covered.

Fiberkompositter. (Fibre Composites).

Aa. Lystrup, presented at the meeting Danmark i Materialealderen, Dansk Ingeniør Forening, Copenhagen, 31 August - 2 September 1987.

A survey of materials, mechanisms, properties, fabrication methods, and applications was given, with special emphasis on continuous fibre composites.

Fremstilling af kompositmaterialer. (Manufacturing of Composite Materials).

Aa. Lystrup, presented at Horsens Teknikum, Horsens, 11 November 1987 and at the meeting Metallurgiafdelingens Industridag, Risø National Laboratory, 17 June 1987.

Different manufacturing techniques for fibre composites were reviewed. More detailed information about fabrication of advanced fibre composite materials by computer controlled filament winding and autoclave curing were presented.

Kompositmaterialer. (Composite Materials).

Aa. Lystrup, presented at Institut for Produktion, Aalborg Universitetscenter, Aalborg, 17 November 1987.

A survey of materials, mechanisms, properties, fabrication methods, and applications was given, with special emphasis on continuous fibre composites.

Kompositmaterialer. (Composite Materials).

Aa. Lystrup, presented to Teknologisk Informationscenter Roskilde Amt, Greve Badehotel, Denmark, 10 September 1987.

A survey of materials, properties, fabrication methods and applications was presented. The state-of-the-art and the perspectives within the Danish industry were discussed.

Kompositmaterialer. Nye egenskaber og nye anvendelser. (Composite Materials. New Properties and New Applications).

Aa. Lystrup, presented at Århus Teknikum, Århus, 18 November 1987.

A survey of materials, mechanisms, properties, fabrication methods, and applications was given, with special emphasis on continuous fibre composites.

Plastbaserede kompositmaterialer. (Polymer Composite Materials).

Aa. Lystrup, presented to Militærteknisk Forening (Dansk Ingeniør Forening), Copenhagen, 21 May 1987.

A survey of advanced composite materials and their military applications was given.

Præparation af fiberkompositter for mikroskopisk undersøgelse. (Preparation of Fibre Composites for Microscopic Examination).

C. Mikkelsen, presented at Dansk Forening for Materialografis Jubilæumsseminar, Kolding, 20 November 1987.

Batterier. (Batteries).

M. Mogensen, presented at a meeting arranged by Procesteknisk Selskab (Ingeniør-Sammenslutningen), Copenhagen, 28 April 1987.

The current state of batteries and fuel cell for traction purposes were reviewed. Both technical and economical aspects were covered.

Brændselsceller. (Fuel Cells).

M. Mogensen, presented to Ungdommens Naturvidenskabelige Forening, Copenhagen, 1 October 1987.

The principles of the different types of fuel cells were outlined. The current states of the different FC-technologies were explained together with the advantages of the different systems such as phosphoric acid fuel cells, molten carbonate fuel cells and solid oxide fuel cells. Some possible impacts of fuel cells on society in the future were presented.

Brændselsceller i fremtidens energiforsyning, teknologiske og økonomiske aspekter, mulige planer for Risø's indsats. (Fuel Cells in Future Electricity Production, Technical and Economical Aspects, Possible Activities to be Undertaken at Risø).

M. Mogensen, presented to Elsam engineers, Skærbæk, 16 June 1987.

The basic principles of fuel cell power plants were presented, and examples of "the state of the art" of fuel cell technology were shown. Also some economics of fuel cell plants were given. Finally a possible fuel cell research cooperation between Risø and the power producing companies was sketched.

Kimdannelse og vækst af LiCl på Li i $SOCl_2$. (Nucleation and Growth of LiCl on Li in $SOCl_2$).

M. Mogensen, presented to EFP-programme participants, Odense Universitet, 19 March 1987.

The most essential experimental results of the last 3 years study of Li passivation in $SOCl_2$ solutions were presented. A passivation model was outlined and measures of controlling the Li passivation were given.

