MECHANICAL PROPERTIES OF THE INTERCRITICALLY ANNEALED 0.15Wt%C- 0.32 Wt%Mn STEEL AND QUENCHED IN SAE ENGINE OIL AT ROOM TEMPERATURE

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ABSTRACT

Mechanical properties of the intercritically annealed 0.15wt%C - 0.32 wt% Mn steel and quenched in SAE engine oil at room temperature were investigated. The steel samples prepared for quenching and those prepared for quenching and then tempering were intercritically heat treated at 750, 760, 770, 780 and 790EC for 1hr in a laboratory muffle furnace and quenched to room temperature in SAE 40 engine oil. The steel samples prepared for quenching and then tempering were further subjected to a low temperature tempering at 150EC for 1 hr and air cooled to room temperature. The results revealed that strength and hardness values increased (from 512.29N/mm^2 at 750EC to 674.62N/mm^2 at 790EC for strength and from 197BHN at 750EC to 241BHN at 790EC for hardness) with intercritical annealing temperatures but ductility and notch impact toughness decreased (from 12.18% at 750EC to 7.42% at 790EC for ductility and from 9.08 J/cm^2 at 750EC to 5.55 J/cm^2 at 790EC for notch impact toughness) with intercritical annealing temperatures. Tempered steel has yield strength values which increased with intercritical annealing temperatures from 180 N/mm^2 at 750EC to 258 N/mm^2 at 790EC. From the values it was observed that tempering gave rise to a decrease in tensile strength (from 674.62 N/mm^2 at 790EC to 637.65 N/mm^2 at 790EC) and hardness (from 241 BHN at 790EC to 190 BHN at 790EC) and an increase in ductility (from 7.97% at 750EC to 12.18% at 750EC) and notch impact toughness (from 9.08 J/mm^2 at 750EC to 76.76 J/mm^2 at 750EC) of the as quenched steel. Tempered steels from the values presented better compromise between strength, hardness, ductility and notch impact toughness for automobile and other structural applications.

Key words: Quenching, tempering, mechanical properties, intercritical annealing temperatures.

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

1.0 INTRODUCTION

Steel is the world's most used material. It is a very versatile material with a wide range of attractive properties which can be produced at a very competitive production cost [1, 2]. The optimization of alloying contents in the iron – carbon alloy system combined with different mechanical and heat treatments lead to immense opportunities for parameter variations and these are continuously being developed [1-3].

The development of new structural materials with good strength, impact and plasticity, which allow for weight reduction of cars, is still an open task for manufacturers. Up till now 63% of car body weight is made of steel structures [4].

Dual – phase steel (DP) is one of the family members of high strength low alloy steels which has a very good combination of strength and ductility. They are characterized by the microstructure consisting of the dispersion of hard martensite particles in a soft ferrite matrix. These steels are very important for the automobile industry and are important in many other application fields, especially in areas related to structural applications [5-12]. The dual phase steels are produced by reheating low carbon steel into the a intercrititical [α + γ] phase field, and cooling at a rate so as to produce the desired microstructure containing martensite phase. They can also be obtained directly from the hot rolled mill, by the control of composition and processing [5].

Dual phase steels have relatively high tensile strength, continuous yielding and low 0.2% offset yield strength and usually higher uniform and total elongation than other high strength steels. This combination of high tensile strength and good ductility is obviously a major point in favour of dual phase steels compared to other high strength steel [5].

The improvement of the mechanical properties of the low Carbon steel leading to increased strength was the goal of some heat treatment technologies developed in the last twenty years [13]. Their potential as superior strength and formability substitutes for current automotive steels, was recognised and has provided an incentive for their rapid development and acceptance [14]. This successful application has preceded the acquisition of a complete understanding of the detailed relationships between their process route, microstructure, and mechanical properties, although some research has been carried out in order to optimize the variables in the strength/formability balance [6, 15, 16]. However, the microstructural evaluations and mechanical properties of tempered dual phase steels is also of interest but has received little attention [1].

2.0 OBJECTIVES OF THE STUDY

The objectives of this work were to investigate the influence of various intercritical annealing temperatures and tempering on the mechanical properties of 0.15 wt% C - 0.32 wt % Mn steel. So the goal of this work was the finding of the intercritical annealing temperature range from which quenching produces better mechanical properties when combined with low temperature tempering.

3.0 MATERIALS AND METHODS

3.1 Materials:

For the experimental work, hot-rolled steel rod of 16mm (5/8 inch) was used. The chemical analysis of the steel is shown in table 1.

Table 1: Chemical analysis of the steel used (wt %) with its critical temperatures (calculated).

C	Mn	Cr	Si	Al	P	Ac_1	AC_3
0.15	0.32	0.03	0.14	0.04	0.004	728	810

The mechanical properties of the original as hot-rolled steel used is given in table 2.

Table 2: Mechanical properties of steel used.

