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STEEL REACTION TO THERMAL CYCLES ON WELDING: CASE STUDY OF STEEL 09G2S USED IN PETROLEUM AND GAS INDUSTRIES

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ABSTRACT

The effects of welding and heat treatment on the mechanical properties of high-strength low-alloy steels known for high pressure resistance were investigated. three types of heat treatment were used: Annealing, Normalizing and Quenching and Tempering at 450 and 600°C.

Results of experiments showed that heat treating steel and weld joints considerably affect residual stresses and steel properties under load. The heat treated and welded samples showed lower hardness, strength and ductility than the unwelded ones.

KEY WORDS: Heat affected Zone; Inclusions; residual stresses; carbon pick up; welded joints.

INTRODUCTION

Steel used in the petroleum and gas industries are subjected to high mechanical stresses caused especially by the pressure of the petroleum and gas products, which had led to high rate of mechanical and metallurgical failures. Several studies have been done in the study of quality of steel used for transporting petroleum and gas products, also the role of welding in the steel industries was well analyzed by Bernard, 1988. These steels are known to combine strength with weldability. One means of achieving this is microalloying. According to Thewlis 1989, the addition of small amount of Aluminium, Titanium or Niobium to a Carbon-Manganese steel produces a fine grained material with improved tensile and fracture toughness properties. Such steels, known as high-strength low alloy steels may contain small amount of molybdenum, nickel, and chromium. The carbon content is kept low to promote weldability, Lancaster,1994.

Non-metallic inclusion may have an adverse effect on the hardenability of the heat-affected zone such as sulphide, oxide and silicate inclusions. It follows that the heat affected zone (HAZ) of clean steel is likely, for any given welding procedure, to be harder than that of less refined material, Thewlis, (1989).

However, the increased hardenability of clean steel may be a problem in the fabrication of offshore structures and pipelines where specifications require a maximum hardness limit in the HAZ of welds in order to minimize the risk of stress corrosion cracking, Suzuki et al. 1978. Studies by Gevlich et al (1989). on stress relaxation of low alloy steels in the temperature range of 300 to 700°C, revealed that relaxation occurs in two stages and may be described by the Maxwell equation, and concluded that the largest decrease in stress takes place at the stage of unsteady relaxation whose duration decreases with increasing heating temperature. The influence of Aluminium, Nitrogen and Calcium on weld metal toughness had been reported, Thewlis, (1989).

In view of several reported cases of leakage on petroleum pipeline by Nelson and Still, 1988, the hardness in the region of the heat influenced zone near a welded joint might be a suitable criterion for estimating the cold cracking sensitivity and stress corrosion cracking. Therefore, data from the mechanical tests can be used to determine the properties of homogeneous joints and also to determine the trends of the properties as a function of fatigue life. This to a greater extent can assist in predicting the life span of materials used in petroleum industries.

This paper discusses the effect of welding on the mechanical properties of steel, and also the effect of heat treatment on the mechanical properties of the welded joints.

EXPERIMENTAL

MATERIALS AND EQUIPMENT.

Low carbon high strength steel samples 09G2S with chemical composition as analyzed in table 1. The steels were obtained from Delta - Steel, Aladja. Coated gauge mild steel electrodes were used for welding the steel samples. A metal arc welding machine was used. In heating the steel samples, a carbolite furnace with a temperature range of between 0 to 1200°C. For hardness tester, a Rockwell hardness tester type 640Z was used to measure the hardness of the

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specimens. A 1.6mm steel ball was used as an indenter.

Table 1. Chemical Composition of As received Steel,(%).

C	Si	Mn	Ni	Cr	Mo	Al	P	S	Sn	Sb
0,1	0.28	1.1	0.54	2.19	0.5	0.039	0.024	0.032	0.006	0.003
Fe										
others										

METHODS

10cm long pieces were cut out from the steel sample and one end of each piece was milled on both sides to form a double-vee joints to ensure proper weld penetration; 15cm long pieces were also cut out which were not milled nor welded but were heat treated, these serve as a basis for comparison. Another set of 15cm long pieces were cut out with grooves at the center. The grooves were filled in the course of welding, and later used for microstructural studies. The metal pieces were treated in the furnace to a temperature of 930°C and soaked for 1 hour. The process was effected to remove residual stresses in the sample.The following treatments were carried out:

Table 2.Types of heat treatment and designation.

