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TO ANALYZE EFFECT OF HEAT TREATMENT ON PROPERTIES OF STEEL SPECIMEN BEFORE WELDING AND AFTER WELDING

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Abstract: **Work was planned to analyse the effect of heat treatment (HT) on mechanical properties of steel alloy specimen before and after welding. Low Alloy Steel (similar to AISI 8740) was first prepared in desired dimensions for heat treatment and then subjected to heat treatment as per phase diagram of alloy. Sample was characterized before and after heat treatment to obtain data for change in mechanical properties. In second section of experiment two specimens of Low Alloy Steel (similar to AISI 8740) were welded using shield arc welding. Welded specimen was then subjected to heat treatment process in electrical Full-Muffle furnace. Welding parameters and heat treatment temperature, soaking time were selected as per phase diagram of specimen material. Welded specimen was then tested for mechanical properties before and after heat treatment. Analysis shows that heat treatment have makeable` effect on mechanical properties of alloy. It is observed that welding introduces some defects in alloy and changes in properties of alloy. HT successfully recovers the properties of welded alloy. For specimen without welding and the welded specimen, mechanical properties obtained after HT have noticeable margin. All this is due to effect of welding on properties of alloy and subsequent effect of HT on two types of samples. Microstructure examination confirms phase transformation with welding and HT for both samples.**

Keywords: **Welding, PWHT, steel alloys, stress relieve, strength, phase diagram**

1. INTRODUCTION

Heat treatment (HT) process is known to involve with almost all applications of metals and alloy. Deep insight into phase diagram of material and then applying suitable heat treatment process always results in some technologically important results. Heat treatment means, heating at some specific rate and then soaking at specific temperature for a period of time. Process aims at achieving desired micro structure and hence required mechanical, thermal, electrical properties [1-5]. Heat treatment well known method to achieve desired properties in various applications of metals and alloys. Iron based alloys are widely undergone heat treatment process to utilise them in various applications. During heat treatment various phase transformation takes place, which results in change of microstructure and hence properties in a solid state. In heat treatment, thermal energy participates that modifies only structure. There are many heat treatment processes for example Thermo mechanical treatments, which modify component shape and structure, and thermo chemical treatments that modify surface chemistry and structure [6, 7]. Welding of any metal or alloys requires care full consideration of effects of welding on that metal or alloy. Welding give rise to stress in metal or alloy component, which greatly affects the performance of component in application. This internal stress affects the mechanical properties of the component (metal or alloy). Shift in strength of specimen, fracture at value smaller than as expected are most common effects of internal stress [8-12]. Solution for this factor is Post weld heat treatment (PWHT). Post weld heat treatment results in stress reliving. Improved properties as reported by many researchers can be achieved by PWHT.[13-20] During welding first step is to select welding process. Welded part is then subjected to HT at some predetermined temperature and soaking for a specified period as per phase diagram of material (metal or alloy). All parameters are set as per material phase diagram [21-23].

In this paper we have investigated the effect of pre (before welding HT) and post weld heat treatment on properties of steel. For this Low Alloy Steel (similar to AISI 8740) was selected.

Shield arc welding was used. Main objective was to study effect of HT before welding and HT after welding. Both samples were characterized for any change in mechanical properties. Change in mechanical properties, heat effected zone were recognized as effect of HT on properties of material.

2. MATERIALS & METHODS

Composition & properties of materials used and various Methods applied in present work are as follows:-

2.1 MATERIAL

Low alloy steel specimens of dimensions 4.7cm X 4.7cm and thickness 0.6cm was prepared in workshop at Arni University.