σ_y(N/mm^2)	σ_t(N/mm^2)	δ(%)	H(BHN)	a_n(J/cm)
276.06	385.29	37.63	177	78.08

3.2 Methods

The samples used for the experimental work were machined from the hot-rolled steel rod. The steel samples prepared for quenching and those prepared for quenching and then tempering were intercritically heat treated at 750, 760, 770, 780 and 790EC for 1hr in a laboratory muffle furnace and quenched to room temperature in SAE 40 engine oil. The steel samples prepared for quenching and then tempering were further subjected to a low temperature tempering at 150EC for 1 hr and air cooled to room temperature to improve ductility and notch impact toughness. Estimation of the critical temperatures AC_1 and AC_3 was made using empirical equations developed by Andrews [17-19].

After the heat treatment of the test samples, tensile tests were carried out at room temperature using 10 ton universal testing machine. Brinnel hardness testing method was used to determine hardness while the Charpy impact testing machine was used for the determination of the notch impact toughness.

4.0 RESULTS AND DISCUSSIONS

The results of measurements made are tabulated in tables 2 and 3.

Table 3: Mechanical properties of heat treated steel samples.

TEC	σ_y q_s N/mm^2	σ_y t_s N/mm^2	σ_t q_s N/mm^2	σ_t t_s N/mm^2	δq_s %	δt_s %	H q_s BHN	H t_s BHN	a_n q_s J/cm^2	a_n t_s J/cm^2
750	-	180.18	512.29	449.13	7.95	12.18	197	148	9.08	76.76
760	-	191.43	541.47	503.91	6.85	11.01	213	154	8.16	73.05
770	-	213.27	596.84	558.22	5.64	10.17	221	166	7.94	70.04
780	-	232.82	631.96	614.48	4.86	8.84	232	177	6.27	66.01
790	-	258.57	674.62	637.65	4.22	7.42	241	190	5.55	61.94

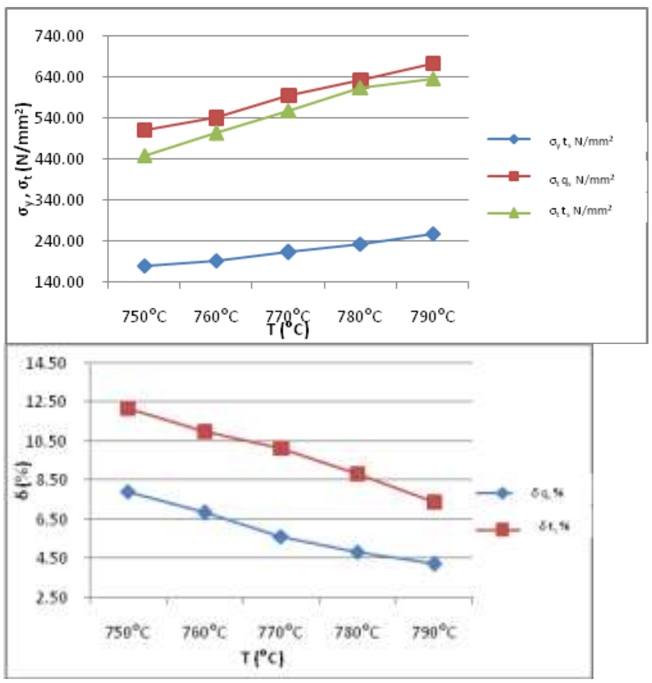

Figure 1. Strength and ductility – temperature relationships of heat treated steel samples.

