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Distribution of Internal Stress by a Shrink-fit for the Aluminum Ring and Plug

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The shrink-fit sample composed of a ring and a plug was designed and made of the aluminum material.Distribution of internal stress of the sample was measured by neutron diffraction method, and the obtained stress value was compared to the computed value.

KEYWORDS: residual stress, thermal expansion stress, internal stress, shrink-fit, neutron diffraction method

§1. Introduction

Based on the guide of Science and Technology Agency of Japan, Workshop on the Utilization of Research Reactors for the Asia area is held every year, there is a field of neutron scattering. The internal residual stress measurement by the neutron diffraction method is planned from 2002.

We designed and made a sample of the shrink-fit ring and plug out of aluminum material as one of the standard samples for the measurement practice. After that, we measured internal strain distribution by the neutron diffraction method and evaluated it with an analysis of residual stress.

§2. Design

Even though an incident monochromatic neutron beam flux is weak, in order to measure an internal stress, it is necessary to choose a material with small neutron absorption coefficient. We chose aluminum materials. Neutron absorption coefficient of aluminum at a neutron wavelength 0.2 nm is 0.012 (cm^{-1}). We chose high strength aluminum alloy A 6063 and A7075 as candidates of the material, since they are heat-treatment type and age hardening type alloys. We made a sample this time by using an A6063. A making dimension was determined by a decay of neutron beam. The sample was composed of a ring with 50 mmϕ an outside diameter, 50 mm height, 25 mmϕ caliber, and a plug. In order to make a shrink-fit sample, the plug was cooled with liquid nitrogen, and the shrank plug was inserted into the ring immediately. Inside pressure that occurs by a thermal expansion depends on eq. (2.1),

$$\sigma = E\varepsilon = E\alpha(t - t_0), \tag{2.1}$$

where σ : stress of the direction of the circumference, E : elastic constant, ε : strain by the thermal expansion, α : expansion coefficient, t : plug cooling temperature, t_0 : normal temperature (20 °C).

A coefficient of linear expansion α at 20 °C of aluminum is 23.6$\times$ 10^{-6}, and an elastic constant is 70 GPa. Therefore, generated thermal stress is 281 MPa. When liquid nitrogen (77.348 K) cooled the plug, temperature rises during inserting into the ring center. Therefore, we measured the characteristic of temperature rises to determine the operation time and the insertion temperature. The measurement was carried out while taking out a plug from liquid-nitrogen and leaving it in the atmosphere, and making touch a ring and leaving after taking out a plug.

It found expansion length by the eq. (2.2),

$$\alpha = \frac{1}{l_R}\left(\frac{dl}{dt}\right), \tag{2.2}$$

where l_R : plug diameter about 20 °C of room temperature, dl : change length with plug diameter at the cooling temperature t : change quantity with temperature. Figure 1 shows a characteristic of the temperature rises.

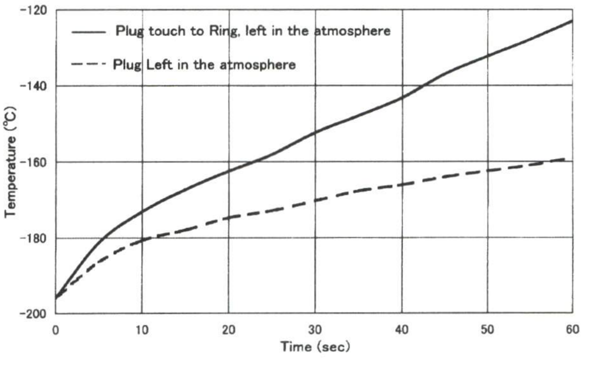

Fig. 1. Characteristic of the temperature rises.

As a result, the operation time is about 30 seconds, the plug surface temperature is about -150 °C then it should manufacture a plug diameter 0.1 mm longer than ring caliber. Even if ring and plug are made by a precise automatic milling machine, but manufacturing precision is 5/1000 mm. Therefore, ring caliber was 25.00 mmϕ +0 mm, -0.005 mm tolerance and plug diameter was 25.10 mmϕ +0 mm, -0.005 mm, tolerance. Manufactured Ring and plug is shown in Fig. 2

The stress induced by the thermal expansion, dispersed and estimated a remaining condition as follows.

