# Effects of Holding Temperature and Time for Austempering on Impact Toughness of Medium Carbon and High Alloy Steel

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***Abstract*** **- Influence of austempering holding temperature and time on hardness and impact toughness of medium carbon and high alloy steel has been studied. The austempering heat treatment produced bainitic structures. The best impact toughness values are achieved when the parts austempered for 1 hour at 325 °C.**

***Keywords*** **- austempering, medium carbon and high alloy steel, impact toughness**

## 1. INTRODUCTION

The medium carbon, high alloy steels are heavily used in military applications in the production of barrels, rifles, tank guns etc. due to their superior mechanical properties. The importance of toughness for these applications is that, they should resist sudden and unstable cracks, which occur without any warning in brittle materials. So the minimization of distortion and obtaining tougher steel needed to be obtained, which is possible by heat treatment.

Austempering is an isothermal heat treatment alternative to conventional quenching and tempering, during which the steel is heated to the austenitic phase and then quenched to a temperature above martensite start (Ms) with the aim of obtaining bainite instead of martensite [1]. Austempering is usually a preferred heat treatment especially to conventional quenching and tempering. This is mainly because the treatment offers [2]:

- improved mechanical properties (particularly higher ductility or notch toughness at a given high hardness)
- a reduction in the likelihood of distortion and cracking which can occur in martensitic transformations.

The microstructural classification of bainite as “upper” and “lower” is an extremely well established characterization. This classification is basically based on the morphology of the structures that results by different transformation characteristics because of the different temperatures at which the structures form. Basically upper bainite forms at higher temperatures, whereas lower bainite forms at relatively lower temperatures. This difference results in clear differences in mechanical properties of upper and lower bainite [3]. The main microstructural difference between upper and lower bainite is the carbide precipitation. In upper bainite, since the transformation temperature is high, the process is fast, thus carbon atoms do not have sufficient time to precipitate inside ferrite plates. On the other hand, during lower bainite formation, the reaction is slow due to relatively lower temperature, and thus, there is an opportunity for carbon atoms to precipitate inside the plates.

In this study, the effect of austempering parameters (time and temperature) on the mechanical properties related to medium carbon and high alloy steels has been investigated.

## II. EXPERIMENTAL PROCEDURE

The material used in this experimental study is medium carbon and high alloy steel. The chemical composition is given Table 1.

**TABLE I**
**CHEMICAL COMPOSITION OF THE MATERIAL**

| Material | C | Mn | Si | P | S | Cr | Ni | Mo | V |
|---|---|---|---|---|---|---|---|---|---|
| % | 0.37 | 0.48 | 0.32 | 0.007 | 0.004 | 1.30 | 2.98 | 0.42 | 0.09 |

The ASTM standard dimensions for charpy V-notch test specimen are 10x 10x50 mm. Due to the fact that the chemical composition of AISI 4340 steel is similar to that of medium carbon and high alloy steel; TTT diagram of 4340 steel [4] is used as a reference during this study. The following empirical formula [2] is used to estimate the Ms temperature. The result is as follows:

$$M_s = 500 - (300\times\%C) - (33\times\%Mn) - (22\times\%Cr) - (17\times\%Ni) - (11\times\%Si) - (11\times\%Mo)$$

(in $^0$C)

For specimens, the calculated Ms temperature is 285.76 °C.