Mechanisms of Lithium Passivation in Liquid Cathods.

M. Mogensen, presented at Duracell Research Centre, Needham, Massachusetts, 7 October 1987.

Mechanisms of formation of Li in $SOCl_2$, SO_2Cl_2, SO_3 and $LiAlCl_4{\cdot}3SO_2$ solution were discussed. Special emphasis was put on the possible means of controlling the homogeneity and thickness of the solid electrolyte layers formed, and how this could improve the battery performance and cyclability.

Passivation of Lithium in $SOCl_2$, SO_2Cl_2 and SO_3.

M. Mogensen, presented at the 172nd Meeting of the Electrochemical Society, Honolulu, 18-23 October 1987. Proceedings to be published.

The passivation of Li electrodes in liquid cathodes has been studied by ac impedance and SEM during exposure times up to four years. The liquid cathodes are 1.8M $LiAlCl_4$ in $SOCl_2$, 1.2M $LiAlCl_4$ + 0.6M SO_2AlCl_3 in $SOCl_2$, 1.5M $LiAlCl_4$ in SO_2Cl_2 and 0.5M $LiAsF_6$ in $SO_2{\cdot}2SO_3$. In the acid $SOCl_2$ a dramatic difference in passivation rates were observed between different Li electrode arrangements. The results are rationalized through a kinetic model in which the rate determining step changes with exposure time. Nucleation and growth of

Li salt crystals is an important step in the formation of the passivating solid electrolyte layers.

Passivation of Li in $SOCl_2$ Solutions.

M. Mogensen, presented at the international workshop Lithium Power Sources with Aprotic Liquid and Solid Electrolytes, Gaussig Castle, Dresden, 9-13 March 1987.

A model for Li-electrode passivation in $SOCl_2$ liquid cathodes was presented. The main new concept of the model is that of nucleation and growth of LiCl crystals in the early stage of Li passivation. The main experimental findings leading to this model were presented.

Hydrogen

A. Schrøder Pedersen, presented to Elsam engineers, Skærbæk, 16 June 1987.

A brief presentation was given of the techniques and economics of hydrogen production and purification. Special emphasis was put into the application of hydrogen in fuel cells for power production.

Fatigue Mechanism Maps.

O.B. Pedersen, presented at Institut für Werkstoffwissenschaften, Universität Erlangen-Nürnberg, Erlangen, FGR, 6 November 1987.

Recent work on the basic mechanisms of low-temperature fatigue has suggested a detailed picture of the successive mechanisms by which cyclic straining leads to crack initiation. The overall process can be visualized by mechanism maps drawn in diagrams of plastic strain amplitude versus cycle number. A brief presentation of the models and observations used to construct the maps will illustrate their limitations and applications.

Physically Based Constitutive Equations for Metallic Composites.

O.B. Pedersen, presented at Institut für Metallphysik und Nukleare Festkörperphysik, Technischen Universität Carolo-Wilhelmina, Braunschweig, FGR, 5 November 1987.

The dislocation theory of obstacle controlled plastic flow can be combined with a mean field theory to provide constitutive equations for the cyclic plasticity of composite materials. In particular, this approach implies that the in-situ matrix hardening is split into isotropic and kinematic contributions. The split is significant for composites of engineering interest, it is a synergistic effect displayed by elastically heterogeneous composites with high fibre contents.

Elektrokeramik - fra højspændingsisolatorer til superledere. (Electro-Ceramics - From High Voltage Insulators to Superconductors).

F.W. Poulsen, presented at Metallurgiafdelingens Industrimøde, Risø National Laboratory, 17 June 1987.

The electrical properties of ceramics can be designed to meet the requirements in numerous applications: as electrical insulators; as semiconductors; as ion-specific membranes in sensors and fuel cells; and finally as electrical wires (high temperature superconductors). The ongoing materials development at the Metallurgy Department is outlined with these perspectives in mind.

