EFFECTS OF VARIOUS QUENCHING MEDIA ON THE MECHANICAL PROPERTIES OF INTERCRITICALLY ANNEALED 0.15Wt%C – 0.43Wt%Mn STEEL

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ABSTRACT

Effects of various quenching media on the mechanical properties of intercritically annealed 0.15wt%C – 0.43wt%Mn were studied. Prequenching of a hot rolled low carbon steel was previously done from 900^{o}C (within the full austenitic range) using SAE 40 engine oil as quenchant. Sets of steel samples made from the previously quenched steel samples were intercritically heat treated from 750^{o}C to 810^{o}C at intervals of 10^{o}C for 1 hr in a laboratory muffle furnace and quenched in SAE 40 engine oil, water and brine quenchants respectively. The effects of quenching media used and the intercritical annealing temperatures on tensile, hardness, ductility and notch impact toughness properties are discussed. The quenching media increased the strength and hardness properties but decreased the ductility and notch impact properties of the original hot-rolled steel. Steel quenched in brine had the highest strength (708.02N/mm^2 at 810EC) and hardness values (233 BHN at 810EC) followed by those quenched in water (666.73 N/mm^2 at 810EC and 226 BHN at 810EC respectively) while those quenched in oil had the least values (618.56 N/mm^2 at 810EC and 215 BHN at 810EC respectively). Steel quenched in oil had highest ductility and notch impact toughness values (24.07% at 750EC and 22.8 J/cm^2 at 750EC respectively), followed by those quenched in water (20.33% at 750EC and 18.14 J/cm^2 at 750EC respectively) while those quenched in brine had the least values (16.49% at 750EC and 13.96 J/cm^2 at 750EC respectively). Higher intercritical annealing temperatures gave higher strength and hardness values (from 445.94 N/mm^2 at 750EC to 708 N/mm^2 at 810EC and from 165 BHN at 750EC to 233BHN at 810EC respectively), but lower ductility and notch impact toughness values (from 10.71% at 810EC to 16.49% at 750EC and from 7.38J/cm^2 at 810EC to 13.96J/cm^2 at 750EC).

Keywords: intercritical, mechanical properties, temperature, quenching media.

Symbol notation:
σ_y = yield strength, σ_t = tensile strength, δ= ductility, H = Hardness, BHN = Brinnel hardness number, a_n = notch impact toughness.

1.0 INTRODUCTION

Applications of steels for engineering components require a complete understanding of material properties and design requirements. Through the last few decades a category of steels known as high strength steels have undergone constant research [1, 2]. As a result, quenched and tempered microalloyed steels are most likely candidate materials for the next generation of high – strength steel sheets. For a given alloy content, quenched and tempered microalloyed steel exhibit good combination of strength and toughness [1-6].

Traditionally, quenched and tempered steel sheets are employed in automotive industry in the areas of structural members, power transmission and impact resistance systems. With the advent of dual – phase (DP) heat treatment, the possibility of introducing dual – phase treated sheets is becoming attractive proposition in those areas. Dual –

phase microalloyed steel consists of martensitic islands in a ductile ferrite matrix [1, 7, 8]. Their potential as superior strength and formability substitutes for current automotive steels was recognized and has provided an incentive for their rapid development and acceptance in this role [9].

It is necessary for an engineer engaged in testing work to have a general understanding of the common methods of testing properties of the metals. Mechanical properties are the most important requirements of the metals from the engineering point of view in selecting them for design purposes. Mechanical properties and microstructures of metals describe their behaviour under mechanical and physical usage [10 – 13]. The required mechanical properties can be altered by method of manufacturing process and heat treatment [14].

2.0 OBJECTIVES OF THE STUDY

The objectives of the present work were to investigate the effects of quenching media and intercritical annealing temperatures on the mechanical properties of prequenched 0.15wt% C - 0.43wt%Mn steel.

3.0 MATERIALS AND METHODS

3.1 Materials

The experimental material was a prequenched low carbon steel rod with a diameter of 16mm. The chemical composition (wt %) and the Critical temperatures of the steel materials are shown in table 1.

Table 1. The chemical composition (wt %) of the steel used, with its critical temperatures (calculated)

C	Mn	Si	Cr	Ti	P	AC_1	AC_3
0.15	0.43	0.37	0.17	0.02	0.001	732	839

The mechanical properties of the steel in its original state and after prequenching from 900°C are shown in table 2.

