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EFFECT OF PREHEAT TREATMENT STRUCTURE ON MECHANICAL CHARACTERIZATION OF AISI 4340 FERRITE BAINITE DUAL PHASE STEEL

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ABSTRACT

Present study attempts to establish comparison of ductility, hardness and impact strength of AISI 4340 steel between conventional treatments and special treatments (dual phase) where conventional treatments serve as preheat treatments. Dual phase treatment consists of partial austenitising and austempering at upper and lower bainitic temperatures (300 and 400°C respectively). Salt bath of $NaNO_2$ *and* $NaNO_3$ *mixture is used for isothermal holding in the bainitic temperature ranges. Dual phase steel contains different amount of high strength bainite phases within ferrite matrix depending upon the austenitisation temperature. On partially austenitising by heating in the intercritical temperature ranges, salt bath quenching followed by isothermal holding at 300°C gives lower bainite while upper bainite is forming by isothermal holding at 400°C. The mechanical characterization is executed as per ASTM standards and the results are analysed. It is observed that the mechanical property of normalized bainite is better than that of annealed bainite. Ductility of normalized is less compared to that of other conditions. Impact resistance of both bainitic phases obtained by different initial phases is higher as compared to bainite free structure. Normalized shows excellent hardness while ductility is maximum in annealed compared to bainitic phases.*

Keywords: AISI 4340; Austempering; Carbide Precipitation; Dual Phase steels; Lower Bainite

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1. INTRODUCTION

AISI 4340 is a type of high strength low alloy steel, its use in as cast condition may be limited due to poor machinability and toughness at room temperature condition. The properties of AISI 4340 can be improved by providing dual phase structures at room temperature by modifying quantity and morphology of phases. The initial room temperature phase has got strong impact on the property and morphology of two phases (Akbarpour, et al., 2010). Annealed structure shows coarser pro eutectoid ferrite and well defined pearlitic colonies with larger interlamellar spacing between two constituent phases of pearlite. The coarser room temperature structure on heating to intercritical temperature converts into coarser austenite with coarser proeutectoid ferrite remains unchanged. Coarser austeninte on austempering gives coarser ferrite and cementite phase mixture known as coarse bainite (Clark, et al., 2013). Similarly normalized structure has got fine pearlite structure, on austenitising provides the finer austeninte and intern gives fine bainite (ferrite and cementite phase) with finer pro eutectoid ferrite phase. In upper bainite, due to high transformation temperature, the incubation period of transformation is longer and carbon precipitation is incomplete inside ferrite regions. During lower bainite formation, the transformation is slower due to lesser kinetics, and carbon atoms precipitate easily inside the plates at enormous nucleation sites (Chuaiphan, et al., 2013). Both process involving transformation of austenite to bainite at constant temperature known as isothermal quenching. The preferred temperature of the quenching bath is generally on the lower side of the bainitic range (Khamedi, et al., 2014). This results in the formation of lower bainite which has better mechanical properties. Austempering results in better machinability compared to equilibrium phases and higher toughness and minimum distortion compared to hardened structure. Since bainite is formed at constant temperature (Manoj, et al., 2014), the properties of austempered steel are uniform throughout the section. Similar to ferrite - banite, ferrite - martensite duplex phase also possible by controlling the process parameters.

According to the literature related to dual phase steels, bainite-ferrite microstructure has better workability and reduced tensile properties than martensite-ferrite and full bainite structures. No considerable variations are observed in macro hardness of all the three grades mentioned above (Alaneme, et al., 2010). Tensile fractography shows marked increase in toughness of bainite-ferrite dual phase compared to ferrite-martensite and full bainite structures.

When dual phases with various ferrite volume fractions are fabricated by changing the soaking durations, the particular condition with increased ferrite volume percentage results decrease in yield strength with increase in ultimate tensile strength (Zhirafar, et al., 2007). The strain hardening index also decreases linearly with increasing ferrite volume fraction.

2. MATERIALS AND METHODS

2.1. Sample preparation

Table1 shows the composition (Spectrometry analysis) of AISI 4340 steel used for the preparation of test samples. All the test samples are divided in to four sets to study the change in their microstructure with progressive heat treatments. Set 1 and 2 constitute the samples which would be conventionally annealed and normalized respectively. Set 3 and 4 consist of samples which would undergo isothermal quenching at 300°C for austempering from normalized and annealed initial room temperature structures respectively. Three trials are performed for each test and the average of two constituent result trials are considered as the representative property result. Preparation of the tensile and impact test samples (ASTM-E8) is carried out on a CNC Turning Center and Vertical Milling Center respectively to ensure dimensional accuracy and good surface finish.

