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Effect of Intermediate Cooling on Mechanical Properties of Spring Steel

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***Abstract*— The effect of intermediate cooling on the mechanical properties and microstructure of 1095 spring steel was studied and evaluated through Vickers hardness test, tensile test and optical microscopy. The proposed heat treatment procedures consisted of Austempering using salt bath furnace with molten salt as the heating medium, Austempering using a box furnace to provide a slower cooling rate, and finally a normalizing heat treatment. The results showed similarities in mechanical properties and microstructure which consisted of fine pearlite and ferrite, with the normalized specimen having a consistent microstructure with balanced grains and good strength compared to other normalized carbon steel, and the research concluded that this makes the normalized 1095 steel a good option for a number of engineering applications with moderate hardness and low cost.**

***Keywords*; Spring Steel, Heat Treatment, 1095, Normalizing.**

I. INTRODUCTION

1095 alloy is a high carbon steel used in applications where high tensile strength is needed and mainly in springs due to its ability to be hardened and achieve higher tensile strength compared to other carbon steel. 1095 alloy forms martensite quite easily when quenching using water or oil due to its high carbon content, and researchers experimented with different heat treatment protocols to enhance its mechanical properties [1].

when talking about heat treatments of steel the first thing that comes to mind is the process called hardening, which is the process that produces the most amount of martensite in the microstructure due to the rapid quenching that gives the highest strength for the material although at the expense of reducing its ductility, the rapid quenching prevents the carbon atoms from diffusing out of the iron crystal lattice and transforms the structure into a body-centered tetragonal called martensite that is super saturated with carbon [2].

On the other hand, researchers experimented with slower rates of cooling on different alloys to maintain the ductility of the parts while having reasonable tensile strength, Yi [3] experimented the slower cooling with medium carbon spring and managed to obtain an almost fully pearlitic microstructure which contributed to more ductility to the alloy, while Chaudhari and Kirad [4] tested 3 different cooling rates (fast 3.5^0C/S, medium 1.7^0C/S and slow 0.3^0C/S) on medium carbon steel and found the appearance of Bainite in fast to medium cooling and ferrite and pearlite in slower rates of cooling. Another form of moderate cooling is the Austempering process. Austempering is the process that involves quenching the part in another furnace to allow for a slow transformation under constant temperature. Liu et al. [5] used the austempering process on 55Si2MnMoV spring steel and recorded an increase of strength and elongation when austempering at 275^0C, and Li, Wang et al. [6] also studied the austempering process on a different kind of spring steel which is the 60Si2CrVNb spring steel, and found out that austempering this steel at 350^0C for 90 minutes resulted in a total elongation of 24%,

Toloczko, Santos et al. [7] investigated the effect of cooling rates on SAE 9254 spring steel and stated that slower cooling rates resulted in a mixture of microstructure consisting of Bainite and Martensite, while Hasan et al. [8] studied the effect of different tempering temperatures on spring steel. and finally, Wang et al. [9] studied the intermediate cooling and normalizing on P91 Steel and determined the resulting microstructure as martensite after normalizing.

As mentioned before, the higher carbon content in 1095 steel makes it interesting to study the effect of moderate quenching on it to achieve moderate strength suitable for a good number of engineering applications, while maintaining a higher percentage of the ductile microstructure whether it's pearlite or ferrite compared to martensite, the goal of this study is to experiment with different heat treatment procedures that deal with the moderate quenching and determine the resulting mechanical properties and microstructure, therefore, this study implemented an austempering process using a salt bath furnace, air furnace, and a normalizing heat treatment which cover the moderate quenching a steel part may encounter.

II. MATERIALS AND METHODS

A. Test Specimens:

1095 Steel was used in this research as the spring steel material and it has the chemical composition shown in (Table 1).

