Influence of Heat Treatment on the Mechanical Properties of 0.13Wt%C Structural Steel.

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ABSTRACT

The mechanical properties of 0.13wt%C structural steel after intercritical normalizing heat treatments were investigated in the work reported here. The steel samples used for the present work were subjected to intercritical normalizing heat treatment at 740, 780, and 810^{o}C for 1, 2, 3, 4, and 5 hours at each temperature. The mechanical properties were determined. The results showed that for the steel under study higher intercritical normalizing temperature and longer holding time gave rise to lower strength and notch impact toughness properties but higher hardness and ductility properties. Hardness and toughness properties exhibited mirror behavior to each other.

(Keywords: intercritical normalizing; mechanical properties; temperature; holding time)

INTRODUCTION

New classes of the high-strength low alloy (HSLA) steels known as dual phase steels (DPS) are developed to improve safety standards and fuel economy. DPS microstructures are produced by intermediate annealing of steels in the $(\alpha + \gamma)$ region of the Fe-C equilibrium diagram. These steel microstructures consist of a ferrite matrix with particles of martensite [1-3].

Depending on the steel chemistry and processing parameters, lower bainite, pearlite may form and some untransformed austenite may be transformed from austenite to martensite, quenching from intermediate temperatures may be sufficiently rapid.

The structural properties of any metallic materials -with certain chemical composition - are functions of its microstructure. So the aim of any heat treatment technology is the improvement, or the control of mechanical properties by controlling the microstructure to suit the requirements restricted on a certain piece, even for use, or for subjecting to a forming or machining technology [7].

An effective heat treatment for improving the mechanical properties of low carbon steels is the intercritical heat treatment (IHT), in which the originals ferrite-pearlite structure, transforms to dual-phase structure of ferrite and martensite. In this treatment, the steel is annealed at a temperature within the intercritical zone (between AC_1 and AC_3) at where the pearlite and a part of ferrite (depending on temperature) transform to austenite, and then quenched or cooled in a high cooling rate to transform the austenite to martensite.

The higher the annealing temperature selected in this zone, the more austenite forms and transforms to martensite, but the less carbon content in this martensite [8-10].

The purpose of the present work was to investigate the effect of different intercritical heat treatments on the mechanical properties of 0.13wt%C structural steel.

MATERIALS AND METHODS

Materials

The initial materials were hot-rolled structural steel rods 16mm in diameter. The chemical composition (wt %) and the critical temperatures of steel investigated was as shown in Table 1. The critical temperatures (AC_1 and AC_3) were estimated with the empirical equations developed by Andrews [11, 12].

Methods

All the samples were made from the as hot-rolled 16mm steel rods and then they were heat treated: held in the temperatures 740, 780, and 810^{o}C for 1, 2, 3, 4, and 5 hours at each temperature and then air cooled to room temperature.

RESULTS AND DISCUSSIONS

The results of the various measurements are tabulated in Tables 2 through 5.

Table 1: Chemical Composition (wt %) of the Steel used, with its Critical Temperatures (calculated).

C	Mn	Si	Cr	Ni	S	P	AC_1	AC_3
0.13	0.44	0.16	0.01	0.15	0.004	0.002	721	830

Tables 2: Mechanical Properties of the As-Received Hot-Rolled Steel Samples.

σ_y N/mm^2	σ_t N/mm^2	δ %	H BHN	a_n J/cm^2
241	375	33	126	74.18

Table 3: Mechanical Properties of Steel Samples Intecritically Normalized at 740^{o}C for 1, 2, 3, 4, and 5 hour Holding Times.

Holding time hours	σ_y N/mm^2	σ_t N/mm^2	δ %	H BHN	a_n J/cm^2
1	277.13	481.46	63.78	128	102.25
2	266.28	473.76	74.36	136	91.07
3	248.84	462.33	82.87	144	83.76
4	244.13	450.03	90.05	157	76.37
5	231.66	444.80	98.53	165	68.66

Table 4: Mechanical Properties of Steel Samples Intecritically Normalized at 780^{o}C for 1, 2, 3, 4, and 5 hour Holding Times.

