Effect of Delay Time between welding and stress relieve annealing on mechanical properties and distortion of 30CrMnSiA steel

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Abstract----The time interval from completion of the welding joint to the subsequent non-destructive testing and stress relief annealing is called delay time. The delay time is one of the important factors which contribute to the amount of residual stresses stored in the welded joints. These residual stresses in return damage the mechanical properties of welded joints. The focus of this research work is to measure residual stress quantitatively as a function of time and establish a linkage between residual stresses and mechanical properties of 30CrMnSiA steel. Two 150 × 150 × 3.8 mm steel sheets were butt welded in flat position by Gas Metal Arc Welding (GMAW). A delay time of 12, 18, 24 and 30 hours was given to different samples before analyzing residual stresses by XRD. The residual stresses with different delay time were compared with base metal. The samples processed for different delay times were tested by bend, tensile and hardness testing to study how residual stress linkup with mechanical properties of 30CrMnSiA steel

Index Words—Welding, Delay Time, GMAW, XRD, Stress Relieve Annealing, Residual stresses

I. INTRODUCTION

Welding is a key process in fabrication of steel and other ferrous alloys, welding induces residual stresses and deformations as a result of high heat input and subsequent cooling [1]. The welding process and residual stresses can have a detrimental effect on mechanical properties of the fabricated structure. Therefore it becomes important to perform a rigorous study of all the parameters associated with welding, one such parameter associated with welding is delay time, which is the time given between welding and subsequent Stress Relieve Annealing (SRA).The study encompasses around the induction of residual stresses after welding and their development and change in distribution and magnitude during delay time. The residual stresses are quantified using peak shift method in X-Ray Diffraction (XRD).

II. EXPERIMENTAL PROCEDURE

A. Welding Procedure

The goal of the study is to quantitatively determine the effect of delay time on mechanical properties of 30CrMnSiA steel, to serve this purpose two 150 x 150 x 3.8 mm sheets were butt welded in flat position according to the schematic shown in Fig. 1

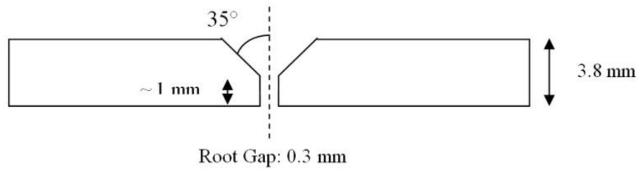

Fig. 1 Schematic of weld position

Root gap was set to be 0.3mm; the bevel angel was set as $35^{o.}$ GMAW was the welding technique used to weld the steel sheets together. The parameters given in Table 1 were used for welding

TABLE.I

	Welding Parameters		
	Parameters	***Value***	***Units***
1	Wire Diameter	1.6	mm
2	Electrode Diameter	4	mm
3	Wire Feed rate	10	m/hr
4	Welding Speed	12-14	m/hr
5	Arc Voltage	13-15	V
7	Gas Flow Rate	10-12	L/min

B. Stress Relieve Annealing

Four 150 x 150 x 3.6 mm welded specimens namely sample 2, 3, 4, 5 were stress relieved annealed after delay time of 12, 18, 24, 30 hours. Sample 1 was not stress relieve annealed and tested in as welded condition

TABLE.II

	Delay Time of Samples	
	Sample	***Delay Time (hours)***

	Delay Time of Samples	
	Sample	***Delay Time (hours)***
1	**1**	Un annealed
2	**2**	12
3	**3**	18
4	**4**	24
5	**5**	30

C. XRD Analysis

XRD analysis was used to quantify residual stresses, the stress relieved sample were compared with non-annealed sample in order to evaluate the decrease in residual stresses after SRA [2]. The non-strained inter laminar spacing "d_o" was measured using the XRD patterns of the reference (base material), after that the strained inter laminar spacing "d" was measured for the welded specimens. The distance between crystallographic planes can be calculated using Bragg's Law [3]

$$n\lambda = 2d\sin\theta \quad (1)$$

The strain in the specimen can be calculated by equation 2

$$\varepsilon = \frac{d - do}{do} \quad (2)$$

Stress can be calculated from the strain by incorporating Elastic Modulus and poison's ratio equation 3

