Residual Stress Measurement using X-Ray Diffraction for Weldments

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Abstract— This Guide is applicable to X- ray stress measurements on crystalline materials. There is currently no published standard for the measurement of residual stress by XRD. This Guide has been developed therefore as a source of information and advice on the technique. It is based on results from three UK inter-comparison exercises, detailed parameter investigations and discussions and input from XRD experts. The information is presented in separate sections which discuss the fundamental background of X-ray diffraction techniques, the different types of equipment that can be used, practical issues relating to the specimen, the measurement procedure itself and recommendations on how and what to record and report. The appendices provide further information on uncertainty evaluation and some recommendations regarding the data analysis techniques that are available. Where appropriate key points are highlighted in the text and summarized at the end of the document.

Key words: TIG, Residual Stress, X-Ray Diffraction

I. INTRODUCTION

With modern analytical and computational techniques it is usually possible to estimate the stresses that exist in a component. This is not sufficient for the reliable prediction of component performance. Indeed, in many cases where unexpected failure has occurred, this has been due to the presence of residual stresses which seriously shorten component life. Residual stresses can arise from differences in thermal expansively, yield stress, or Stiffness. Considerable effort is currently being devoted to the development of a basic framework within which residual stresses can be incorporated into design in aerospace, nuclear, and other critical engineering industries.

Today, there are a large number of residual stress measurement techniques in use. Some are destructive, while others can be used without significantly altering the component; some have excellent spatial resolution, whereas others are restricted to near surface stresses or to specific classes of material [1].

A. Definition

Residual stress is the stress that exists within a material without application of an external load [2], or it can be described as the stress which remains in a body that is stationary and at equilibrium with its surroundings.

B. Diffraction Geometry

The Diffractometer angles used in residual stress analysis are:

1) 2-theta (2θ)
The Bragg angle, this is the angle between the incident (transmitted) and diffracted X-ray beams.

2) Omega (ω)
The angle between the incident X-ray beam and the sample surface. Both omega and 2-theta lie in the same plane.

3) Phi (φ)
The angle of rotation of the sample about its surface normal.

4) Chi (χ)
Chi rotates in the plane normal to that containing omega and 2-theta. This angle is also sometimes (confusingly) referred to as ψ.

5) Psi (ψ)
Angles through which the sample is rotated, in the $\sin^2\psi$ method. We start at psi = 0, where omega is half of 2-theta and add (or subtract) successive psi offsets, for example, 10, 20, 30 and 40°. These angles are illustrated in Figure 6.3, which shows the arrangement in a laboratory type goniometer measuring a large 2-theta angle, as used in residual stress analysis.

II. EXPERIMENT

The experiment was carried out for SS316 material of size 150*50* 5mm thickness is chosen as work piece material. Butt weld joint is made with these 5 mm thick SS plates by maintaining parameter. Experimental trial combinations are carried out at random to minimize the effect of noise factors. The process is carried with current 90Amps, gas flow rate 10 L/min, root gap 1mm.

This work defines residual stresses, and describes the mechanisms of development residual stress in weld joints. Further, the influence of residual stress on performance of weld joints has also been laborated. Methods of controlling the residual stresses have also been presented.

