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Spallation Neutron Source

Science Case for the VULCAN Diffractometer

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1. Introduction.

There has been a steady world-wide increase over the past decade in the demand for diffraction measurements which characterize the strain state, the crystallographic texture or the chemical make-up of engineering components and the structural materials of which they are made. The cost of production of components and the cost penalty of shortened lifetime drive the need for engineering measurements. The avoidance of conservative designs of products, which have to be adopted in the absence of knowledge about the stress state, and the need for extremely high reliability for components in, for example, aircraft and nuclear reactors are also powerful drivers.

It is important to consider why a special instrument is needed for materials engineering. The distinction between materials engineering and materials science is that materials engineering focuses on the state of the component itself, in the form in which it will be used in service, while the latter is concerned more with the material of which the component is made. Generally, the engineer is interested in full-size components rather than scaled down substitutes, which can have different mechanical properties, and this puts unique demands upon the sample mounts and space available for the samples. Samples can vary in size from rivets of order a few mm across to circumferential welds in 500 mm long segments of 912 mm diameter pipe-line.

The importance of neutron diffraction to engineering stems from the high penetration of the neutron into most engineering materials and this leads directly to the possibility of non-destructive measurements at depth. A primary computational tool of the engineer, and one whose use is growing, is finite element modeling (FEM). The trend to FEM will accelerate given the ready access to powerful computers. Nevertheless, FEM requires many assumptions about the constitutive behavior of the material and the thermomechanical history of the manufacture of the component in order to predict stress and distortion accurately. While optical, mechanical and conventional X-ray methods suffice to measure surface strains, or near-surface strains, neutron diffraction provides a method of benchmarking the calculations at depth nondestructively (and *in-situ* under simulated service conditions) with a spatial resolution comparable with FEM.

Unlike other neutron techniques, a set of standard procedures for making strain measurements is being developed at present under the auspices of VAMAS (the Versailles Project on Advanced Materials and Standards). This will be in place by the SNS start-up and provides constraints on accuracy of both positioning and measurement.

The response of the component, *in-situ*, to an applied load at a given temperature and in an atmosphere designed to mimic operating conditions in, perhaps, a hostile environment is of great interest to the engineer. This response is also difficult to obtain by any other technique, even with short wavelength X-rays, when the path lengths through the component are long. Load-frames, furnaces and controlled atmospheres and the ability to translate and orient large samples are considered to be essential elements of a neutron diffractometer for engineering studies. One of the challenges facing the designers of VULCAN will be, besides getting high intensity and resolution, to provide the space and peripherals needed to tackle the future requirements of the engineering community. The design will strive to provide a speed and cost for a single stress measurement of the same order of magnitude as a destructive shallow drilling operation to measure stress and this should open up a wide engineering community.

The scientific case is structured as follows. Firstly, the expected specifications of the instrument are summarized. Then the present status and limitations of research in several areas currently underway, and the expected improvements in these areas, are examined. These areas, it is judged, will still be important in the six to ten year time-frame. Because of the large count rate increase at VULCAN, exciting new possibilities emerge since it will be possible, for the first time, to follow transient behavior of processes in real time and to examine the stresses arising in a component while operating it on the diffractometer. A novel experimental technique, the measurement of the Bragg edges in the neutron beam transmitted by the sample, offers promise of measuring through-thickness properties an order of magnitude faster than from the diffracted spectrum. This will open new fields of time-resolved behavior of components. Since VULCAN will offer perhaps a thirty-fold increase in data rate over equipment to be built in the next two years, SMARTS at Los Alamos National Laboratory and ENGIN-X at ISIS in England, the United States will have a decisive lead in capability for engineering studies for the foreseeable future until the European Spallation Source is built.