$$\sigma = E\,\varepsilon \quad (3)$$

The XRD results for the reference material is given below in Fig. 2

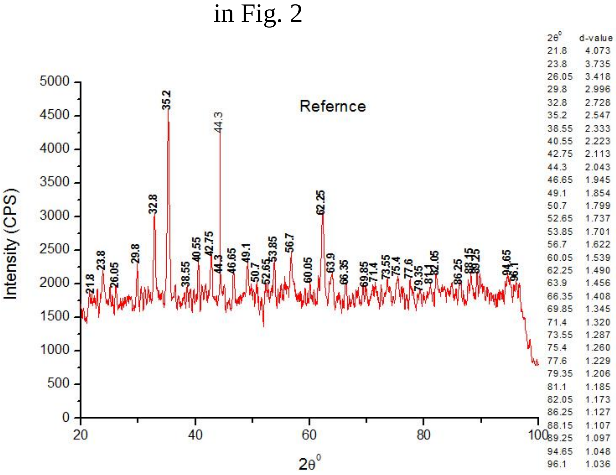

Fig. 2 XRD plot for reference material

The following peaks were identified using the data from International Centre for Diffraction Data ® (ICDD) as the major constituents of the steel [4]

TABLE.III

	Peak Identification	
	Phase	***Diffraction Angle (2θ)***
1	**Ferrite (1 1 0)**	42-44
2	**Ferrite (2 0 0)**	65
3	**Ferrite (2 2 0)**	82-83
4	**Fe_2O_3**	35

The plots of XRD of base material sample compared with the welded samples are shown below

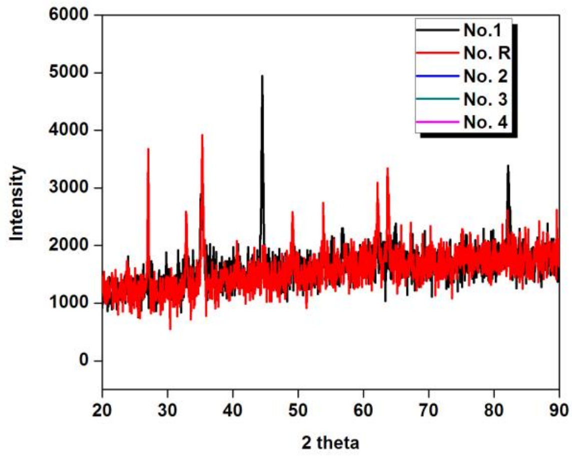

Fig. 3 XRD peaks of 1 & Reference (R)

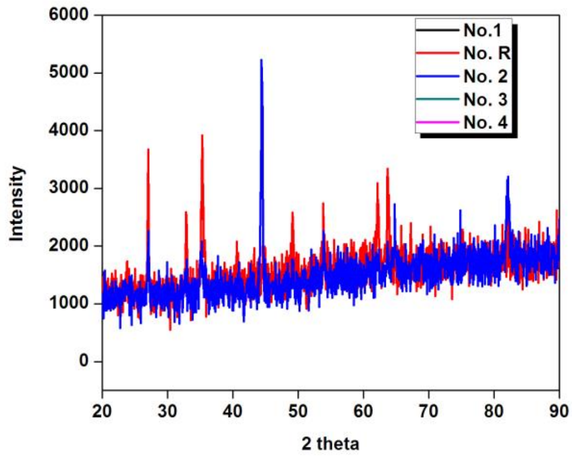

Fig. 4 XRD peaks of 2 & Reference (R)

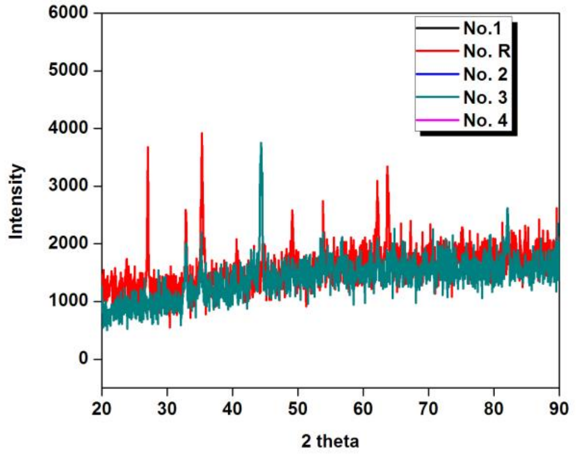

Fig. 5 XRD peaks of 3 & Reference (R)