2.2. Normalizing and Austempering

The as-bought steel is first annealed by heating to 910°C for 2 h followed by furnace cooling (set1). For set 2, normalizing treatment is given by heating at 910°C followed by air cooling. For set 3 and 4 normalizing and annealing treatments respectively are performed initially and are further subjected to dual phase treatment by heating at 790°C for 2 h quenching and cooling isothermally in salt bath (60 wt. % $NaNO_3$ and 40 wt.% $NaNO_2$ mixture) and holding 350°C for 24 minutes (as referred from TTT diagram of AISI 4340 steel).

Table 1 Actual Composition (Wt. %) of AISI4340

Element	C	Mn	Si	S	P	Cr	Ni	Mo	Fe
Wt.%	0.39	0.55	0.18	0.04	0.04	0.91	1.33	0.23	96.33

2.3. Tensile Test

Tensile test of each sample is performed on a Computerized Fatigue Testing Machine with upper load limit of 50 kN. The results produced by the machine are in the form of plots of Displacement v/s Time and Load applied v/s Time. The data points obtained are imported into MATLAB to plot the Stress v/s Strain curves for each test samples. By analyzing the above plots yield strength, ultimate tensile strength, and % elongation at peak load are noted in each case.

2.4. Charpy Impact and Rockwell Hardness Test

Impact testing of each sample is carried out in a Charpy Impact Testing machine. The maximum Impact energy is set to 300 J. The cross sectional areas for each specimen below the notch are determined and impact strength data is calculated.

2.5. Microstructure analysis

The microstructure is recorded by Optical Microscope at 500X by series of sample polishing stages followed by etching with 5 vol% Nitol.

3. RESULT AND DISCUSSIONS

3.1. Tensile test result

All the samples of set 1, 2, 3 and set 4 are tested and stress v/s strain curves are analyzed. Yield strength, ultimate tensile strength, % of elongation are determined for further scrutiny. Figures 1 and 2 show the tensile data in different conditions. The strength analysis of duplex phase obtained by normalized structure (set 3) shows excellent result followed by simple normalizing then plain annealing (set1). This expected increase in the property is due to development of finer dual phase structure (Pouranvari, 2010). Average percentage elongation of set 3 is moderate but that of set 1 is found to be the highest.

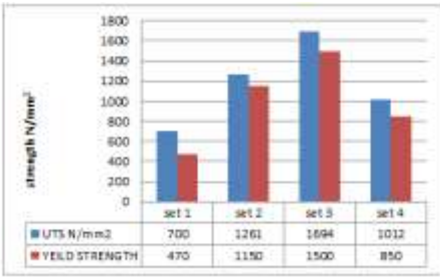

Figure 1 Tensile strength with respect to type of heat treatment.

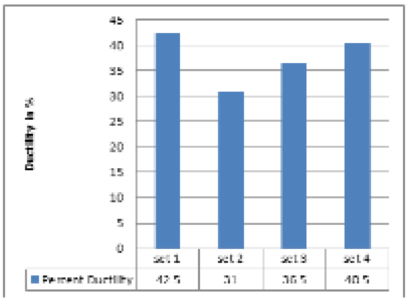

Figure 2 Ductility with respect to type of heat treatment.

While establishing a comparison between the microstructure obtained by different dual phases, the tensile strength characteristic of set 3 is found to be higher than that of set 4. This is due to the increase in bainite quantity with in the dual phase (Adediran, et al., 2015). The percentage elongation of set 4 is marginally higher than that of set 3.

3.2. Impact strength

Samples are tested in a Charpy impact testing machine to obtain the impact strength. Figure 3 shows the impact strength data for each condition of all the four sets.

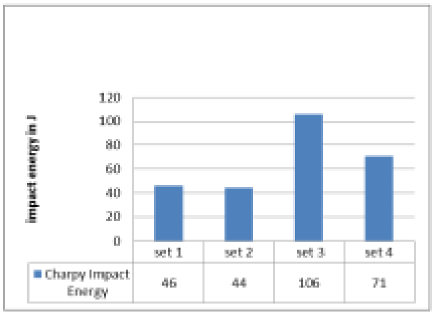

Figure 3 Impact strength with respect to type of heat treatment.

