

# **Experimental Analysis of Residual Stresses in the Various Zones of Arc Welded EN-8 Steel**

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**ABSTRACT:** Residual stresses are internal stresses locked into a rigid part in the absence of external forces or thermal gradients. Residual stresses present in the material lead cracking in the material. Hence, the estimation of residual stresses becomes essential after fabrication processes like welding, casting, etc. In the present work, residual stress has been measured arc welded EN8 steel using high resolution x-ray diffraction method (HRXRD). EN8 steels are used in many machine parts such as axles, shafts, presses & punches parts, piston rods & gear rods. The base material (EN8 steel) has been joined using arc welding process. The residual stress analysis was carried out in the three zones namely, welded zone, heat affected zone (HAZ) and parent zone. In XRD technique, when the stress is positive then the d-spacing increases and when it is negative then the d-spacing decreases. Distributions of residual stresses on the welded zone, heat affected zone and parent zone have been evaluated. The result shows that the residual stress distribution for all the zones is characterized by compressive stresses.

**KEYWORDS:** Residual stress, En8 steel, Arc welding, High-resolution X-ray diffraction (HRXRD), Welded zone, Heat affected zone, Parent zone.

## **I.INTRODUCTION**

Residual stress plays an important role in the engineering components. Higher the residual stresses leads to decrease of performance in the corrosion, fatigue and fracture. Residual stresses can arise from differences in thermal expansion, Yield stress and stiffness [1, 2]. Particularly in welding residual stresses, the differential contractions can be occurred due to this contraction the weld metal gets solidifies. Mostly residual stresses are reduced by heat treatment [3]. By optimization of welding process can minimize the amount of distortion. The effect of shrinkage and weld deposit size is the main function for the magnitude of stress [4]. There are different ways to measure the residual stresses, they are hole drilling method, X-ray diffraction method, Neutron diffraction method and ultrasonic method [5]. The residual stress in welding has been measured by finite element method, in that the transverse residual stresses are very high near the weld region. This is because the part of specimen near the weld region deform plastically under very low external load [6]. The thermally induced residual stress in the hybrid laser-GMA welding can be carried out in both numerical and experimental method. The numerical result shows that the higher residual stresses are distributed in the weld zone and heat affected zone [7]. A residual stress plays an important role in designing the structural elements. The fatigue strength of the welded elements can be reduced due to the residual stresses. The effect of stress concentration can be comparable to the effect of residual stresses at the multi cycle fatigue ( $N > 10^6$  cycles) [8].

## **II. MATERIAL**

### **Material**

EN8 is an unalloyed medium carbon steel with good tensile strength. It is normally supplied in cold drawn or as rolled. Tensile properties can vary but are usually between 500-800 N/mm<sup>2</sup>. The chemical composition and mechanical properties of En 8 steel after are listed below in table 1 and 2 respectively. The width of the weld plate was 150 mm and the thickness was 12 mm. The test plate was welded using arc welding. Low strength ER100-G filler wire

was used for welding (Composition of ER 100-G wire: C 0×07%, Si 0×45%, Mn 1×24%, Mo 0×42%, Ni 1×51%). If high strength filler wires are used preheating the weld plate becomes necessary to avoid cracks during welding. But in this case, since ER 100-G was of lower strength, pre-heating of the weld metal was not needed. The welding parameters adopted are given in table 3.

Table 1: Chemical composition of the EN 8 Steel

Elements	C	Mn	Si	P	S	Cr	Mo	Ni	N
EN 8 (Min)	0.35	0.60	0.05	0.015	0.015	.....	.....	.....	.....
EN 8 (Max)	0.45	1.00	0.35	0.06	0.6	.....	.....	.....	.....

Table 2: Mechanical properties of 5086 & 7075 aluminium alloys

Mechanical property	Ultimate strength (Mpa)	Yield strength (Mpa)
EN 8	700-850 Mpa	465

Table 3: The welding parameters

Experiment	Welding current (I (A))	Welding voltage (U (V))
1	120	30
2	200	34

Each sample was prepared for calculating the residual stresses in the dimensions of height of 10mm and a diameter of 32mm which is shown in the figure 1. It is also important to note that, it is unavoidable to introduce new stresses to the samples during sample preparation. However, amount that is introduced during the preparation reduced to minimum by taking necessary precautions. For instance, first a diamond saw used to obtain small samples, and then these small samples were cut using a precision cut to get smaller samples. Hence, instead of obtaining samples at one step, several steps were taken to reduce the amount of error due to preparation step. Also, each sample was cut along the wavy lines if it was possible.