Table 2. The mechanical properties of the steel in its original state and after prequenching from 900°C

Mechanical properties	σ_y	σ_t	δ	H	a_n
-	N/mm^2	N/mm^2	%	BHN	J/cm^2
Original	242.13	426.28	36.58	141	72.64
After prequench	-	570.00	13.56	225	24.32

3.2 Methods

Test samples were prepared from previously prequenched heat-treated steel, grouped into sets and clearly marked. The prequenched heat-treated steel was produced by heating the original as hot-rolled 16mm diameter steel rods to 900EC in a laboratory muffle furnace and quenched to room temperature in SAE 40 engine oil. Each set of steel samples was intercritically heat treated from 750EC to 810EC at intervals of 10EC for 1 hour in a laboratory muffle furnace and quenched to room temperature in a prepared quenchant. Three quenchants were used SAE 40 engine oil, water and brine. The critical temperatures AC_1 and AC_3, which define the ferrite + austenite region, were calculated using empirical equations developed by Andrews [15, 16]. Properties investigated were the yield and tensile strengths, notch impact toughness and hardness properties. A 10 ton universal testing machine was used for tensile testing, Charpy impact testing machine for notch impact toughness testing and the Brinnel hardness method for hardness testing.

4.0 RESULTS AND DISCUSSIONS

The results of the various measurements are tabulated in tables 2, 3 and 4.

Table 3. Mechanical properties of sets of steel samples quenched in oil, water and brine after intercritical annealing heat treatment

T	σ_y oil N/mm^2	σ_y water N/mm^2	σ_y brine N/mm^2	σ_t oil N/mm^2	σ_t water N/mm^2	σ_t brine N/mm^2	δ oil %	δ water %	δ brine %
750EC	-	-	-	410.74	438.17	445.94	24.07	20.33	16.49
760EC	-	-	-	435.79	461.32	470.01	23.82	19.88	15.25
770EC	-	-	-	466.83	500.04	512.31	22.48	18.28	14.69
780EC	-	-	-	502.16	533.59	555.08	21.4	17.13	13.74
790EC	-	-	-	535.91	580.72	610.49	20.64	16.98	12.08
800EC	-	-	-	568.2	613.61	647.88	19.76	15.37	11.87
810EC	-	-	-	618.56	666.73	708.02	18.04	14.22	10.71

Table 4. Mechanical properties of sets of steel samples quenched in oil, water and brine after intercritical annealing heat treatment.

T	H oil BHN	H water BHN	H brine BHN	a_n oil J/cm^2	a_n water J/cm^2	a_n brine J/cm^2
750EC	150	157	165	23.41	18.14	13.96
760EC	160	165	174	22.81	17.85	12.04
770EC	170	175	183	21.43	16.33	11.36
780EC	180	185	198	20.76	14.36	9.75
790EC	190	200	210	19.16	13.14	9.09
800EC	204	215	222	17.23	11.67	8.47
810EC	215	226	233	16.33	10.04	7.38

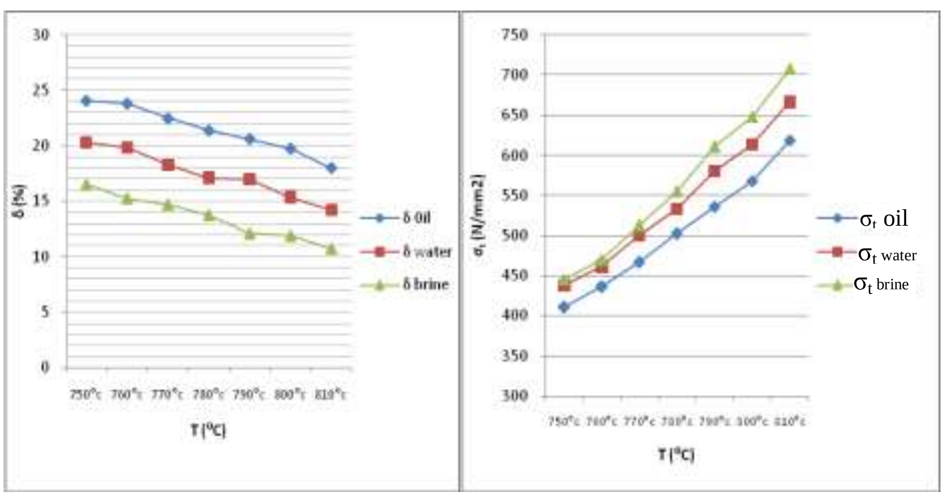

Figure 1. Strength and ductility – temperature relationships of sets of steel samples quenched in oil, water and brine.

Tables 2, 3 and 4 show that quenching in different media eliminated the yielding point, increased the tensile strength and hardness properties but decreased the ductility and notch impact toughness properties of the original hot-rolled steel sample.

Figure (1) shows the strength and ductility – temperature relationship of the three groups of steel samples intercritically heat treated from 750EC to 810EC at intervals of 10EC quenched in oil, water and brine. Table (3) and figure (1) clearly show that intercritical annealing temperatures and the quenching media had significant effect on the strength and ductility properties. Sets of steel samples quenched in brine had the highest strength values (708.02 N/mm^2 at 810EC) followed by those quenched in water (666.73N/mm^2 at 810EC) while those quenched in oil had the least strength values (618.56N/mm^2 at 810EC). Reversely, sets of steel samples quenched in oil had the highest ductility values (24.07% at 750EC) followed by those quenched in water (20.33% at 750EC) while those quenched in brine had the least ductility values (16.49% at 750EC). Generally, higher intercritical annealing temperature gave higher strength (from 445.94 N/mm^2 at 750EC to 708.02N/mm^2 at 810EC) but lower ductility values (from 10.71% at 810EC to 16.49% at 750EC). The mechanical properties improvement especially strength is (in compliance with Hall – Petch equation [13]) a function of the grain size of the transient phase (austenite), which depends on the heating and transforming rate and a function of the quality of the final structure, which depends on the cooling rate [17].