The toughness (impact strength) of set 3 samples is found to be higher than that of set 4. Comparing to set 1 and set 2, toughness of the former is found to be higher than the latter and is very less compared to set 3 and 4. This indicates that toughness of the specimens also increase by the dual phase treatment, but fineness of the phases dominating in the impact resistance values compared to coarser structure (Zhu, et al., 2014).

3.3. Hardness test results

The samples are tested for Rockwell hardness numbers. Figure 4 shows the hardness values for samples of each set in different conditions. The resistances to indentation value of austemperd samples are found to be moderate compared to high value of normalized one. This is due to the reduction in the interlamellar spacing of ferrite and cementite phases of pearlitic colony (shetty, et al., 2016). Resistance to indentation of set 3 is found to be more than that of set 4. This is due to the formation of finer bainite in the pro eutectoid ferritic matrix. Set 3 shows better hardness compared to set 4 because normalizing gives more wt. % of pearlite and on heating to intercritical temperature more wt. % of austenite forms which in turns produces more wt. % of bainite phase compared to that obtained from initial annealed structure (Set4).

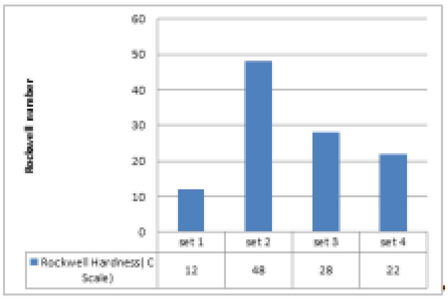

Figure 4 Hardness strength with respect to type of heat treatment.

3.4. Microstructure analysis

Annealed microstructure shows coarse grained pro eutectoid ferrite phase in the coarser pearlitic colony (Figure 5). Normalized shows finer pearlitic colonies embedded with finer proeutectoid-ferrite phases (Figure 6). Figures 7 and 8 show typical band like bainitic phases similar to martensite because characteristic of bainite in alloy steels resembles martensitic structure (Chuaiphan, et al., 2013). Annealed duplex bainite structure is comparatively coarser than that of normalized one.

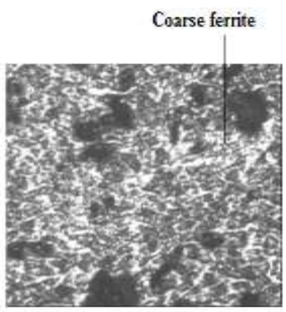

Figure 5 Set 1 microstructure

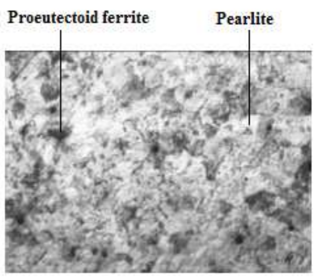

Figure 6 Set 2 microstructure

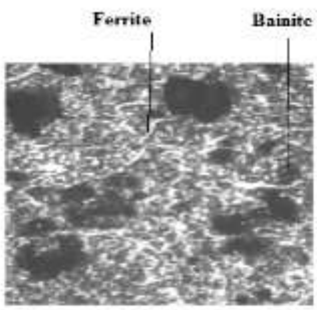

Figure 7 Set 3 microstructure

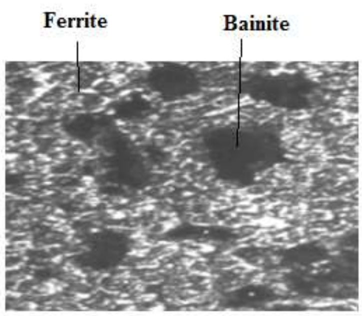

Figure 8 Set 4 microstructure

4. CONCLUSION

The AISI 4340 steel is successfully subjected to heat treatment with favorable property outcomes. Based on the present investigation study, AISI 4340 steel positively responds to dual phase (ferrite-banite) treatment.

- The bulk strength in tensile of normalized bainite is higher than that of annealed bainite but normalized shows in between.
- Percentage elongation of normalized is less compared to that of other conditions. Impact resistance of both bainitic phases shows higher value as compared to the other conditions and is least for annealed.
- Normalized shows excellent hardness compared to bainitic phases. Microstructure shows well difined ferrite and pearlitic colonies in annealed and finer in normalized but both austemperd show similar band like pattern.
- Microstructure of dual phase steel shows dark bainite discrete phases in ferrite matrix.

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