Figure 1: Tested samples

### **III. EXPERIMENTAL METHOD**

A crystal lattice is a regular three-dimensional distribution of atoms in space. The atoms are arranged so that they form a series of parallel planes separated from one another by a distance  $d$ . When a monochromatic X-ray beam with wavelength  $\lambda$  is incident on lattice planes in a crystal at an angle  $\theta$ . The diffraction occurs only when the distance travelled by the rays reflected from successive planes differs by a complete number  $n$  of wavelengths which is expressed by Bragg's law. The diffracted X-rays are collected by detector at Bragg angles of  $2\theta$ .

The XRD experiments regarding this work were performed on a High-resolution X-ray diffraction method (HRXRD) (PANalytical Make, IIT Kharagpur) which is shown in the figure 2. This device is having a secondary graphite monochromator and automatic divergence slits. A PW3068/00 automatic texture cradle ATC-3 is present on the right side. The Samples that have a maximum diameter of 32 a maximum height of 10 mm and a maximum mass of 30 g can be analyzed using in his cradle and diffractometer is present on the left side. The sample can be rotated over  $360^\circ$  around a  $\phi$  axis, tilted around a axis  $\Psi$  from  $-90^\circ$  to  $+90^\circ$  and translated over a maximum distance of 10 mm in the X direction (along the goniometer axis). The X'pert software provides a common platform for data collection and the analysis.

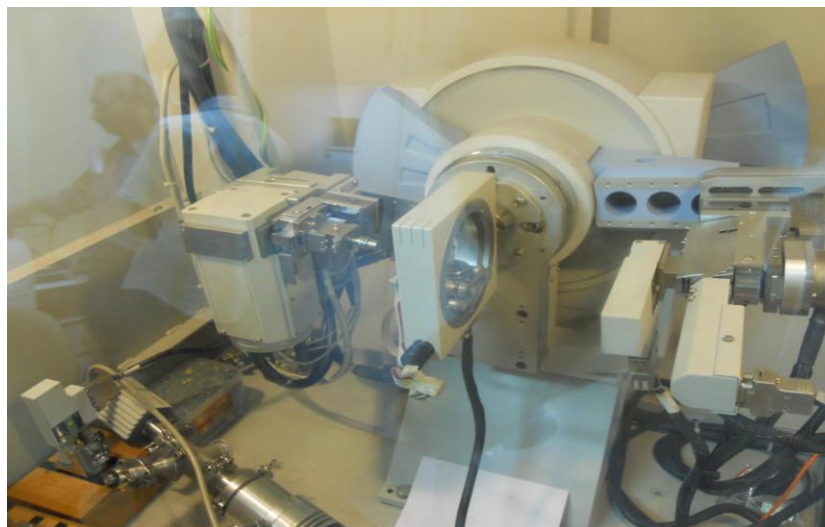


Figure 2: High-resolution X-ray diffraction (HRXRD)

### **IV. RESULTS AND DISCUSSIONS**

#### **4.1 INTENSITY RESULTS**

The figure 3, 4, 5 shows the  $2\theta$  Vs intensity values for the welded zone, heat affected zone and parent metal zone. Whereas the data in red indicates the angle and the  $d$ -spacing which is used in calculations, because the relative intensity has the maximum intensity at this value.