2. Proposed Physics Design of VULCAN

The physical parameters of the diffractometer were designed using the figure of merit principle developed by the ISIS group. The figure of merit, F, for accuracy in a strain measurement is proportional to the integrated intensity in the peak, I, divided by the square of the full-width at half maximum, w, as follows

$$F \propto I/w^2$$

The figure of merit is broadly optimized at a path length from source to sample around 50 m. The requirement of very high intensity for some types of measurement suggests that the sample station could be somewhat closer to the source than the location based in I/w^2 alone. The 60 Hz repetition rate of the source limits the wavelength bandwidth available for measurement of diffraction peaks, with no frame overlap, to 1.3Å. For scattering at 90º, where the gauge volume is minimized in spatial extent, and therefore most useful for strain scanning, the bandwidth in d-spacing is 1.3/√2 ~0.9 Å. This bandwidth may be centered anywhere in the wavelength range by means of choppers in the incident beam. For diffraction, the most useful wavelength range is 1-2 Å and this means that the moderator is basically a thermal source. The bandwidth may also be doubled, at the expense of halving the intensity, by cutting out every second pulse.

Major increases in intensity can be achieved by the use of thermal guides, as first shown for the SMARTS spectrometer and these will also be used for VULCAN to maximize the intensity. A curved guide section is proposed to cut out fast neutrons and gamma rays from the incident beam. The curved section will enable lower backgrounds to be achieved because measurements made at considerable depths below the surface, or on small samples, can create signal-to-noise problems as severe as those encountered in inelastic neutron scattering. The curved section thus provides background improvement judged to be vital, but it has the consequence that the spectrometer cannot be used to measure neutron resonance absorption in the keV range, which has engineering applications in the area of temperature and velocity measurements.

The improvement of intensity over SMARTS from the source flux is expected to be a factor of about 10x. The improvement from beam optics may be about 1.5x while the counter coverage extending from 60° to 120° will generate a further factor of two. It is worth noting that SMARTS and ENGIN-X are both second generation state of the art instruments and it is not straightforward to make further large gains. A measurement on a gauge volume, the volume in the sample from which diffraction is accepted by the optics, of 1 mm³ in a 12 mm thick section of a Ni-based alloy in transmission geometry on SMARTS is expected to take, conservatively, 60 min. A complete diffraction pattern with perhaps twelve peaks would be accumulated in this time. With an improvement of x30, such a measurement will take 120 sec at VULCAN. For the case of Ni-based alloys the intrinsic background from 5 barns of incoherent scattering is unavoidable and an iron alloy would be about 50% faster because of the better signal to noise ratio. A measurement of the Bragg edge spectrum of steel in transmission at SMARTS is expected to take 30s. With an improvement of x10 in flux and x1.5 in beam optics, a measurement at VULCAN would take 2s to accumulate good statistics for Bragg edges in transmission.

The need to accommodate large samples and peripheral equipment was mentioned in the introduction and from this it follows that the sample region will be enclosed in an 10x12 m² “block-house” enclosure rather than a 0.5x0.5 m² section enclosure characteristic of most spectrometers. This has the extra advantage that noisy equipment, such as running engines, or hazardous samples such as radioactive materials or samples with corrosive environments may be accommodated within the regulations governing personnel exposure with greater ease.

Two further factors affect the economics and the usefulness of the spectrometer. A duplicate sample table away from the beam will be provided with theodolites for aligning and indexing samples. After transferring the component on its fixture to the sample table and performing a limited number of positional checks, measurements can begin promptly. The input data required for the measurements such as positions in space, counting sequences and times would have been prepared ahead of time. The Rietveld fitting procedure will be transparent to the user and parameters such as strain, texture or phase content will be updated automatically as the count progresses. Analysis of the data will proceed on-line following the methodology developed for SMARTS. This is an interactive code that guides the user through the interpretation of the data and will likely become the platform of choice world-wide.

3. Extensions of Current Research Areas.

Currently there are several major areas of neutron scattering research that deals with materials problems in engineering components, which are briefly review below.