Faststoffelektrolytt-forskningen ved Forskningscenter Risø, Roskilde. (Solid Electrolyte Research at Risø National Laboratory).

F.W. Poulsen, presented at Institutt for Uorganisk Kjemi, Norges Tekniske Højskole, Trondheim, 13 November 1987.

The ongoing research in the field of solid electrolytes at Risø is reviewed. Structural and electrochemical characterisation of composite electrolytes and oxygen ion conductors are emphasized. Applications of solid electrolytes in sensors and fuel cells are described.

Risøs hidtidige indsats - anvendelse af ionledende materialer. (Application of Solid Electrolytes in Fuel Cells).

F.W. Poulsen, presented to Elsam engineers, Skærbæk, 16 June 1987.

Activities at Risø in fuel cell research are described. Investigations of oxygen ion conductors for high temperature fuel cells (SOFC) and membrane development for a near ambient temperature Ni-hydrogen battery are discussed.

Defect Transport and Segregation in Irradiation Environments.

B.N. Singh, presented at Materials Development Division, AERE-Harwell, 28 January 1987.

Experimental evidence demonstrates that vacancy accumulation is considerably enhanced in a wide zone near planar sinks. The mechanism for this inhomogeneous segregation has not yet been identified, but could be due to an excessive loss of interstitials from the grain interiors. Transport of self-interstitial atoms (SIA) might occur by one- or two- dimensional diffusion mechanisms or dynamically by atoms channelling and replacement sequences from damage cascades. The results of analytical calculations made to evaluate the capability of different diffusion mechanisms to yield the observed enhancement in vacancy accumulation will be described and discussed.

Fusion Related Damage Studies in Metals and Alloys.

B.N. Singh, presented at ENEA, Cassacia, Rome, 1 December 1987.

Results of experimental and theoretical studies on effects of helium generation rate and recoil energy spectrum on microstructural evolution will be described. Relevance of Positron Annihilation, Small Angle Neutron Scattering and Transmission Electron Microscopy techniques in the quantitative characterization of microstructural components will be discussed.

Keramik - fremtidens materiale. (Ceramics - Materials for the Future).

O. Toft Sørensen, presented to Konstruktionsafdelingen, Risø National Laboratory, 18 June 1987.

Keramiske iltionledere og deres anvendelse i iltsensorer. (Oxygen Conduction Ceramics and Their Application in Oxygen Sensors).

O. Toft Sørensen, presented to Dansk Elektrokemisk Forening, Danmarks Tekniske Højskole, 30 April 1987.

Keramiske Materialer. (Ceramic Materials).

O. Toft Sørensen, presented at Thrige-Titan A/S, Odense, 28 October 1987.

Risøs forskning inden for konstruktionskeramik og ionlederkeramik samt oxygensensorer. (Risø's Projects on Engineering and Electro-Ceramics as well as Oxygen Sensors).

O. Toft Sørensen, presented to Sandviken, Stockholm, 23 June 1987.

Risøs fremtidsplaner inden for avanceret teknisk keramik. (Risø's Future Plans in the Field of Advanced Ceramic Materials).

O. Toft Sørensen, presented at Metallurgiafdelingens Industrimøde, Risø National Laboratory, 17 June 1987.

Zirconia Toughened Ceramics: Research and Development at Risø National Laboratory, Denmark.

O. Toft Sørensen and **J.J. Bentzen**, presented at the conference Ceramic Materials '87, Göteborg, 2-3 June 1987.

Research and development in the field of high performance ceramics are in Denmark mainly carried out in collaboration between three institutes: the Technical University of Denmark (DTH), the Technological Institute, and Risø National Laboratory. After a brief survey of the current general Danish national ceramic research programme at these institutes, the programme at Risø which is concentrated on zirconia toughened ceramics will be presented and discussed in greater details.

Metalhydrider. (Metal Hydrides).

B. Vigeholm, presented at a meeting arranged by Procesteknisk Selskab (Ingeniør-Sammenslutningen), Copenhagen, 28 April 1987.