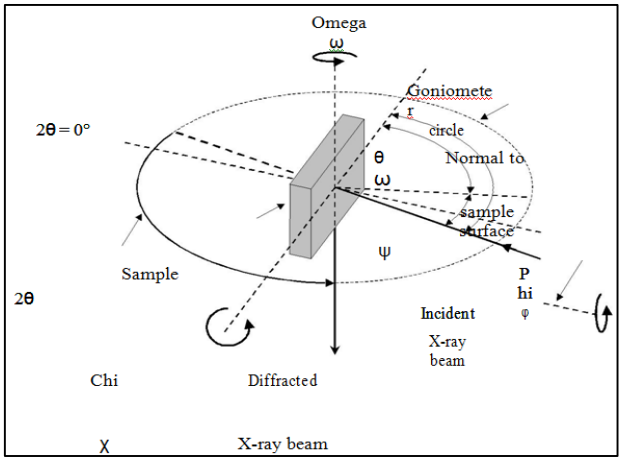

Fig. 1: Angles and rotations used in residual stress measurement

Residual stresses are locked-in stresses present in the engineering components even when there is no external load and these develop primarily due to non-uniform volumetric change in metallic component irrespective of manufacturing processes such as heat treatment, machining, mechanical deformation, casting, welding, coating etc. However, maximum value of residual stresses doesn't exceed the elastic limit of the metal because stresses higher than elastic limit leads to plastic deformation and thus residual stresses greater than elastic limit are accommodated in the form of distortion of components. Residual stresses can be tensile or compressive depending up on the location and type of non-uniform volumetric change taking place due to differential heating and cooling like in welding and heat treatment or localized stresses like in contour rolling, machining and shot peening etc.Table:1 shows the results from X-Ray diffraction

III. RESULTS AND DISCUSSIONS

$$\frac{d_{\emptyset\varphi}-d_0}{d_0} = \frac{1+v}{E}\sigma_{\emptyset}sin^2\varphi - \frac{v}{E}(\sigma_{11}+\sigma_{22}) \qquad (1)$$

This equation can be modified as

$$d_{\emptyset\varphi} = d_0\frac{1+v}{E}\sigma_{\emptyset}sin^2\varphi - d_0\frac{v}{E}(\sigma_{11}+\sigma_{22}) + d_0 \quad (2)$$

Multiplier of the $sin^2\varphi$ term is the slope of the d vs. $sin^2\varphi$ graph. Equation 1 can be rearranged for the slope m,

$$m = d_0\frac{1+v}{E}\sigma_{\emptyset} \qquad (3)$$

Equation 5.2 can be further modified to give the stress,

$$\sigma_{\emptyset} = \frac{m}{d_0}\left(\frac{E}{1+v}\right) \qquad (4)$$

The equation 3 is a very simple equation

$$\sigma_{\emptyset=25} = \frac{-0.0000012}{1.0819055}\left(\frac{193}{1+0.29}\right)10^9 \text{ MPa}$$
$$= \text{-165.94MPa}$$

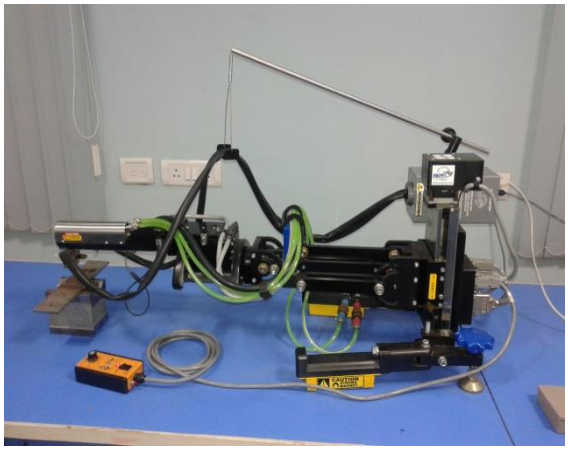

Fig. 2: Equipment of X-Ray Diffraction

Fig. 3: Measurement of the residual stresses

Beta Angles	Psi	Sin^2psi	D-Spacing	2Theta	Strain*E3	FWHM	Breadth	Intensity
25.00	38.60	0.3892	1.081098	153.16	-0.746	3.202	4.07	1502.13
21.12	34.72	0.3244	1.081235	153.10	-0.620	3.215	4.05	1653.02
17.02	30.62	0.2595	1.081419	153.01	-0.449	3.189	3.97	1698.83
13.60	27.20	0.2089	1.081490	152.98	-0.384	3.253	4.13	1651.44
7.51	21.11	0.1297	1.081691	152.89	-0.199	3.275	4.11	1642.02

1.16	14.76	0.0649	1.081838	152.83	-0.062	3.220	4.12	1684.91
0.00	13.60	0.0553	1.081823	152.84	-0.076	3.185	4.03	1685.90
-1.16	12.44	0.0464	1.081882	152.81	-0.022	3.182	4.01	1676.53
-7.51	6.09	0.0112	1.081886	152.81	-0.018	3.119	3.88	1742.43
-13.60	0.00	0.0000	1.081887	152.81	-0.017	3.182	3.83	1788.33
-17.02	-3.42	0.0036	1.081893	152.81	-0.012	3.133	3.93	1810.84
-21.12	-7.52	0.0171	1.081790	152.85	-0.107	3.195	4.03	1774.45
-25.00	-11.40	0.0391	1.081744	152.87	-0.149	3.267	4.12	1691.68