Table 1- Chemical Composition of 1095 Steel

Fe	C	Si	Mn	Cr	S
98.3%	0.91%	0.208%	0.42%	0.109%	<0.003%

B. Heat Treatment Procedures:

To achieve the main goal of this study, 3 heat treatments procedures were proposed and implemented:

- the first heat treatment procedure included heating the specimen using a salt bath furnace set at the austenization temperature 810^{0}C, holding at that temperature for adequate time, and then quenching the part in another salt bath furnace set at a temperature to allow for austempering (450^{0}C) for 1 hour, then cooling in air.
- the second heat treatment procedure consisted of heating the specimen to austenization temperature using a conventional box furnace at 810^{0}C, holding at that temperature for adequate time, then quenching the part using another box furnace at 400^{0}C for 1 hour, and finally cooling in air.
- The third heat treatment procedure included heating the specimen to austenitization temperature using a box furnace at 810^{0}C, holding for adequate time and then quenching in air (Normalizing).

Figure 1- Box furnace used in heat treatment with the austenization temperature set to 810^{0}C.

Figure 2- Salt bath furnace used in heat treatment with molten salt as the heating medium.

C. Hardness Test:

Metrology Vickers hardness tester VHT-A9010ED was used to measure the hardness of the specimens, this device is equipped with a screen and a microscope and 5 different points of the specimens surface were tested and the average reading was shown in the results.

METROLOGY

Figure 3- Vickers Hardness Tester VHT-A9010ED.

D. Tensile Test:

IBERTEST-IBMU4 was used to measure the mechanical properties of the heat-treated specimens.

Figure 4- IBERTEST-IBMU4.

E. Optical Microscopy to Evaluate Microstructure:

An optical microscope Nikon SMZ800 was used to evaluate the resulting microstructure in the steel after implementing the heat treatment procedures.

Figure 5- Nikon SMZ800.

III. RESULTS

A. Hardness Test:

The following table shows the Vickers hardness test results for the 3 heat treated specimens:

Table 2. Vickers hardness test results

Specimen	Hardness [HV]
Austempering at 450^{0}C (Salt Bath)	326
Austempering at 400^{0}C (Box Furnace)	321
Normalizing	315

B. Tensile Test:

The following table shows the results for the tensile tests conducted on the specimens:

Table 3. Tensile test results

Specimen	R_m [MPa]	$R_{p.02}$ [MPa]	Elongation [%]
Austempering at 450^{0}C (Salt Bath)	1073	915	2.110
Austempering at 400^{0}C (Box Furnace)	1059	890	2.214
Normalizing	1082	959	2.475

C. Microstructure Evaluation:

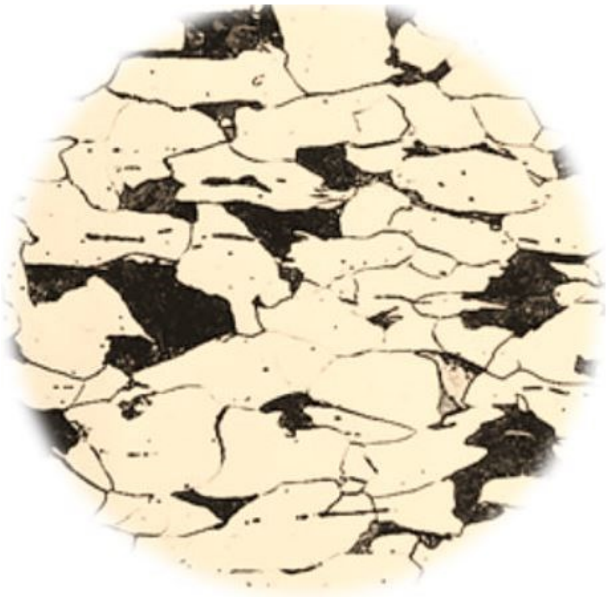

Figure 6- Austempering at 400^{0}C in Box Furnace. *[etching (5) ml HNO3 + (95) ml ethanol, x200]*