- *Strain mapping* is carried out in parts such as welds, for example, to discover the location and magnitude of stresses that may adversely affect function.
- *Intergranular strain* measurements, where the strains have the spatial extent of order of the grain size, are carried out on composites such as Al:SiC to find the intrinsic thermal strains as well as the load-sharing capability. Intergranular strain measurements are also of great importance for testing models of the mechanical behavior of polycrystalline aggregates at the grain level, which in turn strongly influence the interpretation of strain in terms of stress.
- *Crystallographic texture*, the degree of randomness of the grain orientation, has important consequences for the forming of metal components. Texture is also a sensitive measure of plastic deformation undergone by the sample, and may vary as a function of position in the sample.
- *Surface modifications*, which provide compressive stresses near a surface such as shot-peening, are often carried out to improve the fatigue properties of the component. Neutrons currently give strains as close to the surface as 0.2 mm and, more importantly, detect the balancing tensile stresses below the surface non-destructively and they can also examine buried interfaces.
- Examining the *response of a component loaded in-situ* on the diffractometer, perhaps at an elevated temperature or in a particular gaseous environment gives the engineer the test information he or she requires to establish behavior in service. In addition, measuring the strain response to stress of a material gives the elastic constants in the elastic regime and shows how residual strains develop when the load exceeds the yield point.
- There is strong interest in the properties and behavior of *low symmetry* materials, including *ceramics and ceramic structures.*
- Finally neutrons are used to follow solid-state reactions within *chemical reaction* vessels in-situ.

It is anticipated that interest will continue to grow in these established fields in the next decade and it is important to examine the difference that VULCAN will make to them.

3.1 Strain Mapping

Most strain mapping has historically been conducted at reactors because the time taken for measurement of a strain at a single location with the aid of one reflection was about 10x faster than at spallation sources even for a medium flux reactor. Reactor measurements on 1 mm^3 of iron in say, a 6 mm section, typically took about 30 min. for adequate statistics. At present the time to obtain data is adequate for line scans and spot checks in components, but becomes too long to allow two-dimensional (2D) or three-dimensional (3D) mapping around crucial regions such as cracks or welds. In addition the usual practice is to measure only 3 orthogonal strain components. This essentially ignores the tensor character of strain and does not identify the principal axes of the strain tensor. SMARTS will provide a mapping capability at a speed comparable with a medium flux reactor but with the advantage that a complete diffraction pattern is collected in that time. VULCAN will permit measurements to be made in about 60 sec. on 1 mm^3 of iron and therefore makes it practical to map stress fields rapidly and completely. Alternatively, the intensity at VULCAN can be used to reduce the gauge volume by a factor of 30x for the same time, if this is desirable, or to permit measurements through a much greater path length.

Examples here include the measurement of stress distributions in critical parts, such as aircraft landing gear, in the vicinity of rivets or around cracks in pressure tubes. A Ti:SiC ring inserted in a Ti turbine disc reduces the weight of the structure by 50%. Yet, very little work has been done on how the insert affects the stresses in the disc. Weld stresses represent a huge field as new methods of joining similar and dissimilar metals, such as friction stir welding, are developed. Reliable measurements of residual stress in well-characterized welds will facilitate the reduction of stresses by intelligent weld process design or by subsequent thermal or mechanical treatments. This area will definitely attract industrial interest in the capabilities of VULCAN. It is also here that the connection with FEM is made. Often the stresses are required close to discontinuities in a component such as a corner or a crack where there is a local stress enhancement so that it is important to be able to sample the strains in small volumes. Gauge volumes with spatial section as small as 0.1x0.1 mm^2 will be accessible with modern bent crystal techniques, at the expense of losing some (hkl) information, but the use of gauge volumes with 0.3x0.3 mm^2 sections will be routine. The area of stress scanning in biomaterials is an area that has not been investigated widely, yet there is great potential for understanding the stresses in crystalline bone material for example.