Holding time hours	σ_y N/mm^2	σ_t N/mm^2	δ %	H BHN	a_n J/cm^2
1	236.67	447.89	78.03	135	95.46
2	224.90	432.49	85.55	149	84.90
3	215.65	418.59	93.92	158	77.27
4	192.19	391.85	103.61	165	69.91
5	179.80	379.42	111.22	174	60.67

Table 5: Mechanical Properties of Steel Samples Intecritically Normalized at 810°C for 1, 2, 3, 4, and 5 hour Holding Times.

Holding time	σ_y	σ_t	δ	H	a_n
hours	N/mm^2	N/mm^2	%	BHN	J/cm^2
1	225.29	436.74	84.88	145	89.30
2	216.22	427.89	94.82	156	81.27
3	204.47	419.20	102.43	168	70.69
4	187.47	408.75	114.22	176	61.80
5	166.22	389.50	126.76	184	54.38

Figures 1-3 show the strength and ductility - holding time relationships of three groups of samples of steel intercritically normalized at different temperatures 740, 780, and 810°C and for various holding times 1, 2, 3, 4, 5 hours at each, respectively. Figures 4-6 show the relationships between holding time and hardness and toughness.

With increase in the normalizing temperature and holding time a decrease in strength and increase in ductility is observed which is due to the formation of a coarse ferrite-pearlite structure. The intercritical temperature and duration of the intercritical normalizing heat treatment should be as low as possible to ensure a fine-grained structure after intercritical normalization [13].

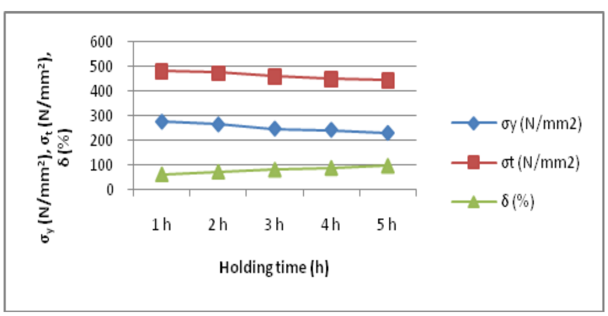

Figure 1: Strength and Ductility - Holding Time Relationship of Steel Samples Intercritically Normalized at 740°C for 1, 2, 3, 4, and 5 hours.

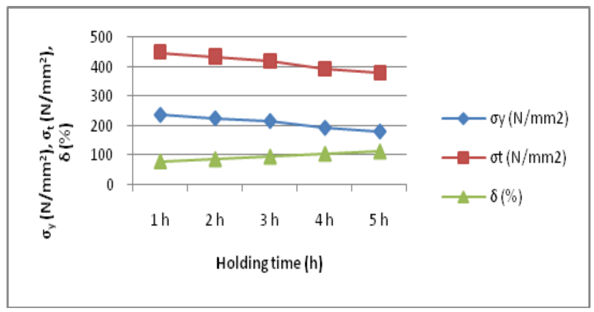

Figure 2: Strength and Ductility – Holding Time Relationship of Steel Samples Intercritically Normalized at 780°C for 1, 2, 3, 4, and 5 hours.

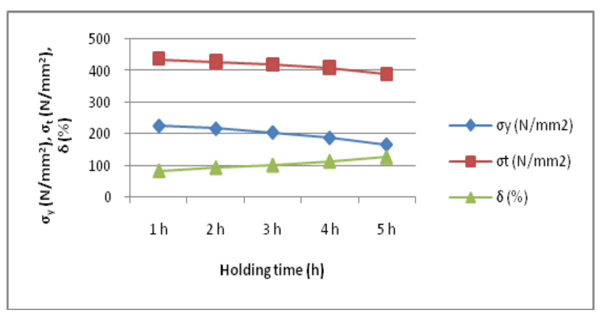

Figure 3: Strength and Ductility - Holding Time Relationship of Steel Samples Intercritically Normalized at 810°C for 1, 2, 3, 4, and 5 hours.