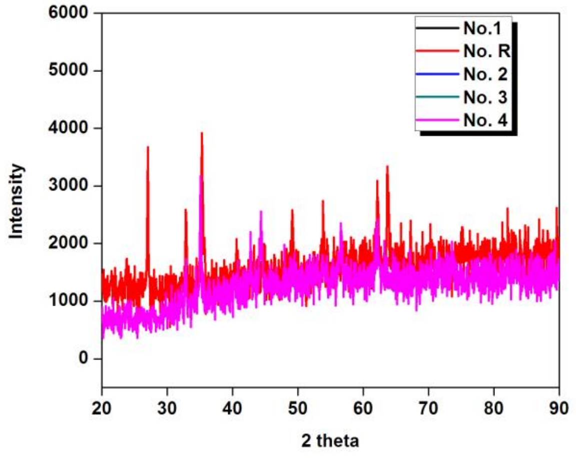

Fig. 6 XRD peaks of 1 & Reference (R)

The peak shifting can be denoted from Fig.1, Fig. 2, Fig. 3, and Fig. 4. Ferrite (2 0 0), Ferrite (1 1 0), Ferrite (2 2 0) were the peaks was used to measure the extent of peak shifting in the samples these were the most intense peak in all the samples, corresponding "d" values can be found and the corresponding residual stresses were calculated using equation 1, 2 and 3

TABLE.IV

	Quantification of Residual Stresses in Samples	
	Sample	***Residual Stresses***
1	**1**	356.11 Mpa
2	**2**	20.56 MPa
3	**3**	61.7 MPa
4	**4**	88.9 MPa
5	**5**	87.9 MPa

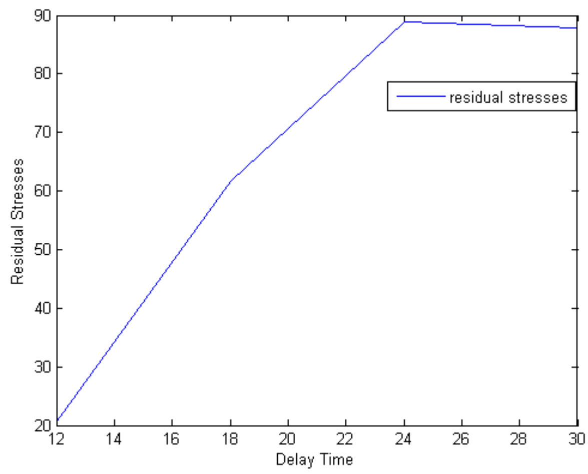

Fig. 7 Profile of Residual Stresses with time

The quantified residual stresses indicate that more residual stresses stay in the structure as more delay time is given to the samples; all the residual stresses are tensile in nature which is responsible for the decrease in tensile properties of the steel.

D. Mechanical Testing

Tensile test, Bend test and hardness test were the mechanical testing methods used for the evaluation of 30CrMnSiA steel. All the specimens were prepared by using Electric Discharge Machining (EDM) to minimize the residual stresses introduced due to machining. The specifications of each test has been given below

1) Tensile Test

Tensile test is the most appropriate mechanical test for the evaluation of mechanical properties [5], three tensile specimens were extracted having dimensions according to ASTM-E8 [6]. . The specimens were extracted from each sheet having delay time of 12, 18, 24, 30 hours

TABLE.V

	Tensile Properties	
	Sample	***Average UTS***
1	**1**	516 MPa
2	**2**	602 MPa
3	**3**	586 MPa
4	**4**	560 MPa
5	**5**	505 MPa

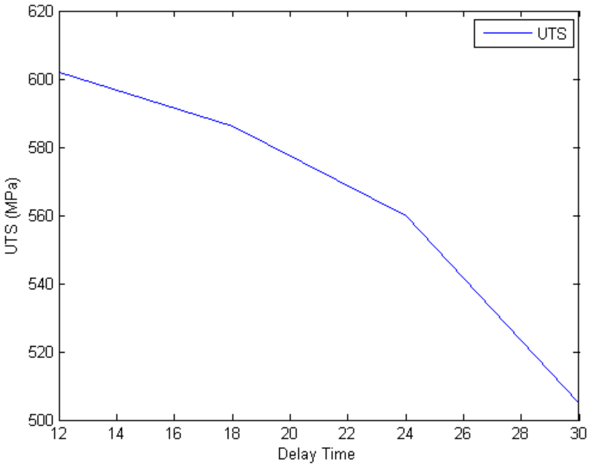

Fig.8 Plot of UTS with Delay Time

2) Hardness Test

The hardness profile is an important test for the distinction of Heat Affected Zone (HAZ) from base metal based on hardness values, the increase in hardness in the HAZ and weld area is probably due to formation of carbides of alloying elements present in the steel, in this case Chromium, Manganese and Magnesium. The hardness profiles of sample 1, 2,3,4,5 are given in Fig. 9