3.2 Interphase and Intergranular Strains.

The field of interphase strain measurement with neutrons includes metal-matrix composites, cermets such as Co:WC and ceramic matrix composites where the goal is to obtain the average phase strains. The impetus for early intergranular measurements on zirconium arose because the macroscopic creep and growth of calandria tubes in a radiation environment strongly depends on stress and texture. The stress and texture measurements lead to an understanding of the problem. Recently the emphasis has been on examining the effects of thermomechanical treatment such as rolling or extrusion or creep loading, i.e., processing parameters, on the phase stresses. Such measurements play a role in determining how materials are processed to achieve a satisfactory end product. Currently, the time taken for such measurements has limited their study.

The (hkl) dependence of strain in cubic Ni, Fe and Al based alloys which have been plastically deformed is used to test polycrystalline models. Polycrystalline models will be, in the near future, incorporated into FEM calculations to provide constitutive models of aggregate behavior. This work provides a second example, this time at the grain level, of benchmarking models of material behavior. Currently the experiments are slow, taking typically several days to measure five (hkl) reflections at say 27 discrete sample orientations distributed over a hemisphere of orientation around the direction of plastic deformation. Where the strains are small, as in the case for the [111] orientation of Ni, present experiments only give an uncertainty of around 50% of the size of the strain. An improvement of a factor of 2 in accuracy and a factor of x30 in data gathering will mean that many materials may be tested and complete strain pole-figures obtained routinely for all (hkl).

The stresses developed when highly anisotropic materials such as U, Mg, Ti and Zr are thermally cycled are of high current interest.

3.3 Crystallographic Texture.

The HIPPO diffractometer now being built at Los Alamos National Laboratory to measure texture rapidly at relatively low resolution and with good coverage of scattering solid angle represents the state of the art. The data gathering capability of VULCAN for texture measurements will provide a smaller gain over HIPPO than it does over SMARTS. However, the higher resolution of VULCAN will be advantageous in texture measurements on materials with complex spectra originating in low symmetry or the presence of multiple phases. Texture mapping, not possible at HIPPO, will be straightforward at VULCAN because of its positioning capability. Texture mapping shows, for example, how the deformation in a forging or plate varies with depth from the surface. It may reveal non-random variations stemming from prior grain structure. The texture and the accompanying elastic strain determine how a component will distort when machined from the forging or plate and mapping it allows one to optimize stress relief strategies to avoid wastage of machined parts. Currently it would take about 36 hours to scan a 15x15x50 cm^3 aluminum forging completely for one reflection at a reactor with a 2.5x2.5x2.5 cm^3 sampling volume.

Such measurements at VULCAN will provide a good sampling of the inverse pole-figure at each location in about two hours.

The plastic deformation can be a measure of the remaining life of a component so it is important to have non-destructive measures of plasticity. There is a strong correlation between plastic deformation and diffraction peak linewidth and a linear relation between plastic deformation and texture and these may be used to characterize plastic deformation.

3.4 Surfaces and Buried interfaces

Once material properties are optimized, the surfaces of components are often treated by such means as shot-peening to provide superior performance. The compressive stresses associated with shot-peening decrease with depth and become tensile in the range 0.5-1.0 mm to provide stress balance. A crack penetrating this far will experience a tensile stress and may propagate. Neutron diffraction measurements in this area are hampered by systematic errors that occur when the gauge volume is not completely within the sample so it is important to work with gauge volumes with small sections. It follows that the time taken to do each measurement is long. Currently the smallest spatial section of gauge volume is 0.3x0.3 mm^2. Even for an advantageously shaped sample, such as a flat plate, where the gauge volume may resemble a matchstick in shape, the time to obtain a single data point is of order 60 min. For curved surfaces such as ball-bearings the time requirement makes the experiment impossible at present. A reduction to a 0.1x0.1 mm^2 section of gauge volume will give adequate spatial resolution to follow the strain gradients but will be time-consuming. This can be achieved with modern bent crystal methods at the expense of losing (hkl) information. Surface stress measurements (5-100 μm) will remain the domain of x-ray diffraction but at greater depths than this neutrons will be important especially for high atomic number materials.