Figure 1 shows the strength and ductility – temperature relationships of the steel samples prepared for quenching and those prepared for quenching and then tempering intercritically heat treated at 750, 760, 770, 780 and 790EC for 1hr in a laboratory muffle furnace and quenched to room temperature in SAE 40 engine oil. The steel samples prepared for quenching and then tempering were further subjected to a low temperature tempering at 150EC for 1 hr and air cooled to room temperature. Table 3 and figure 1 reveals clearly that intercritical annealing temperature and low temperature tempering had a significant effect on the strength and ductility values. Steel samples quenched in oil had higher tensile strength values (from 512.24N/mm^2 at 750EC to 674.62N/mm^2 at 790EC) than those subjected to low temperature tempering after oil quenching (From 449.13N/mm^2 at 750EC to 637.65N/mm^2 at 790EC). Conversely, steel samples tempered after oil quenching had higher ductility values (from 7.42% at 790EC to 12.18% at 750EC) than that quenched in oil but not tempered (from 4.22% at 790EC to 7.95% at 750EC). Also, the results show that higher intercritical annealing temperatures gave higher tensile strength values (from 512.29N/mm^2 at 750EC to 674.62N/mm^2 at 790EC) but lower ductility values (from 12.18% at 750EC to 7.42% at 790EC). The higher the annealing temperature selected in the intercritical temperature region the more austenite forms and transforms to martensite, but the less carbon content in this martensite [20]. The prediction of mechanical properties of dual phase steels based on mixture-role calculation [13] should take into consideration not only the volume fraction of martensite but also the variation of its properties due to variation of its carbon content by varying the annealing temperature. It is pertinent to note that steel samples tempered after oil quenching had yield strength values unlike those quenched but were not subjected to low temperature tempering. It is also of note that the yield strength values increased with intercritical annealing temperatures (from 180.18N/mm^2 at 750EC to 258.57N/mm^2 at 790EC). The large influence of the intercritical annealing temperature on the volume fraction of new ferrite can also be explained in terms of the austenite hardenability. A reduction in the intercritical annealing temperature will result in a smaller fraction of intercritical austenite, with higher carbon content and therefore higher hardenability. In consequence, this will lead to a slower epitaxial ferrite reaction. As the epitaxial ferrite reaction will be diffusion controlled, a higher carbon concentration will require more time to deplete the transformation front diffusionally [21]. Intercritical heat treatment is the way to enhance low alloys (carbon less than 0.2%) steels to dual phase microstructure with superior strength – ductility combination. This thermal treatment involved heating the specimens in intercritical temperature range to obtain ferrite and austenite followed by quenching to obtain dual – phase (martensite – plus – ferrite) structure [22].

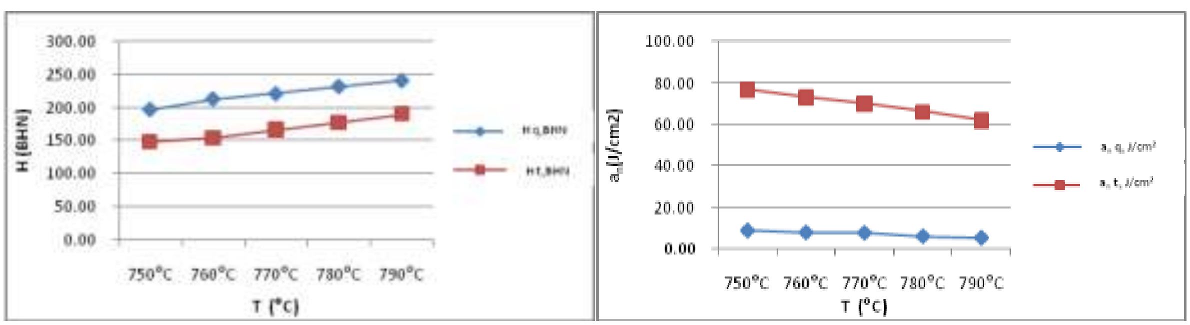

Figure 2. Hardness and notch impact toughness – temperature relationships of heat treated steel samples.

Figure 2 shows the hardness and notch impact toughness versus temperature relationships of the steel samples prepared for quenching and those prepared for quenching and then tempering were intercritically heat treated at 750, 760, 770, 780 and 790^o C for 1hr in a laboratory muffle furnace and quenched to room temperature in SAE 40 engine oil. The steel samples prepared for quenching and then tempering were further subjected to a low temperature tempering at 150^o C for 1 hr and air cooled to room temperature. Table 3 and figure 2 indicates that intercritical annealing temperature and low temperature tempering had a significant effect on the hardness and notch impact toughness values. Steel samples quenched in oil had higher hardness values (from 197 BHN at 750EC to 241 BHN at 790EC) than that subjected to tempering after oil quenching (from 148 BHN at 750EC to 190 BHN at 790EC). Contrarily, steel samples tempered after oil quenching had higher notch impact toughness values (from 61.91 J/cm^2 at 790EC to 76.76 J/cm^2 at 750EC) than that quenched in oil but not tempered (from 5.55 J/cm^2 at 790EC to 9.08 J/cm^2 at 750EC). Also, the results show that higher intercritical annealing temperatures gave higher hardness values (from 197 BHN at 750EC to 241BHN at 790EC) but lower notch impact toughness values (from 9.08 J/cm^2 at 750EC to 5.55 J/cm^2 at 790EC). By tempering process, the properties of quench steel could be modified to decrease hardness and increase ductility and impact strength gradually [1]. An increase in austenitizing temperature resulted in coarsening of the grain structure, increased dissolution of carbides, increased as quenched and tempered hardness capability, and decreased impact toughness [23].

5.0 CONCLUSIONS

- Strength and hardness values increased with intercritical annealing temperatures
- Ductility and notch impact toughness decreased with intercritical annealing temperatures
- Tempered steel has yield strength values which increased with intercritical annealing temperatures. As quenched steel has no yield strength values
- Tempering gave rise to a decrease in tensile strength and hardness and an increase in ductility and notch impact toughness of the as quenched steel
- Tempered steels presented the better compromise between strength, hardness ductility and notch impact toughness

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