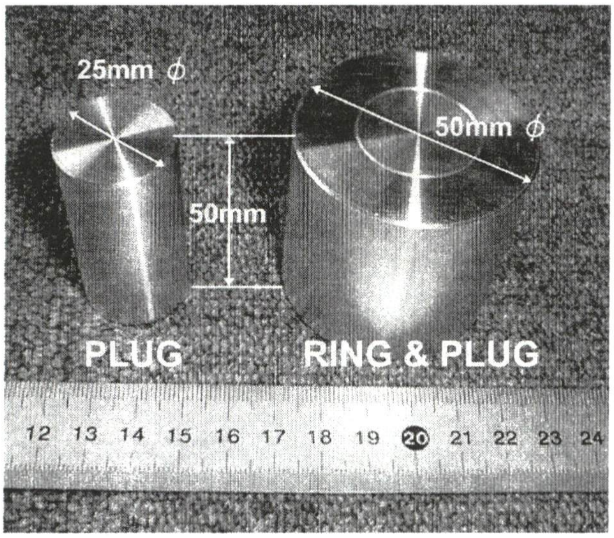

Fig. 2. Manufactured ring and plug.

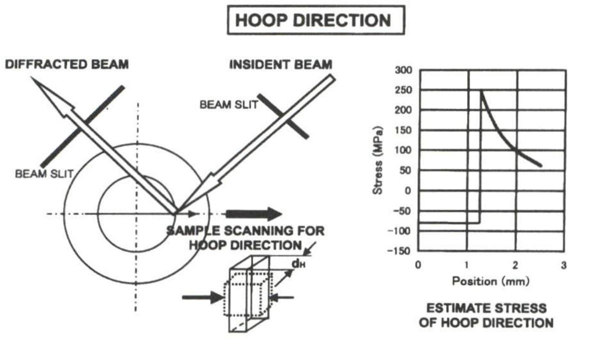

Fig. 3. The measurement method and estimated stress in the hoop direction.

The stress equivalent condition will be achieved at the contacting boundary of the ring and plug: the ring was pressurized whereas the plug is compressed. The samples are not constrained to the axial direction. In polar coordinates system the axis symmetric stress condition of the elastic body is described by eq. (2.3),

$$\varepsilon_R = \frac{(\sigma_R - \nu\sigma_H)}{E}$$
$$\varepsilon_H = \frac{(\sigma_H - \nu\sigma_R)}{E} \tag{2.3}$$

where ε_R : radial strain component, ε_H : hoop strain component, σ_R : radial stress component, σ_H : hoop stress component, ν : Poisson's ratio, and E : Young's modulus. After shrink fit the plug was compressed by the pressure $-P(P>0)$, then its stress state to the radius direction as well as to the hoop direction is given by $\sigma_R - \sigma_H = -P$. The pressure P is denoted by eq. (2.4),

$$P = E\delta\frac{(b^2 - c^2)}{b^2 c}, \tag{2.4}$$

where $\delta = a\text{-}b$, a : diameter of plug, b : outer diameter of ring, c : internal diameter of ring. A circumferential stress components for the internally pressurized cylinder is obtained:

$$\sigma_H = \frac{P}{4r^2}\left[\frac{b^2c^2}{b^2 - c^2}\right], \tag{2.5}$$

where r is distance from the center. Substituting P in eq. (2.5) gives eq. (2.6),

$$\sigma_H = \frac{E\delta c}{4r^2}. \tag{2.6}$$

§3. Measurement and Result by the Neutron Diffraction

It is only a neutron diffraction method, which can measure the state of stress disperse in the sample that generated at the 281 MPa by the thermal expansion.

The measurement method and the expected distribution of stress for HOOP direction is shown in Fig. 3.

The internal stress measurement using the neutron diffractometer for residual stress analysis (RESA) installed at the T2-1 port in the thermal guide hall of JRR-3M in JAERI.

An equipment and strain measurement conditions are shown next.

Monochromator crystal : Si(311) Bending and focusing method. Crystal mosaic spread : 0.23°. Scattering angle of monochromator crystal : 80.00°. Wavelength : 2.01 nm. Collimation : $\alpha_1 = 0.35°$, $\alpha_2 = 0.3°$, $\alpha_3 = 0.33$. Strain was measured at 33 positions within ± 23 mm from the sample center. In the arrow, which was written in the upper part of the sample, according to the direction of the scattering vector, strain was measured in the 3 directions of radial, hoop, and axial, and diffraction plane was (220) where the gauge volume is small, but this material had strong texture then measurement in axial direction was difficult. Therefore, analysis of stress in radial and hoop was carried out. The observed texture is shown in Fig. 4. The strain free lattice spacing d_0 was measured by the plug sample.