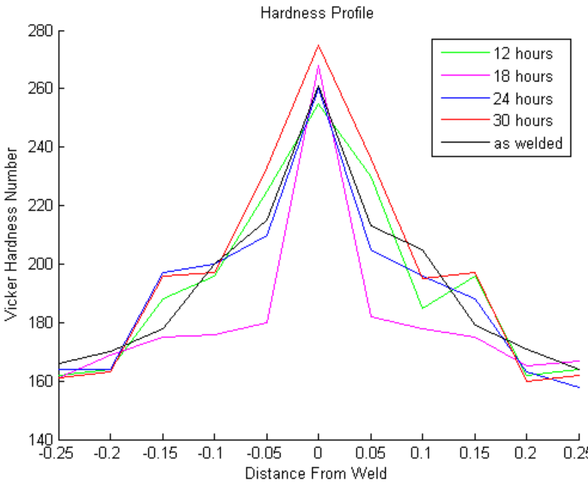

Fig 9 Plot of UTS with Delay Time

3) Impact Test

The test was used to quantify the effect of cracking due to welding and the residual stresses on the energy absorption characteristics of 30CrMnSiA steel. The samples were prepared for different delay times and then tested using charpy impact test v-notch technique; the charpy impact specimens were fabricated having dimensions (55 x 10 x 3.8 mm) having a notch of 45 degrees and 2mm depth according to ASTM standard ASTM A370-20[7], results obtained are shown in Fig. 10

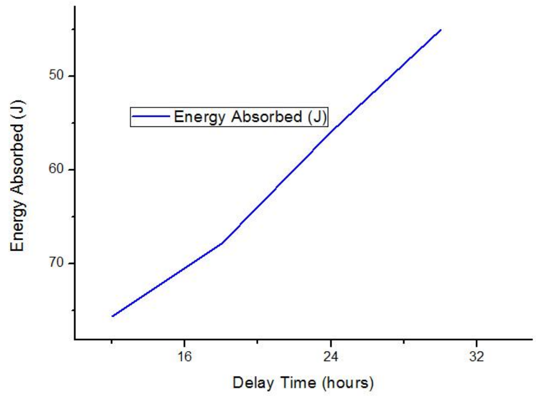

Fig. 10 Impact Profile of Samples

4) Bend Test

30CrMnSiA has vast applications in vessel construction. Mechanical evaluation of the bend characteristics of the steel can be performed by the transverse face bend test. The transverse face bend test replicates the in-service conditions for steel, guided transverse face bend was performed on the specimens according to ASTM E290-09, the guided bend test used fixture of 30mm diameter and the distance between two supports was set as 41mm according to equation given in ASTM E290-09[8] to qualify the extent of cracking in the samples. Dye penetrant test was used on the curved surface for the extent of cracking. Sample 2 showed no cracking at all while sample 5 showed small amount of cracking but the cracking was not enough to impose a fracture even after a displacement of 45mm of the specimen

III. Results and Discussions

The mechanical properties are a clear indication that as delay time is increased these mechanical properties deteriorate, this is due to the the ability of residual stresses to jam in the structure and not being removed completely after SRA and these residual stresses remain in the structure leading to deterioration of mechanical properties. The XRD analysis was used to quantify the residual stresses; the peak shifting due to strained lattice of the ferrite was used to determine the residual stresses; the calculations can be further improved by incorporating peak broadening along with peak shifting. The quantified residual stresses indicate that more residual stresses stay in the structure as more delay time is given to the samples; all the residual stresses are tensile in nature which are responsible for the decrease in mechanical properties of the steel. Tensile test clearly indicate an improvement in tensile properties as delay time is decreased, this is due to the presence of tensile residual stresses present in the specimens that are given an excess amount of delay time. Hardness has an indirect relation to mechanical properties and an empirical but strong correlation with residual stresses; the higher hardness values of specimens which are given a greater delay time suggest a higher amount of residual stresses present in the structure. The impact test also provided a conclusive evidence of the deterioration of the impact properties with the increase in delay time, based on these results minimum delay time must be given to steel to avoid deterioration of mechanical properties.

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