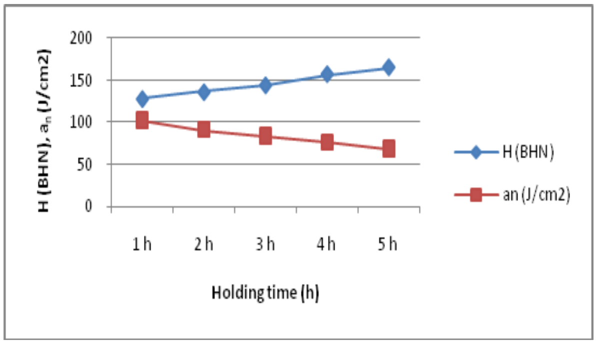

Figure 4: Hardness and Toughness - Holding Time Relationships of Steel Samples Intercritically Normalized at 740°C for 1, 2, 3, 4, and 5 hours.

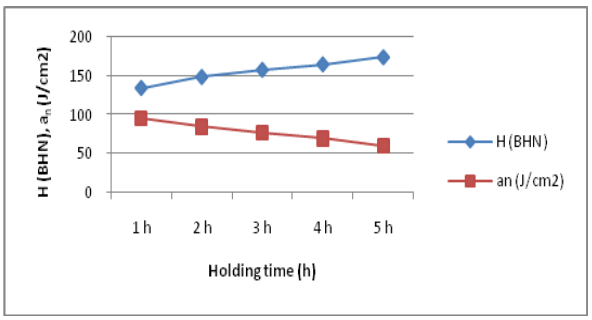

Figure 5: Hardness and Toughness - Holding Time Relationships of Steel Samples Intercritically Normalized at 780°C for 1, 2, 3, 4, and 5 hours.

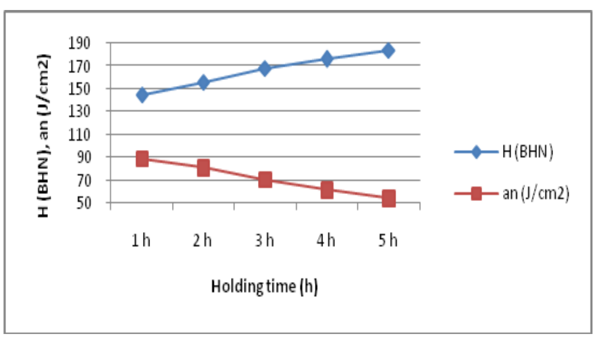

Figure 6: Hardness and Toughness - Holding Time Relationships of Steel Samples Intercritically Normalized at 810°C for 1, 2, 3, 4, and 5 hours.

With an increase in the normalizing temperature and holding time, a decrease in toughness and increase in hardness was observed. Hardness and toughness properties exhibited mirror behavior to each other. Hardness is well correlated with the solution heat treatment temperature and hardness increases with rising of the solution temperature [14]

A combination of superior hardness (to maintain a high degree of dimensional accuracy) and good toughness (to avoid fracture failure) is a basic requirement in engineering parts. Variation patterns need to be studied very closely to decide what optimum heat treatment strategy should be adopted to yield reasonably high hardness together with good toughness. As expected, hardness and toughness exhibit mirror behavior; if the hardness curve is decreasing - increasing the toughness curve shows an increasing - decreasing pattern [15].

By lowering the AC_3 temperature (from 910 - 830°C) the austenite stabilizing elements reduce the under cooling, and hence the driving force for transformation of austenite, at any lower temperature. This effect increases hardenability. On the same basis, ferrite stabilizing elements, because they increase undercooking, by reducing the AC_1 temperature (from 723 - 721°C), would be expected to decrease hardenability, but here another factor enters: most ferrite stabilizing elements tend to segregate between austenite transformation products to a greater extent than do the austenite stabilizers. The rate of austenite transformation is thereby delayed by diffusion of solutes. Other factors that may delay transformation are preprecipitation clustering of substitutional and interstitial solutes and solute drag by the advancing $\gamma - \alpha$ interface boundary [12]

CONCLUSIONS

The following conclusions are drawn from this work:

1. Higher intercritical normalizing temperature and longer holding time gave rise to lower strength and higher ductility properties.

2. High intercritical normalizing temperature and longer holding time gave rise to lower notch impact toughness but higher hardness properties.

3. Hardness and toughness properties exhibited a mirror behavior to each other.

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