With VULCAN measurements made currently at the limit of 0.3x0.3mm^2 will be routine. Buried interfaces will still be the domain of neutron diffraction. Coatings, such as thermal barrier coatings especially those containing heavy elements such as zirconium which are difficult for X-rays, and ceramic multilayers are examples which will benefit from this high spatial resolution.

If one wishes to monitor the changes in the near-surface strains in a sample due to cyclic thermal or mechanical processes, neutron diffraction would be the method of choice since the method is non-destructive and the gauge volume is the same for all the strain components.

It is worth noting that measurements of the in-plane strains cannot be made with short wavelength X-rays with better spatial resolution than neutrons since the gauge volume is elongated though the sample for this geometry. In addition, the path length for a measurement of the normal strain rapidly becomes prohibitively long as the depth below the surface increases since the diffraction angle is very low.

3.5 *In-situ* Loading

An in-situ loading test to examine the behavior of 8 reflections, including three superlattice reflections at room temperature in Waspaloy, a Ni-based superalloy, took about 350 hours. While this was admittedly a hard experiment, the time requirement ensures that few materials are tested and only at easily accessible temperatures. In addition, the current accuracy in strain measurements, ±50με, is inadequate in many cases. VULCAN would permit hard measurements such as these to be made in about 12 hours. The furnace capability on VULCAN would allow high temperature effects, in the temperature range where the material has unique properties and is used in turbine discs, to be investigated.

In-situ loading of components has been carried out in a few cases with a spatial resolution of 1 mm^3. However, the experiments were difficult and time consuming. There was inadequate coverage of the crucial regions where the strain gradients are large and the complete stress tensor was not investigated. Measurements of the development of stresses under load around cracks in compact tension weld specimens containing matrix, heat-affected zone and melt zone, are examples of tests which would be of high value for the information they would give on hot-cracking and cold-cracking phenomena through the various microstructures.

3.6 Structural Ceramics and Low Symmetry Materials

It is probably fair to say that the field of stress measurement by neutron diffraction in structural ceramics is not very well developed. A round robin test conducted on behalf of VAMAS on the ceramic matrix composite Al_2O_3:SiC in neutron laboratories worldwide showed a disturbing variation in apparent strain. The reason for this is partly that the diffraction spectra are complex, since the materials have low symmetry, or display several polytypes. High accuracy is required to separate the peaks and also, since the strains of interest are small because of the high elastic constants, high accuracy is needed to obtain the peak shifts. Full pattern refinement is needed for such studies that are ideally suited to time-of-flight diffraction. To date very little strain mapping has been done in engineered ceramics for lack of intensity and wavelength resolution. In general VULCAN will be well placed to characterize low symmetry materials with large elastic anisotropy. There are many potential applications including measurements on electrostrictive (and ferroelectric, in general) materials, such as $PbMnNbO_2$, magnetostrictive materials, and engineered “smart materials” like aluminum alloyed with the shape-memory material NiTi designed to have an interaction between component phases so that phase changes achieve load sharing. Another example, which falls in this category, is a prototype actuator which consists of an insulator package containing Pt electrodes spaced by a few millimeters of polycrystalline piezoelectric. The interest is in measuring the strains with good spatial resolution in the piezoelectric material under applied electrical or mechanical loading. Such use of VULCAN for *in-situ* studies will undoubtedly enable new research on ferroelectric and magnetostrictive materials. Another potentially significant use of VULCAN in ceramics research is the characterization of sintering-induced residual stresses in these materials. These stresses arise due to the differential shrinkage that usually accompanies sintering and are a major source of weakening in sintered components. The unprecedented spatial and temporal resolution predicted for VULCAN, coupled with additional capabilities such as SANS (to characterize pore size evolution during sintering) and measurement of volume changes via a dilatometer-type setup will yield valuable information about sintering that cannot be obtained otherwise.