A technical description was given of metal hydrides as means of storing energy. Economical considerations were included.

Pulverteknologi. (Powder Technology).

B. Vigeholm, presented at Metallurgiafdelingens Industrimøde, Risø National Laboratory, 17 June 1987.

The experiences, capability and expertices of the Metallurgy Department, Risø National Laboratory, were outlined and illustrated by examples.

3. Posters

Quasielastic Diffuse Neutron Scattering From Yttria Stabilized Zirconia at Elevated Temperatures.

S. Hull, N.H. Andersen, K.N. Clausen, T.W.D. Farley, M.A. Hackett, W. Hayes, M.T. Hutchings, R. Osborn and W.G. Stirling, presented at the 6th International Conference on Solid State Ionics, Garmisch-Partenkirchen, 6-11 September 1987. To appear in solid State Ionics.

Coherent diffuse scattering from single crystals of six concentrations of Y_2O_3 in ZrO_2 has been studied at temperatures between 293K and 2780K. The results are interpreted in terms of the scattering calculated from a model of the crystal comprising a vacancy-free tetragonal region, and a region in which there are vacancies and aggregates of vacancy pairs with a range of sizes. The vacancies and possibly the smaller aggregates appear to be most mobile as the temperature increases.

Comparative Fracture Strength Measurements on YPSZ (Yttria Partially Stabilized Zirconia).

J.J. Bentzen, O. Toft Sørensen, T. Lepistö and T. Mäntylä, presented at the conference Ceramic Materials '87, Göteborg, 2-3 June 1987.

An important property of ceramic materials is the fracture strength as, for instance, determined by the 4-point bending technique. The fracture (or bend) strength obtained by this technique is, however, subject to several uncertainties such as type of testing machine and fixture used, sample preparation and sample homogeneity. In an attempt to evaluate the importance of these parameters, comparative measurements using the 4-point bending technique on standard YPSZ-samples were carried out at Risø, Denmark, Tampere University, Finland, and at Joint Research Centre, Petten, Holland. In this poster the results obtained from these measurements will be presented and discussed.

Evaluation of 2- and 4-Point Conductivity Measurements on Oxide Ion Conductors.

J.J. Bentzen, N. Hessel Andersen, F.W. Poulsen, O. Toft Sørensen and R. Schram, presented at the 6th International Conference on Solid State Ionics, Garmisch-Partenkirchen, 6-11 September 1987. To appear in Solid State Ionics.

A comparison between different ac measuring techniques has been performed and evaluation methods for the determination of ionic conductivity in oxygen conductors are described. 2- and 4-point impedance measurements using two different frequency response analysers (Solartron FRA-1174 and FRA-1250) are compared. The materials studied were polycrystalline cubic ceria-gadolinia, tetragonal zirconia-yttria ceramics and single crystalline YSZ. Empirical rules for the determination of conductivity by geometrical methods from "overlapping" semicircles in the complex plane representation of the imittance data were established. This was supported by model calculations and non-linear least squares fitting techniques.

Recoil Energy and Helium Effects on Cascade Microstructure in Pure Metals.

A. Horsewell, B.N. Singh and W.F. Sommer, presented at the Third International Conference on Fusion Reactor Materials, Karlsruhe, 4-8 October 1987.

In recent years, the irradiation-induced microstructural evolution has been intensively studied using fast neutrons and energetic charged-particles. However, very little is known about the role of the primary damage state and concurrently produced transmutational impurities (e.g. hydrogen and helium) in the evolution of cavity, dislocation and precipitate microstructures.

The primary damage state may be characterized by displacement cascade size, sub-cascade propensity and the density of defects associated with individual cascades. The variation in the nature of the primary damage state may effect the nature of microstructural evolution. A further complication is likely to arise due to changes in helium/hydrogen generation rates as a result of changes in the recoil energy.