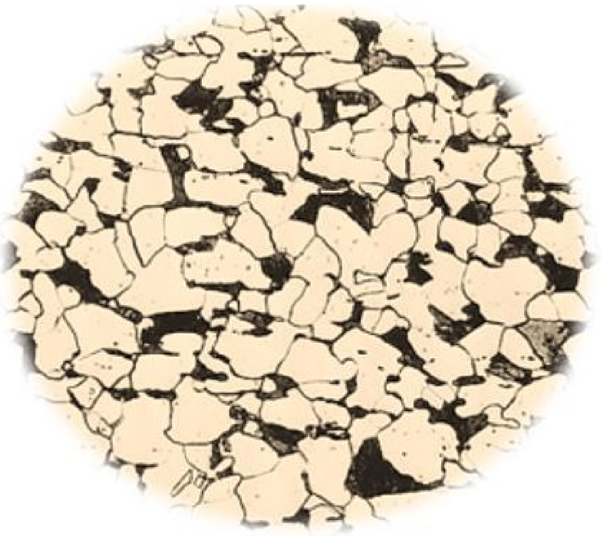

Figure 7- Normalized Specimen. *[etching (5) ml HNO3 + (95) ml ethanol, x200]*

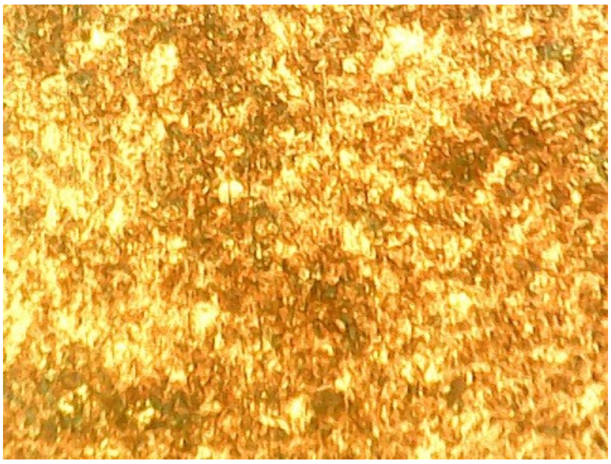

Figure 8- Austempering at 450^{0}C in Salt Bath, x200.

IV. DISCUSSION

The intermediate cooling in the proposed heat treatment procedures for the 1095 steel had close results in terms of mechanical properties and microstructure, meaning there is no significant importance of using the austempering process on this steel, as the normalizing process had similar mechanical properties and better microstructure, and taking the costs of austempering process into consideration due to the need of using other heat treatment furnace and the power consumption it can be said that it is better to either normalize the 1095 steel or do a normal hardening on it by quenching it in oil or water.

The results for the normalized specimen were interesting as the resulted mechanical properties are better compared to other carbon steel that had been normalized, and it can be said that this steel can be used in its normalized state in some engineering applications because it possessed good tensile strength and good yield strength with moderate hardness.

There was no significant difference between using the salt bath furnace that uses molten salt as the heating medium and the box furnace when austempering the 1095 steel, as the former furnace has somewhat faster cooling rate because of the direct contact between the heat-treated part and heating medium, this increase in cooling rate wasn't enough to produce finer pearlite or bainite than the box furnace specimen.

The microstructure that was produced in 1095 steel after intermediate cooling using the proposed heat treatment procedures were fine pearlite and ferrite, and the normalized specimen had a consistent grain structure with grains of similar shapes and sizes and this explains the good mechanical properties of the material.

V. CONCLUSIONS

The effect of intermediate cooling on the properties and microstructure of the 1095 spring steel was studied and evaluated through Vickers hardness test, tensile test, and optical microscopy. it was found that the austempering process and normalizing had similar mechanical properties and microstructure consisted of fine pearlite and ferrite, with the normalized specimen having a consistent microstructure and balanced grains that gave it good mechanical properties compared to other normalized carbon steel. It was also concluded that the good mechanical properties of the normalized 1095 steel make it a good choice in some engineering applications that require moderate hardness and good strength with minimal effort and heat treatment costs.

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