

Determination of Residual Stress by Neutron Diffraction Analysis

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1 Abstract

2 Introduction and Background

2.1 Diffraction

Diffraction consists of a range of phenomena that occur when a wave interacts with physical objects. When a wave approaches the edge of an object it is bent around it into the area that geometrically should be in shadow. Once a wave diffracts around an object, various interference effects can occur. These interference effects are the result of multiple waves interacting with each other out of phase, and can have both constructive and destructive effects. Constructive effects occur when the peaks or troughs of the waves align and add together, increasing the amplitude of the wave. Destructive effects, on the other hand, occur when a peak of one wave intersects with the trough of another, causing the waves to cancel out. These interference effects occur with the diffraction of waves but are most apparent when the size of the opening is close to the wavelength. Diffraction from multiple apertures also leads to a variety of interference patterns. A prominent example of this is Young's double-slit interferometer, in which Young passed a beam of monochromatic light through two adjacent slits and observed an interference pattern, proving the wave nature of light. This same effect has an easily accessible analog in water (1).

2.2 Quantum Diffraction

One of the fundamental concepts in quantum mechanics is that of wave-particle duality. This concept first originated with Einstein's idea that like an electromagnetic wave, could also be propagated by discrete quantum particles, photons. From this de Broglie theorised the converse, if light has properties of both a wave and a particle, then all

Figure 1: A demonstration of interference effects in water, similar to Young's Experiment

particles have properties of waves. The de Broglie wavelength of a particle was derived from rearranging the formulae for the Planck-Einstein relation,

$$E = h\nu$$

and momentum,

$$p = \frac{E}{c} = \frac{h}{\lambda}$$

where ν

2.3 Elastoplasticity

2.4 Strain Measurement

A strain diffractometer is a device that uses the principles of quantum mechanics and diffraction to provide insight into the behaviour of material at the nanoscale. A material behaving elastically under an applied stress will have a corresponding strain in accordance with Hooke's Law. This strain manifests itself physically as an elongation but on the nanoscale it can be measured as a change in the atomic spacing of the material. This change in atomic spacing can be observed by comparing the positions of a diffraction peak, caused by the lattice structure in the material, before and after a stress is applied. This measurement technique is both non-destructive and non-contact, making it ideal for use in many engineering situations. The output of the strain diffractometry measurements will be two angles, those of the diffraction peak before, and while, the strain is applied. These angles can be converted into spacings using Bragg's Law, and further converted into strain (ϵ) using the following formula where d is the control spacing and d' is the strained spacing.

$$\epsilon = \frac{d' - d}{d}$$

The region of material that is tested is known as the "Gauge Volume", and the measured strain represents the average value over this region. The gauge volume is formed at the intersection of the incoming beam and the diffracted beam. The direction that the strain is measured in is also the direction that bisects the two beams, thus it is important to take two (or three) perpendicular measurements in order to get a complete strain state. It is important to note that this measurement technique will not measure any plastic strain in the sample. Elastic strain is caused by the change in lattice spacings due to applied stress, whereas plastic strain is the result of the movement of defects and displacements in the lattice of the material. Plastic strain does not affect the lattice spacing, only the location of atoms in the lattice.

3 Experimental Details

3.1 Preparation of Samples

The samples to undergo residual stress testing were cut from sheets of aluminium from a supplier based in Sydney. The stress was applied using a four point bending device

and displacement was measured with a steel ruler

3.2 Testing of Mechanical Properties

In order to determine the residual stress in a material by the neutron diffraction method, it is critical to know some of the important mechanical properties of the material. Namely: the Young's Modulus (E), and Poisson's Ratio (ν). The Young's Modulus (or Modulus of Elasticity) is the relationship between stress (σ) and strain (ϵ) in accordance with Hooke's Law.

$$\sigma = E\epsilon$$

Poisson's Ratio is used for stress and strain in three dimensions:

The mechanical properties of the materials were determined by the use of the University's tensile testing facilities on small samples of each material. The samples used were small 'dogbone' coupons, cut from the original stock plates of aluminium. A schematic of these 'dogbones' is shown below.

These coupons were put through a standard tensile test, involving the application of an increasing tensile load until failure while simultaneously recording measurements with a load cell and a strain gauge. Once the sample had passed its yield stress and begun plastic deformation the strain gauge was removed and the load was increased to the point of failure. The final load (F_F), and ultimate strain (σ_U) are recorded in Table 1.

Table 1: Final load and ultimate strain measured for the tensile test coupons

Sample	F_F (MPa)	σ_U
6061-T6	18.1	0.2
7075-T6	34.7	0.18

3.3 Bragg Institute

3.4 Data Processing

3.4.1 Determination of Elastic Properties

Once the raw data had been gathered from the experiments it needed to be processed and used in calculations to determine the residual stress. The data was processed using Anaconda, which is a scientific distribution of Python. The first data to be processed was the stress/strain data as that would allow for the determination of the elastic properties of the two metals, allowing further calculations. The data, which consisted of two columns, gauge length and applied force, was loaded from text files to a Numpy array, then sorted by displacement values before being transformed into stress and strain values. In order to find an elastic modulus (E) from this sorted data, a linear regression fit was carried out on the first 20% of the data. This 20% was chosen as it contained a linear

Figure 2: Stress/Strain curve for 6061-T6 and 7075-T6 Aluminium samples

region of the elastic behaviour of the metal, while being minimally affected by the non-linearities caused by plastic deformation. The results of this fit are recorded in Table 2 and Figure 2 show plots of the stress/strain curve and the calculated elastic modulus.

Table 2: Linear Regression results for the stress/strain datasets

Sample	E (MPa)	R value	P value	S error
6061-T6	1	1	1	1
7075-T6	1	1	1	1

3.4.2 Strain Diffractometry Data

The data from the diffractometry measurements was also stored in a plaintext format. This data consisted of 5 columns: Y position along the sample, axial lattice spacing (d_a), axial error, transverse lattice spacing (d_t), and transverse error. All data was measured in Angstrom (\AA), except the Y position which was measured in mm.

4 Discussion

5 Conclusion

6 References

7 Appendices