3.7 Chemical Reactions

The penetrating power of the neutron through container walls makes it a useful probe of chemical reactions occurring in the solid-state in reaction vessels at elevated temperatures. To date the most complete work has been carried out on the reduction reaction of nickel spinel to give aluminum oxide and metallic Ni. This served as a model system for many solid state reactions which involve a volume change and hence generate residual stress. In this case, the neutron beam bathed the whole sample and this permitted the fractions of the phases to be followed in real time. However, scanning the sample to find the spatial extent of the reaction layer, which proceeds from the surface, as well as the time dependence, was not possible at present time. Spatial scanning to map the spatial and temporal extent of the reaction will become possible only with the VULCAN diffractometer. It is also extremely important to carry out conventional weight loss measurements as the reaction progresses. This will allow a direct comparison of diffraction data with the traditional thermogravimetric analysis (TGA) so that conclusions can be made about reaction mechanisms and the type of effective kinetics. A combined TGA and diffraction experiment will yield invaluable data about solid state reactions and phase transformations. The method will be of value in investigating heterogeneous catalysis and examining, for example, the recrystallization of NaA zeolite from a sol and many oxidation and reduction reactions that are of technological importance in materials processing.

4. Dynamic Stress Measurements

In the previous section the impact of VULCAN on already existent fields of engineering and materials science was examined. In this section we consider how it will lead to completely novel capabilities. Needless to say, the treatment in this section is more futuristic and sketchy. Major advances will be made, because of the speed at which the data is obtained, in measuring strain as a function of time. This includes strains in operating equipment, in the time dependence of chemical reactions or physical processes such as recrystallization, during *in-situ* processing operations such as welding, casting, and powder processing, and in the transient response to applied loads or temperatures.

Currently it is not possible to measure the stresses that are induced at the root of a gear tooth, for example, when the gears mesh. While the speed at which data is gathered may not be insufficient to capture a single event with one pulse, it is feasible to design strobing experiments where the stress profile at a particular location, averaged over all the teeth on the gear, is measured. The location of the measurement for a given reflection may readily be obtained from a signal from an electronic pick-up fixed on the sample. By appropriate phasing of the rotation of the gear and the arrival time of each neutron wavelength and correcting for the Doppler effect the complete cycle of contact stresses can be followed. The technique would be applicable to measuring the stresses, for example, in ball races and in running engines.

The development of strains during the actual welding operation is another area that will become accessible in well-designed in-situ experiments. In an instrumented spot-weld, for example, the diffraction signal and hence strain at a particular radial distance from the melt-zone could be measured during welding and then followed as the sample cools. For a ferritic weld the appearance of the transformation strains, generated by the phase change from the face-centered cubic structure to the body-centered cubic structure, could be monitored. Likewise, it will become feasible to examine processes such as the extrusion of metals with lab scale equipment placed in-situ on the diffractometer, or the strains that develop in a casting as it cools.

An area of current interest is the effect of high cycle fatigue on the residual stress in components. In this case the load is less than the yield point but the number of loading cycles is very high. The test geometry might be a compact tension sample or perhaps a cold-expanded rivet hole in aircraft aluminum. It is feasible to begin high cycle fatigue loading of a test sample on a tensile test machine and mount this on the spectrometer after preselected numbers of cycles have elapsed to monitor the progress. The precision mounting will permit the user to return to exactly the same location for each measurement. By making use of the relative phasing of the 60Hz pulse and the fatigue cycle, the strain response can be sampled over a complete cycle of applied load. Of interest also is how the combination of applied stress and temperature affects the fatigue life.