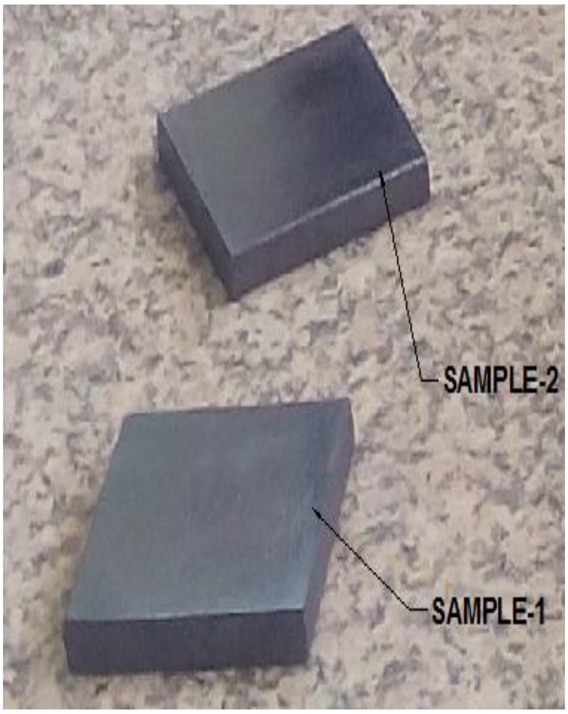


Figure 1: Low alloy steel specimens before heat treatment.

The chemical compositions and mechanical properties of low alloy steel are given in Tables.

ELEMENTS	LOW ALLOY STEEL (In Wt %)
C	0.38/0.43
Si	0.10/0.35
S	0.040(Max)
P	0.025(Max)
Mn	0.70/1.00
Ni	0.40/0.70
Cr	0.40/0.60
Mo	0.20/0.30
V	------------
Cu	------------
W	------------
As	------------
Sn	------------
Co	------------
Al	0.032 (Max)
Pb	------------
Ca	------------
Zn	------------
Fe	Balance*

(*Reference to the ‘balance’ of a composition does not guarantee this is exclusively of the element mentioned but that it predominates and others are present only in minimal quantities.)

Table 1: Chemical Compositions of Low alloy steel.

MECHANICAL PROPERTIES	TENSILE STRENGHT	YIELD STRESS	ELONGATION %	HARDNESS HRC
LOW ALLOY STELEL	850/1000	680(Mini)	12	50 HRC

Table 2: Mechanical properties of Low alloy steel.

2.2. EXPERIMENTAL METHODS

(a) Sample/specimen preparation (for welding) & welding process

Single Butt V-weld butt joints were prepared by welding two alloy specimens by using shield arc welding process. Length and width of each weld pad was 4.6 cm and 1.2 cm respectively and thickness 0.3 cm. The weld joint design is given in Figure 3.

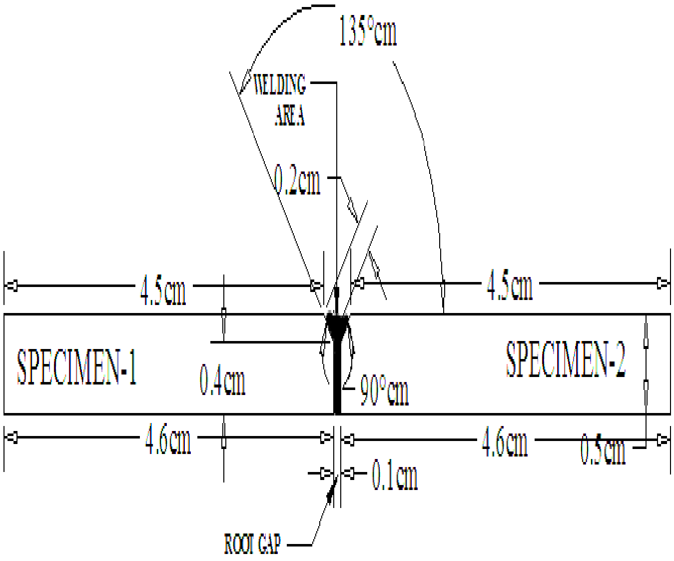


Figure 2: Top view of welded joint (CAD software).

PROCESS NAME	FREQUENCY/VALUE/TYPE
Welding Type	Shield arc welding
Welding Position	Flat
Welding Speed (mm/min)	180
Welding Amperes (Amp)	90-130
Arc Voltage (Volts)	60
Preheat Temperature (K)	410
Arc Welding Temperature(C°)	3600-4000
Dimension of electrode (Dia. x len.) mm	3.15 X 450
Type of Electrode	Consumable E6013
Angle of Electrode	75°-80°
Length of Arc (mm)	46
Gas Used	Argon

Table 3: Welding Parameters in present experiment.

(b) Pre weld heat treatment

To study effect of heat treatment (specimen without welding), samples prepared with desired dimensions as mentioned above were subjected to heat treatment with Electrical Muffle furnace at the predetermined temperature range as per sample material phase diagram. These samples were then soaked and air cooled at room temperature.