Specimen	Heat treatment	Designation
i) Two pairs of milled and three unmilled	quenched in diesel oil	Q;
ii) A pair of milled and one unmilled	normalized in air	Norm
iii) A pair of milled and one milled from each grade from (i)	tempered at 450 and 600°C for 24 hours,	QT_1 QT_2

Welding was carried out on the heat treated milled and grooved pieces. The welded pieces were machined to tensile test specimens with the joint at the middle. The unwelded pieces were also machined. They were subjected to tensile stresses until fracture occurred. The other pieces were used for hardness tests. All tests were carried out under laboratory conditions at temperature of 25°C. The specimens for microstructure were mounted using Epomet powder and rammed at 1.4KN force. The specimen were grounded and polished on different grades of abrasive papers. In the final polishing, Alumina and Chromic oxide were added on the emery cloth. 25% nitral was used as enchant to reveal the surface and methanol to prevent oxide formation on the polished surface. Photomicrography were obtained from the specimen at a magnification of x100.

The Tensile Strength was calculated from:

$$\text{Tensile strength} = \frac{\text{maximum load}}{\text{original cross sectional area(mm}^2\text{)}};$$

and

$$\text{Ductility} = \frac{\text{Extension of gauge length x100}}{\text{Original gauge length}}$$

RESULTS AND DISCUSSION

Table 3 shows the tensile strength of the unwelded but heat treated steel, (UHT); Table 4 shows that for the heat treated and welded low carbon steel, (HTW); and Table 5 shows the percentage elongation (ductility) for all samples.

EFFECTS OF WELDING ON THE MECHANICAL PROPERTIES OF STEEL.

In all cases, the measured mechanical properties to the welded are lower than those of the unwelded as can be observed in the tables and figures. This observation can be explained thus:

(a) Inclusions into the metal during welding are located in the grain boundaries after solidification of the weld. These impurities thus weakened the grain boundaries giving rise to failure at lower loading;

(b) During solidification of welds, large columnar grains are formed in the weld zone, this gives rise to lower strength;

(c) Carbon pick up from the base metal in the fusion zone during welding makes it to be brittle - also hardening the adjacent and heat affected zones due to heating effect of the base metal resulting in many failure in this zone.

EFFECT OF HEAT TREATMENT ON THE MECHANICAL PROPERTIES OF WELDED JOINTS.

From tables 3 and 4, it is observed that tensile strength increases in the following order of heat treatment:

Annealed (ALD) > Quenched and Tempered at 600°C (QT_2) > Quenched And Tempered at 450°C (QT_1) > Normalized (NORD) > Quenched in Oil (Q).

Table 3: Unwelded but Heat Treated Steel

CODE	ELASTIC LIMIT(N)	YIELD STRESS(Nmm^{-2})	MAX. LOAD (N)	TENSILE STRENGTH(Nmm^{-2})
Q	5300	280.61	7400	377.35
QT_1	4300	219.39	5900	301.02
QT_2	4100	209.18	5600	285.71
ALD	3300	168.37	5200	265.31
NORD	4500	229.59	6500	331.63

TABLE 4. Heat Treated and Welded Steel.

CODE	ELASTIC LIMIT, N	YIELD STRESS Nmm^2	MAX. LOAD N	TENSILE STRENGTH Nmm^{-2}
Q	5000	255.5	6900	352.04
QT_1	4100	209.18	6100	311.22
QT_2	3900	198.98	5500	280.61
ALD	3600	183.67	4700	239.80
NORD	4800	244.90	6700	341.84

TABLE 5. Heat Treated and welded Steel.

CODE	Hardness
Q	85
QT_1	76.2
QT_2	73.3
ALD	68.13
NORD	74.

TABLE 6. Ductility.

CODE	UHT	HTW
Q	5.35	4.91
QT_1	15.08	14.11
QT_2	16.57	16.47
QLD	18.36	17.75
NORD	9.80	9.7

In table 6, ductility varies in the following order of increase:
Quenched in Oil(Q) > Normalized (NORD) > Quenched and Tempered at 450°C (QT_1) > Quench and tempered at 600°C > Annealed(ALD).

CONCLUSION.

From the results obtained, the following conclusion could be made: mechanical properties of the welded samples are lower than those of the unwelded, making them suspectable to mechanical failures. To a large extent, the heat treatment has considerably reduces the residual stresses developed in the steel during production process.

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