Table 1: The residual stress measurement is conducted by X-Ray diffraction

Fig. 4: Measuring of residual at transverse direction

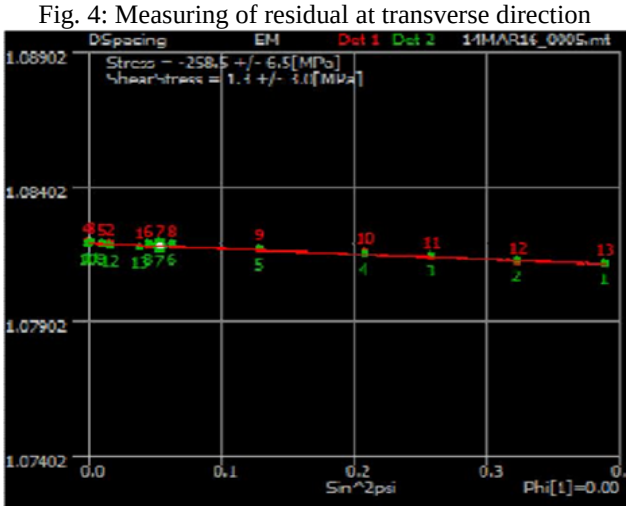

Fig. 5: A linear graph of d vs. sin2ψ fitted to diffraction data with a negative slope

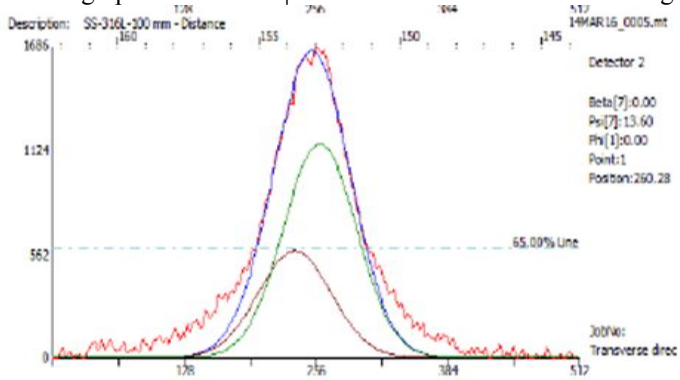

Fig. 6: Two Peak Values of scattering angle θ are given together with the corresponding d-spacing values

IV. CONCLUSIONS

The X-ray diffraction (XRD) is one of the best developed methods available for residual stress determination. It is a non-destructive technique. XRD technique uses the distance between crystallographic planes (d-spacing) as a strain gage. This method can only be applied to crystalline, polycrystalline and semi-crystalline materials. When the material is in tension, the d-spacing increases and when the material is in compression, the d-spacing decreases. Among the samples, B1 and B6 have

negative values of residual stresses which means the state of residual stress exist in the both samples are compressive. On the other hand, for the rest of the samples it is tensile since they have positive values of residual stresses.

The presence of residual stresses in the material produces a shift in the x-ray diffraction peak angular position that is directly measured by the detector. In Figures:5 the shift in the peak positions can be observed for different samples. It is important to obtain a diffraction peak of suitable intensity. The peaks must be free of interference from neighboring peaks. So that the diffraction angle 2-theta can be measured experimentally and the d-spacing is then calculated using Bragg's law.

The most common problems in using X-ray diffraction technique arise due to the location of diffraction peak. For peak fitting purposes, the high precision is necessary which in turn requires accurate sample alignment and precise methods of diffraction peak location.

One of the major disadvantages with XRD is the limitation imposed on the test piece size and geometry. The geometry has to be such that an X-ray can both hit the measurement area and still be diffracted to the detector without hitting any obstructions. However, due to irregular geometry of some of the samples, it was not possible to get clear diffraction data.

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