The stress was obtained from the measured strain using eq. (3.1). An analysis of the stress for hoop and radial directions are shown in Fig. 5,

$$\sigma_{R,H} = \frac{E}{1-\nu}\left[\varepsilon_{R,H} + \frac{\nu}{1-2\nu}(\varepsilon_R + \varepsilon_H)\right]. \tag{3.1}$$

§4. Consideration

VAMAS TWA20* made a shrink-fit sample already, and stress distribution measurement of the sample was done by the neutron diffraction in many countries. Since the method of the design and making was not informed in detail, we took original design and making method.

The maximum stress in the hoop direction at the boundary part of plug and ring is about 150 MPa from the measurement result. The result is 100 MPa lower than the estimated value. Concerning the difference it was considered that the plug size was made smaller than 25.100 mm as well as it stores up that there was texture

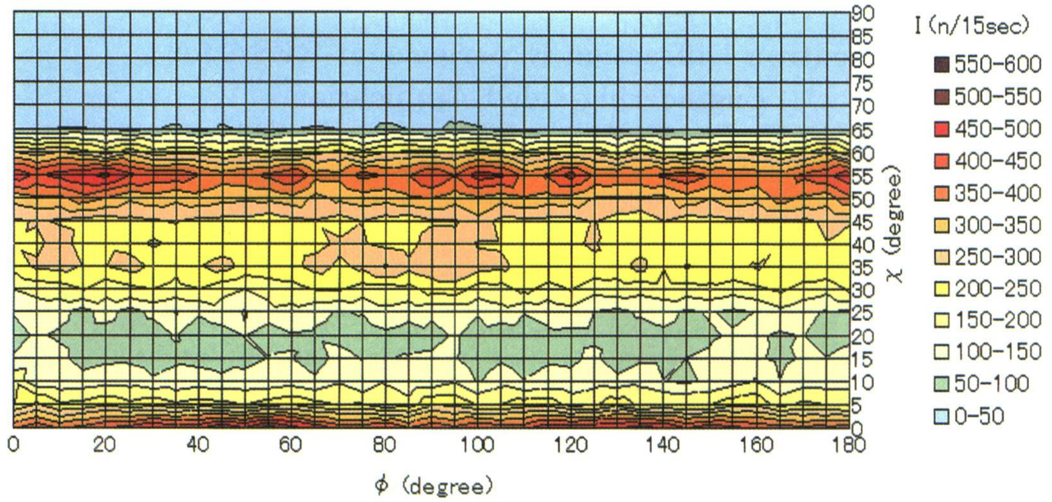

Fig. 4. Texture of A6063 (220).

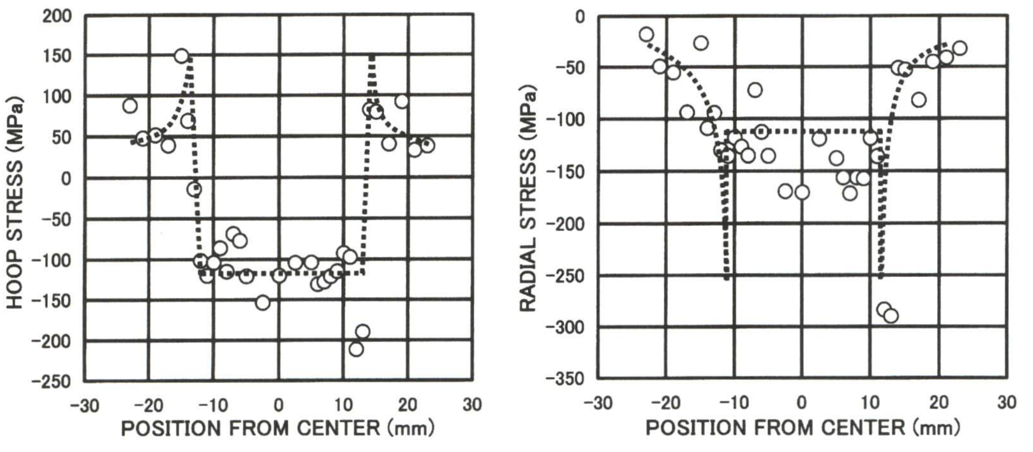

Fig. 5. An analysis of stress for the hoop and the radial directions.

which is strong in the plug to have used for the measurement of spacing of lattice planes d_o in the measurement of the stresses condition.

It is possible to say that the following item is important in the standard sample manufacturing this time.

1) The computation of the thermal expansion stress, because the plug outer size, the ring caliber size influence precision mainly, improve manufacturing and size measurement precision.

2) The aluminum material has very small neutron absorption coefficient although the grain orientation is so big. It is necessary to measure texture every each index in the manufacturing of the standard sample and to fix the plug and ring direction of the cut out from the material.

* Versailles project on Advanced Materials and Standards, Technical Working Area 20: it worked on measurement of residual stress by the neutron diffraction method.