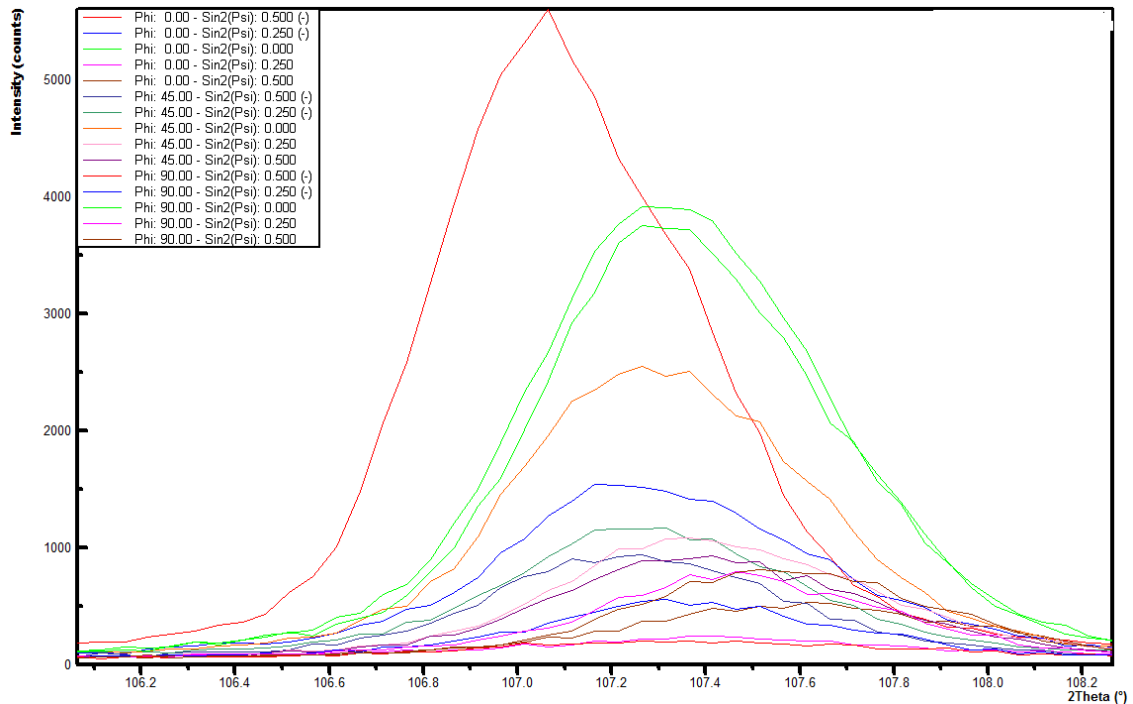


Figure 3: Shows the 2theta Vs intensity values for the welded zone

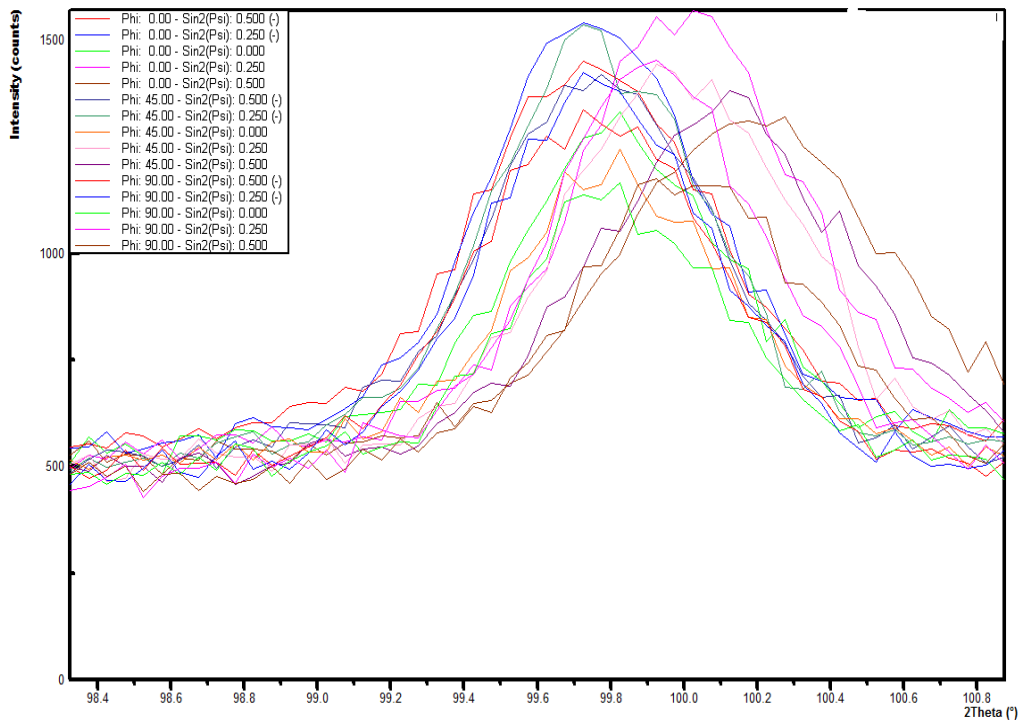


Figure 4: Shows the 2theta Vs intensity values for the heat affected zone

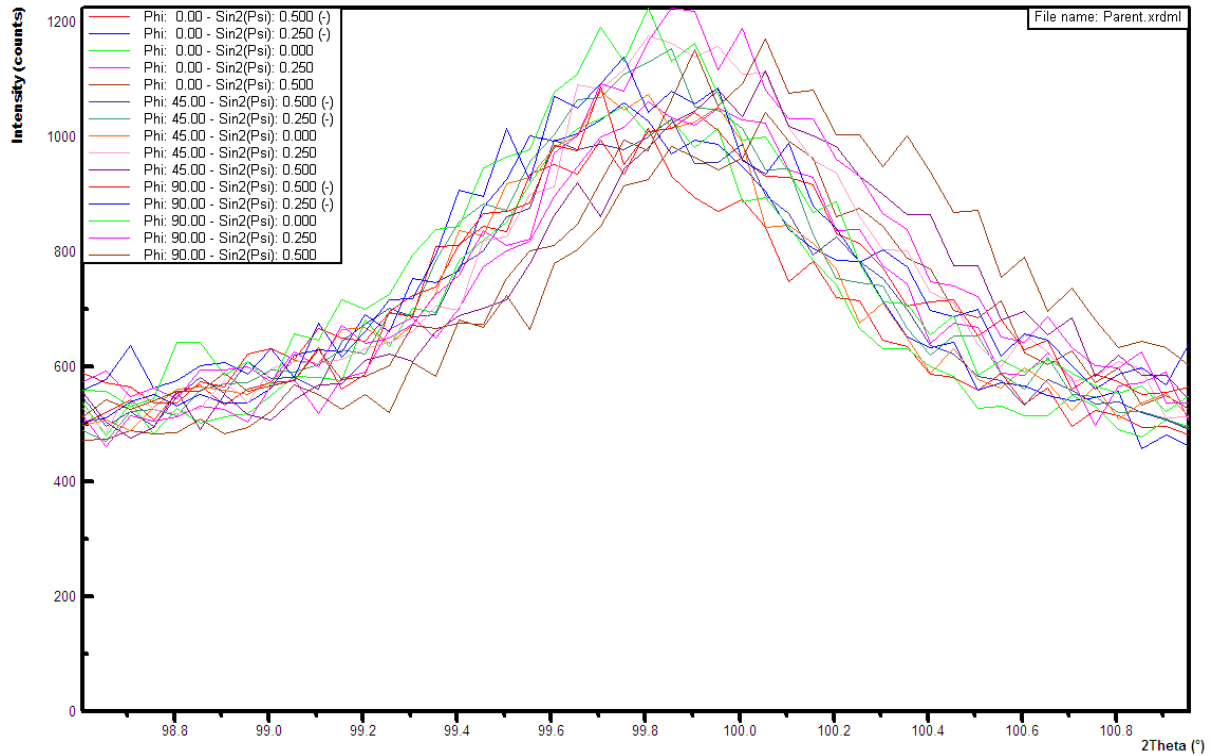


Figure 5: Shows the 2theta Vs intensity values for the parent zone

From the above experiments, In the welded zone, maximum intensity of 5602 counts is obtained while the tilt angle is 45, Phi angle is 0 degree and 2 theta is at 107.065. In the heat affected zone, maximum intensity of 1554 counts is obtained while the tilt angle is 30, Phi angle is 0 degree and 2 theta is at 99.925 & 100.75. In parent zone, maximum intensity of 1225 counts is obtained while the tilt angle is 30, Phi angle is 90 degree and 2 theta is at 99.805 & 99.855.

#### 4.2 RESIDUAL STRESS RESULTS

##### a) Welded zone

The figure 6 shows the Sin square Psi Vs d-spacing for calculating the stresses and the table 4 shows the residual stresses in various Phi degrees.