Figure 3: Low alloy steel specimens (without welding) after heat treatment

(c) POST WELD HEAT TREATMENT

To study effect of Post-weld heat treatment, two specimen of low alloy steel were prepared with desired dimensions as mentioned above. These specimens were then first welded under above mentioned welding parameters and then subjected to heat treatment with electrical Full-Muffle furnace at the predetermined temperature range as per sample material phase diagram. The welded sample was then soaked and air cooled at room temperature.

Furnace Temperature(C°)	550 to 650
Furnace Wall Material	Stainless Steel
Insulation Material	Glass Wool
Heating Element	Nycrone8020
Wall Filler Material	Ceramic Fibre
Cycle Time	1 Hr 30 Minutes
Soaking Time	45 Minutes

Table 4: Heat treatment process parameter.

Figure 4: Welded sample before Heat Treatment.

Figure 5: Welded sample after Heat Treatment

(d) SAMPLE PREPARATION FOR MICROSTRUCTURE EXAMINATION

All samples (single and welded) were polished with diamond polishing machine using alumina abrasive and different grades of emery papers . After this they are subjected to etching with Nital reagent to expose the microstructure of specimen. Microstructure analysis was then performed with optical microscope to study effect of pre and post weld heat treatment on the sample microstructure.

(e) RESIDUAL STRESS MEASUREMENT

There are many methods such as Weld Strength measurement, X-Ray diffraction per ASTM E915-83, High Speed Hole Drilling with strain gauges per ASTM E837-85, Barkhousen Noise Analysis method for making any kind of determination that stresses have been reduced. In the present work tests to confirm the stress relieve in specimen is to measure the strength of the weld joint using Universal Testing Machine after stress relieve heat treatment and hardness after heat treatment

3. RESULTS & DISCUSSIONS

3.1 STRENGTH MEASUREMENT

As per theory of welding, various stresses introduced in the sample after welding. This is a mechanical stress which introduced in the sample, because of rapid melting of material and solidification of weld joint. Stress in the weld joint, decreases the strength of bonding between welding pieces (Low Alloy Steel) and also a surface under residual stress cannot sustain additional stress during service life. After Heat Treatment, stress relieves results in the enhanced strength of weld joint.

In present work two samples one single specimen and second welded specimen as shown in figures above were prepared and analyze before and after heat treatment.

Stress type = Tensile stress, Peak load = 187.12 KN, Maximum cross head travel =20.7 mm
Tensile strength **(Before HT)** = 649.7 N/mm², Load at break = 167.32 KN

SPECIMEN	MAXIMUM LOAD (KN)		LOAD AT BREAK(KN)		PERCENTAGE ELONGATION(%) & REDUCTION IN AREA (mm²)		TENSILE STRENGTH (N/mm^2)	
	Before HT	After HT	Before HT	After HT	Before HT	After HT	Before HT	After HT
Single (Before welding)	167.32	170.4	164.32	166.6	Negligible		649.7	658.2
Welded Specimen	165.72	168.6	160.3	163	Negligible		611.8	618.4

Table 5: Tensile Strength test data (pre and post weld Heat Treatment)

3.2 HARDNESS MEASUREMENT

Samples were prepared for hardness testing. Hardness test was performed before and after heat treatment. Rockwell hardness Tester in HRC mode is used for hardness measurement with a load of 150 Kg.

Indenter Used = Diamond Cone, Load Applied = 150 Kg,Hardness before heat treatment = 50 HRC

SPECIMEN	LOAD APPLIED (Kg)	*TOUCH POINT HARDNESS (HRC)	HARDNESS (HRC)	
			Before HT	After HT
Single (before welding)	150	256	50	54
Welded Specimen	150	255	48	51

Table 6: Hardness data (PWHT samples)

***Touch point hardness-:** It refers to hardness when indenter just touches the surface of specimen, before actually pressing it.