In order to understand some of these problems, we have studied the variations in the primary damage state as a function of recoil energy and atomic density. Specimens of pure metals with different atomic mass density (e.g. from copper to tungsten) have been irradiated by fast neutrons at ambient temperature (~ 313K). In addition, specimens of some of the metals have been irradiated with different particles and energy to obtain helium generation rates in the range ~ 1 to ~ 1000 appm/dpa. In all cases, the irradiation dose has been kept to a relatively low level (i.e. ~ 10^{-3} to ~ 1 dpa). The relaxed cascade microstructure has been studied using transmission electron microscopy. In a number of cases, additional information about the nature, density and size of the defect clusters has been obtained using positron annihilation technique.

The implications of the correlation between the primary damage state and the recoil energy spectra will be considered. Furthermore, the role of helium atoms in preventing collapse of cascades of different sizes and of different vacancy density will be discussed. Finally, the relevance of these results to the problem of simulating the effects of 14 MeV neutrons will be briefly discussed.

Mullite-Zirconia Ceramics Prepared from Cheap Raw Materials.

P.L. Hansen and O. Toft Sørensen, presented at the conference Ceramic Materials '87, Göteborg, 2-3 June 1987.

Insst Abstract.

Positron Annihilation in Helium Bubbles in Aluminium.

K.O. Jensen, R.M. Niemienen, M. Eldrup and B.N. Singh, presented at the 1987 Solid State Physics Conference, Bristol, 16-18 December 1987.

Theoretical and experimental results for positron annihilation in He bubbles are presented. The state of a positron trapped at an Al-He interface has been studied theoretically. The distribution of He across the interface was calculated by the molecular dynamics technique. The influence of the He atoms on a positron trapped in the image potential well at the Al surface was determined in the corrugated mirror model. The annihilation rate of an interface-trapped positron is increased compared to the clean surface annihilation rate due to annihilation with He electrons. This allows a relation to be established between positron lifetime and He density.

Experimental positron lifetime results are presented for Al samples which contain He bubbles as a result of being irradiated with 600 MeV protons. The

samples were studied both as-irradiated and after thermal annealing. Helium density values determined from the positron lifetimes using the theoretical results agree well with independent, albeit uncertain, estimates based on transmission electron microscopy (TEM) data. Bubble radii and concentrations can be estimated based on the positron lifetime results, employing an empirically determined relationship between cavity size and specific positron trapping rate. The values obtained agree well with TEM data on the same samples and data from the literature.

Passivation of Lithium in $SOCl_2$, SO_2Cl_2 and SO_3.

M. Mogensen, presented at Nordisk Kontaktsymposium i Elektrokemi, Helsingør, 26-27 August 1987.

The poster described some important results from studies of solid electrolyte layer formation on Li in oxidising liquids. Possible mechanisms involved were illustrated, and similarities and differences between the Li passivation in the mentioned liquids were explained.

Mapping of Low-Temperature Fatigue.

O.B. Pedersen, presented at the Europhysics Study Conference on Mechanisms and Mechanics of Plasticity, Aussois, France, 1-10 april 1987. To appear in Revue de Physique Appliquee.

The stages of flow, structural evolution and cracking in low-temperature fatigue can be summarised in "fatigue mechanism maps" of plastic strain amplitude versus cycle number. Maps were presented for single crystals of copper, aluminium and molybdenum.

Keramiske iltionledere og deres anvendelse inden for energisektoren. (Ceramic Oxygen Sensors and Their Application Within the Energy Sector).

F.W. Poulsen, O. Toft Sørensen and **J.J. Bentzen,** presented at Nordisk Kontaktsymposium i Elektrokemi, Helsingør, 26-27 August 1987.

There are numerous applications for oxygen ion conducting ceramics, for example:

- *in oxygen sensors for combustion control (higher efficiency, less pollution)*
- *in fuel cells for lower production*
- *in electrolysers for H_2-production on gas purification.*

The properties of the electrolyte materials depend on composition as well as preparation technique. The poster describes the preparation and characterisation techniques used at Risø for the evaluation of electrical and mechanical properties.