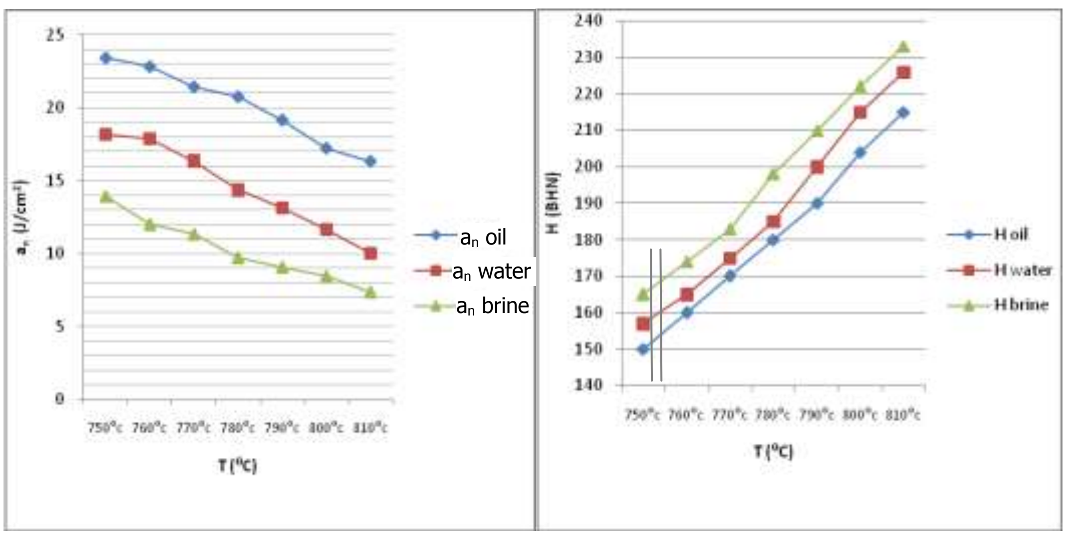

Figure 2. Hardness and notch impact toughnesss – temperature relationships of sets of steel samples quenched in oil, water and brine.

Figure (2) shows the hardness and notch impact toughness temperature relationships of the three groups of steel samples intercritically heat treated from 750EC to 810EC at intervals of 10EC and quenched appropriately in oil, water and brine. Table (4) and figure (2) clearly show that intercritical annealing temperatures and the quenching media had significant effect on the hardness and notch impact toughness properties. Sets of steel samples quenched in brine had the highest hardness values (233 BHN at 810EC) followed by those quenched in water (226 BHN at 810EC) while those quenched in oil had the least hardness values (215 BHN at 810EC). Reversely, sets of steel samples quenched in oil had the highest notch impact toughness values (23.41 J/cm^2 at 750EC) followed by those quenched in water, (18.14 J/cm^2 at 750EC) while those quenched in brine had the least notch impact toughness values (13.96 J/cm^2 at 750^{o}C). A close observation showed that higher intercritical annealing temperatures gave higher hardness values (from 174 BHN at 750EC to 233 BHN at 810EC) but lower notch impact toughness values (from 7.38 J/cm^2 at 810EC to 13.96 J/cm^2 at 750EC).

As the hardness decreased with increasing temperature, the toughness increased with corresponding increasing temperature in the corresponding quenching media thus indicating a mirror behavior by both properties. This is in line with an earlier report in literature [18] that hardness and toughness exhibit mirror behaviour, if the hardness curve is decreasing – increasing the toughness curve shows an increasing – decreasing pattern [18]

The contributions of hardening mechanisms in the martensitic structure according to [19, 20] include the solid solution hardening, the precipitation hardening, the primary austenitic grain size hardening and the martensite morphology hardening. The dominant hardening effect of martensite in dual phase steels is the carbon concentration in martensite [20].

5.0 CONCLUSIONS

- The quenching heat treatments increased the strength and hardness values but decreased the ductility and notch impact values of the original hot-rolled steel.
- The yield points of the quenched steel were eliminated.
- Steel quenched in brine had the highest strength and hardness, values followed by those quenched in water while those quenched in oil had the least values.
- Steel quenched in oil had highest ductility and notch impact toughness values, followed by those quenched in water while those quenched in brine had the least.
- Higher intercritical annealing temperatures gave higher strength and hardness values but lower ductility and notch impact toughness values.

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