Recrystallization is a phenomenon exhibiting many unanswered questions and it plays a significant role in controlling the properties of commercial alloys. Experiments can be envisaged on small samples, held in controlled temperature environments, to measure the kinetics of the recrystallization texture, manifested as a redistribution of the intensity across the counters. The linewidth of the diffraction peaks would give information about the size of the nucleating regions in the early stages of the process. Texture scanning tests can also be carried out on large rolled plates, for example, held in a controlled environment in order to follow the recrystallization as a function of depth from the surface. Since the amount of deformation varies strongly with depth in a rolled plate so does the texture and consequently the recrystallization does not proceed homogeneously through the plate. These effects are now beginning to be modeled and the experimental measurements are vital to guide the model development. Degradation processes, such as stress-corrosion cracking, are also controlled by the texture and the stress field.

Experiments that follow the effect of processing a sample will be both novel and useful to industry. Examples include: determining exactly how high a temperature and how much time is needed to reduce residual stress in a stress relief scenario, determining the kinetics of stress reduction by thermal creep, and determining the kinetics of lattice parameter change generated by processes such as carburising or nitriding. The latter processes are designed to harden the surface and create a compressive strain state near the surface. The time to carry out many of these energy intensive processes is a major factor in the economics and conservative estimates of the time rather than experimental evidence are costly. Other examples of diverse fields where kinetic measurements would be useful are the curing and freezing of concrete, the stresses developed during powder processing and the time dependence of precipitates such as Mg_2Si to form in aluminum since this strongly affects the process for making beverage cans.

5. New Techniques

The neutron beam transmitted by the sample carries with it information about the neutrons diffracted out of the sample in the form of the inverse of the Bragg edges. Bragg edges are discontinuities that occur at the wavelengths where Bragg's law is no longer fulfilled. The edge spectrum provides a measure of the average lattice spacing along the line of the beam. An edge measurement, with sufficient statistics to permit the analog of Rietveld fitting, can generally be made in about 10% of the time to perform conventional diffraction. For VULCAN this time will be about 1 sec. If the technique could be refined to the point where single pulses can be analyzed then a time scale for measurements of 1/60 sec may be achieved. Finally, if stroboscopic measurements can be devised for the material under test, the ultimate time scale could be of order a few msec, i.e. the difference in arrival time of successive (hkl) edges. This would permit access to examining processes occurring on very fast time-scales as in electrostrictive devices and phase changes. The method is sensitive to phase composition, since both phases present edge spectra. With refinement the method will permit strain and texture, averaged through thickness, to be obtained and perhaps lead to Bragg edge radiography and tomography.

The simultaneous measurement of both small angle scattering and diffraction would be very valuable. For NiAlMo alloys at elevated temperatures the morphology of the sample, measured by SANS, is governed by the mis-fit between the matrix and the superlattice, measured by diffraction. Slight changes in composition or slight changes in temperature in two separate experiments on nominally the same material leads to ambiguities. Current research aims at understanding the phase transitions in superalloys subjected to thermomechanical processes since a degradation of the microstructure leads to a degradation of the high temperature properties of the turbine blades made from these materials. There would be many other engineering applications for SANS scanning across a component, ranging from welding microstructures to nucleation and growth. The factor which makes it possible to design a SANS detector for the forward direction is the small size of the irradiated volume of material which in turn means that the detector does not have to be placed so far back to obtain good Q-resolution.

The simultaneous use of a collimated γ-ray detector with the neutron detector would be useful for examining welds in spatial regions where there are likely to be compositional gradients. The γ-rays emitted from the gauge volume following neutron absorption, give a measure of the chemical composition alone while the lattice parameter changes stem for chemical composition as well as residual strain.

7. Summary

The rapidly growing area of engineering measurements with neutrons will benefit greatly from a dedicated diffractometer at the Spallation Neutron Source and will give the United States a decisive lead in capability. A dedicated instrument will open new avenues particularly in the area of kinetic measurements. It will also permit experiments to be carried out on smaller gauge volumes, at greater depths and in time-slices commensurate with realistic processes, in addition to shortening the time for others in already existent fields. New techniques offer the promise of investigations at remarkably fast time scales or a two-fold attack on microstructure and phase content and strain.

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