Super Ionic Conduction in Alkali Metal Hexachloro Niobates and Tantalates.

F.W. Poulsen, N. Hessel Andersen, K.N. Clausen, D.R. Sadoway and L.H. Øgendal, presented at the 6th International Conference on Solid State Ionics, Garmisch-Partenkirchen, 6-11 September 1987. To appear in Solid State Ionics.

Ac-conductivity, DSC, and neutron diffraction studies of the ionic conductors $KNbCl_6$ and $KTaCl_6$ are presented. The first order phase transitions to the super ionic state occur at temperatures in the range 299 to 334°C. Conductivities up to 0.35 S/cm are observed. The lowest transition is from a hexagonal to a cubic

FCC structure, whereas no definite conclusions could be drawn concerning the structure of the super ionic phases, since only three diffraction peaks were observed in the diffractograms.

Cascade Stability and Cavity Nucleation.

B.N. Singh and A.J.E. Foreman, presented at the 3rd International Conference on Fusion Reactor Materials, Karlsruhe, 4-8 October 1987. To appear in J. Nucl. Mater.

The possibility that the concurrent generation of collision cascades and gas atoms during irradiation may enhance the cavity nucleation is examined. The number of helium atoms required to prevent cascade collapse in Cu, Al and 316 stainless steel is calculated. It seems rather unlikely that at realistic helium generation rates the cascades can be stabilized in the form of three-dimensional cavity embryos. The role of uncollapsed vacancy aggregates in cavity nucleation is evaluated by calculating the probability of helium atoms reaching the aggregates within their lifetime. The effect of collision cascades on vacancy nucleation is found to depend very sensitively on the stability against collapse, size and structure of the cascades and the mobility of gas atoms.

Nucleation and Growth of Precipitates and Helium Bubbles in High-Purity Al-Mg-Si Alloy Irradiated with 600 MeV Protons.

M. Victoria, W.V. Green, D. Gavillet, **B.N. Singh** and **T. Leffers**, presented at the 3rd International Conference on Fusion Reactor Materials, Karlsruhe, 4-8 October 1987. To appear in J. Nucl. Mater.

Irradiation-induced changes in the precipitation behaviour of age-hardening alloys is not well established. Very little is known about the problem of precipitation and precipitate stability particularly under fusion irradiation conditions leading to concurrent production of displacement damage and gaseous impurities at high rates.

The main objective of the present work has been to study the effect of displacement damage, in the range from 0.01 to 1.63 dpa, with simultaneous production of helium atoms at a high rate (~ 214 appm/dpa) in a high purity Al-0.75% Mg-0.42% Si alloy; the composition is similar to that of the commercial type 6061 Al-Mg-Si alloy. In order to study the effect of irradiation on the nucleation and growth of precipitates and the aggregation of concurrently produced helium atoms, the alloy was irradiated in the solution annealed condition (535°C, 35 min.). The irradiation temperature varied between 120 and 260°C. After irradiation, the nucleation, growth and dissolution of Mg_2Si-type precipitates as a function of irradiation dose and temperature were studied by transmission electron microscopy (TEM). The results show that the precipitation of Mg_2Si-type particles occurs on a finer scale during irradiation than during thermal aging of the solution treated Al-Mg-Si alloy (at the temperature of irradiation). The needle-shaped Mg_2Si-type precipitates in the thermally aged and the irradiated specimens are found to lie along the <100> matrix directions.

Information regarding nucleation and growth of helium bubbles in the matrix, at precipitate-matrix interfaces and at grain boundaries has also been obtained by TEM. Long rows of bubbles are found to be associated with the Mg_2Si-type precipitates. The bubbles at the precipitate-matrix interfaces and at the grain boundaries are found to grow faster than those in the matrix. The implications of these results will be briefly discussed.

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