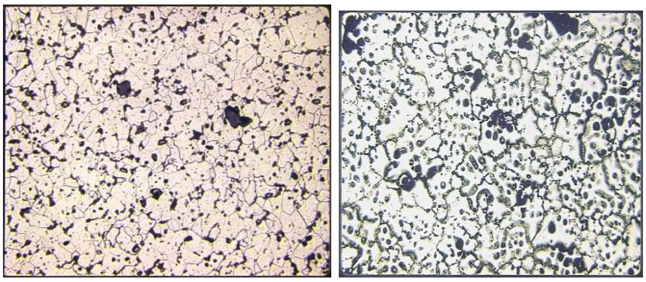
Results shows increase in hardness after heat treatment in both single and welded specimen. Also one additional parameter involved with welding id decrease in hardness after welding and retains some hardness value after heat treatment. This is due to stress relieve and due to refinement of grains, which results in improvement in hardness after HT. Phase change in the alloy with formation of martensite (it contributes to hardness of material), also explains improvement in hardness after HT. Percentage of carbon in the iron alloy is another factor that decides, how much of improvement will be there in hardness after heat treatment. The plot below shows formation of phase with percentage of carbon & variation in Hardness of material.

3.3 MICROSTRUCTURE ANALYSIS

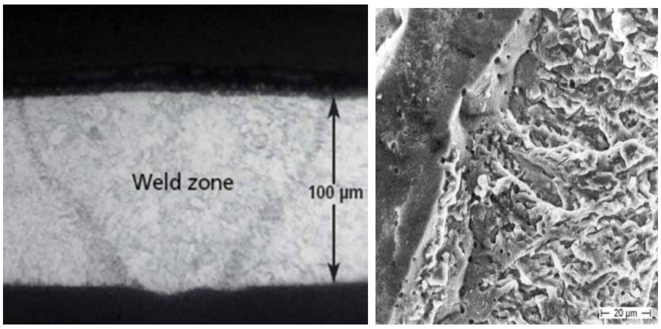
The investigated material is a low alloy carbon steel with carbon in range of 0.38 -0.43 percent. Specimen for microstructure examination was prepared by cutting a weld sample (before and after HT) in the smallest cross-section to examine the material microstructure. Single specimen examine by cutting directly in desired dimensions. Sample shows a normalized microstructure (Before HT) Figure 6.

Examination of the microstructure (After HT) along the cross-section of a specimen shows a martensitic microstructure. Specimen shows a mixture of martensite and ferrite in depth. In core the initial microstructure made of ferrite and pearlite is not affected by the heat treatment. Phase transformation in steel during Heat Treatment is related to the diffusion of interstitial carbon. Also the amount of martensite that forms is a function of the temperature to which the austenite is cooled and not a function of time.[1-10]

Figure 6: Martensite phase microstructure. [5]



(a)



(b)

Figure 7: Optical microstructure of (a) Single sample (Before & after HT)
(b) welded specimen (Before & after HT)

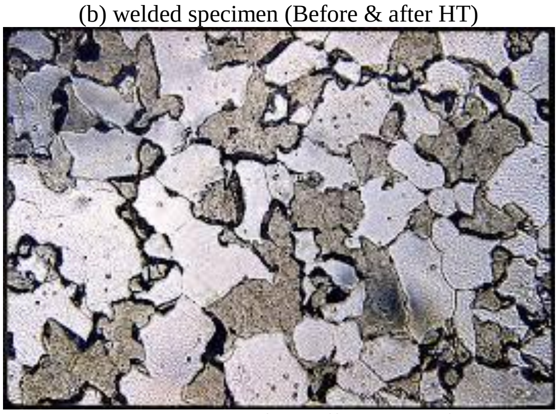


Figure 8: Optical microstructures of heat effected zone after Nital solution etching.

3. CONCLUSIONS

From all the characterizations and study of various parameters involved in heat treatment, welding and post weld Heat Treatment we conclude that Heat treatment of carbon steel always results in improvement in hardness, tensile strength and also refines grain boundaries that can be confirmed from study of mechanical properties after HT. Welding results in introduction of stress in the welded specimen, which reflects some kind grain boundary deformation in specimen. This results in decreases in tensile strength of material (Metal or alloy). Post weld heat treatment results in increase in strength of welded joint, thus stress relieving objective can be achieved by suitable HT mechanism, along with improvement in other mechanical properties. Increase in hardness confirms formation of hard phase i.e. martensite, that is also confirmed by microstructure examination. Improvement in hardness is not much as expected from PWHT, but tensile strength has excellent refinement after PWHT. This is because in case of small content of carbon in alloy. Overall Heat Treatment is an excellent tool for improvement in properties of material and also minimizes defects introduced by welding of materials, but the properties of materials plays an important role in achieving objectives of Heat Treatment.

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