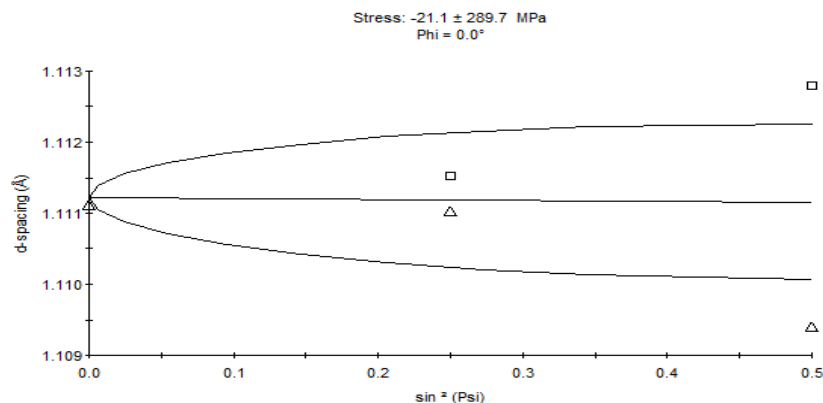


Figure 6: Sin square Psi Vs d-spacing for calculating the stresses in welded zone

Table 4: Residual stresses in various Phi degrees in the welded zone

Phi (°)	SigmaPhi (MPa)	StdDev (MPa)	TauPhi (MPa)	StdDev (MPa)	Sig11+Sig22 (MPa)	StdDev (MPa)
0.00	-21.1	289.7	-174.8	64.8	-----	-----
45.00	-38.1	92.6	-85.4	20.7	-----	-----
90.00	-278.2	73.4	-97.3	16.4	-----	-----

From the experiment the calculated Stress Tensor is

$$\sigma_{ij} = \begin{Bmatrix} -21.1 & 111.6 & -174.8 \\ 111.6 & -278.2 & -97.3 \\ -174.8 & -97.3 & 0.0 \end{Bmatrix}$$

Calculated Stress free d-spacing is 1.11115 Å

Calculated Principal Stresses (MPa) is

$$\sigma'_{ij} = \begin{Bmatrix} 20.6 & 0.0 & -197.8 \\ 0.0 & -319.9 & -30.1 \\ -197.8 & -30.1 & 0.0 \end{Bmatrix}$$

b) Heat affected zone

The figure 7 shows the Sin square Psi Vs d-spacing for calculating the stresses and the table 5 shows the residual stresses in various Phi degrees

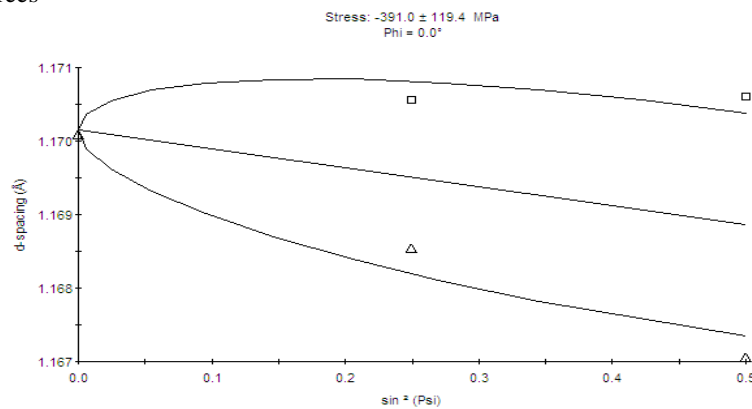


Figure 7: Sin square Psi Vs d-spacing for calculating the stress in heat affected zone

Table 5: Residual stresses in various Phi degrees in the heat affected zone

Phi (°)	SigmaPhi (MPa)	StdDev (MPa)	TauPhi (MPa)	StdDev (MPa)	Sig11+Sig22 (MPa)	StdDev (MPa)
0.00	-391.0	119.4	-230.4	26.7	-----	-----
45.00	-250.0	69.5	-185.4	15.5	-----	-----
90.00	-185.5	82.6	-145.8	18.5	-----	-----

From the experiment the calculated Stress Tensor is

$$\sigma_{ij} = \begin{Bmatrix} -391.0 & 38.2 & -230.4 \\ 38.2 & -185.5 & -145.8 \\ -230.4 & -145.8 & 0.0 \end{Bmatrix}$$

Calculated Stress free d-spacing is 1.16886 Å

Calculated Principal Stresses (MPa) is

$$\sigma'_{ij} = \begin{Bmatrix} -397.8 & 0.0 & -200.9 \\ 0.0 & -178.6 & -184.3 \\ -200.9 & -184.3 & 0.0 \end{Bmatrix}$$

c) Parent zone

The figure 8 shows the Sin square Psi Vs d-spacing for calculating the stresses and the table 6 shows the residual stresses in various Phi degrees

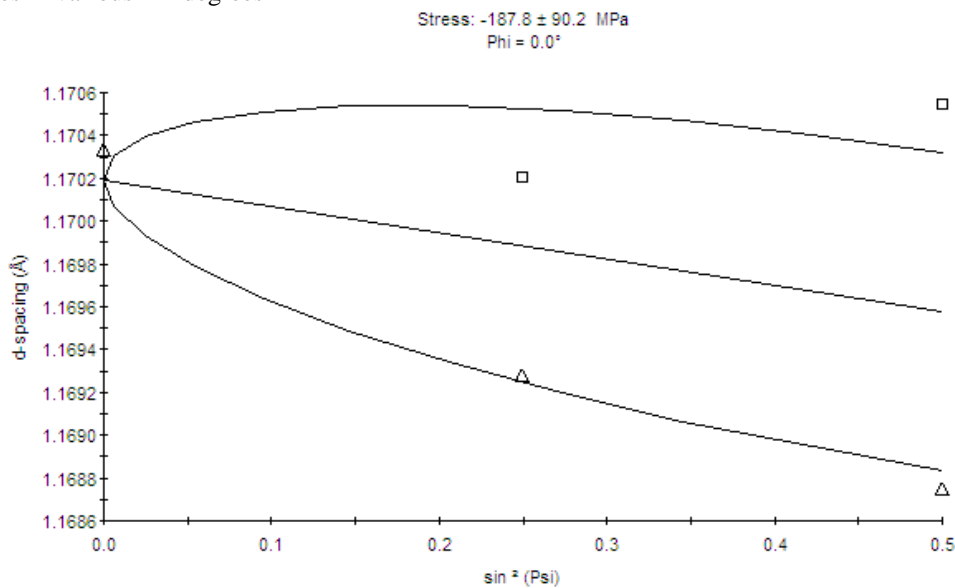


Figure 8: Sin square Psi Vs d-spacing for calculating the stress in parent zone

Table 6: Residual stresses in various Phi degrees in the parent zone

Phi (°)	SigmaPhi (MPa)	StdDev (MPa)	TauPhi (MPa)	StdDev (MPa)	Sig11+Sig22 (MPa)	StdDev (MPa)
0.00	-187.8	90.2	-112.5	20.2	-----	-----
45.00	-287.4	18.5	-95.7	4.1	-----	-----
90.00	-351.0	19.3	-100.8	4.3	-----	-----

From the experiment the calculated Stress Tensor is

$$\sigma_{ij} = \begin{Bmatrix} -187.8 & -17.9 & -112.5 \\ -17.9 & -351.0 & -100.8 \\ -112.5 & -100.8 & 0.0 \end{Bmatrix}$$

Calculated Stress free d-spacing is 1.16958 Å

Calculated Principal Stresses (MPa) is

$$\sigma'_{ij} = \begin{Bmatrix} -185.8 & 0.0 & -100.9 \\ 0.0 & -353 & -112.4 \\ -100.9 & -112.4 & 0.0 \end{Bmatrix}$$

## V. CONCLUSION

The following conclusions are drawn from the studies conducted.

1. The high resolution X-ray diffraction (HRXRD) is one of the best developed methods available for residual stress determination.
2. 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.
3. The diffraction angle 2-theta and the d-spacing can be measured directly by this HRXRD method.
4. The welded zone, heat affected zone and parent zone have negative values of residual stresses which means the state of residual stress exist in the all zones are compressive. There is no positive value of residual stresses which means the state of tensile stress cannot exist in any of the zones.
5. The heat affected zone has more compressive stress than the other zones.

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