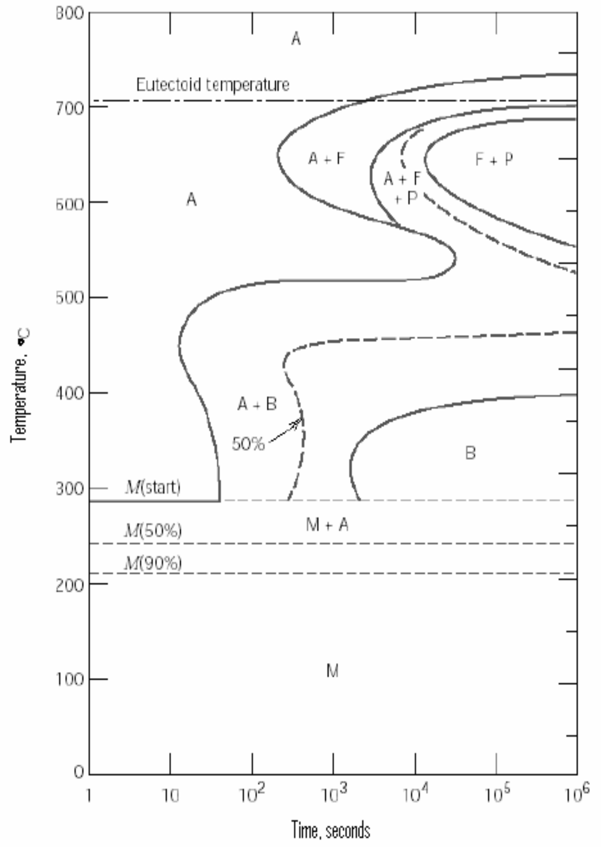

**Fig. 1. Time-Temperature-Transformation diagram of AISI 4340 steel**

As a result of a thorough literature review and careful interpretation of the TTT diagram of AISI 4340 steel, three austempering temperatures and four time intervals are selected (Table II). The austenitizing temperature and time are 850 °C and 1 hour. Austempering is applied within a salt bath heated to the desired temperature. Quenching media is water (Fig. 2).

TABLE II

AUSTEMPERING TEMPERATURES AND TIMES

| | | | | | |
|---|---|---|---|---|---|
| Charpy specimen | 350$^0$C | 1 min | 10 min | 1 hr | 10 hr |
| Charpy specimen | 325$^0$C | 1 min | 10 min | 1 hr | 10 hr |
| Charpy specimen | 300$^0$C | 1 min | 10 min | 1 hr | 10 hr |

The standard ASTM procedure defined with designation number E 23-93a (Standard test methods for notched bar impact testing of metallic materials) was employed in this study. The test consists of measuring the energy absorbed in breaking, by one blow from a pendulum. The standard ASTM procedure defined with designation number E18–1989 was applied by using a digital Rockwell hardness tester in C scale under a major load of 150 kgf.

Optical microscope was used to analyze the microstructures obtained at the end of heat treatments. A JEOL, JSM-6400 electron microscope was employed for detailed analyses of the microstructures obtained.

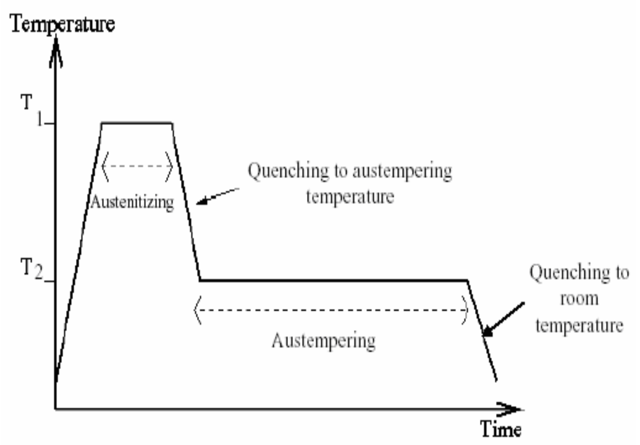

**Fig. 2. Austempering**

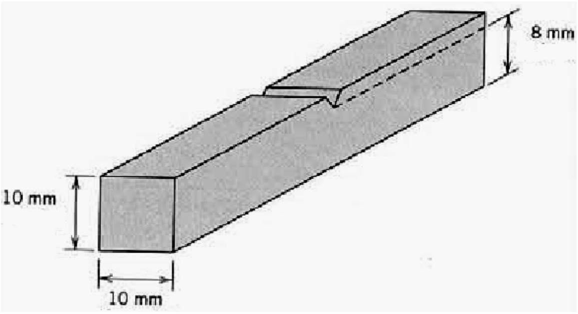

**Fig. 3. .Dimensions of Charpy specimen**

## III. RESULTS AND DISCUSSION

Three test specimens were tested and the averages of the three readings were used to plot the graphs.

### *A. Effect of Austempering on the Hardness*

The hardness of as-received specimens is approximately 39 HRC. The effect of austempering on the hardness is shown in Fig. 4. The existence of the hard and brittle phase martensite is the main reason of the higher hardness values obtained. At all transformation temperatures, hardness values decreased as isothermal holding time increased. This was due to the transformation of austenite to bainite. As isothermal holding time increased, the amount of bainite in the microstructure increased. As the amount of bainite increased, there was less austenite to transform to martensite during quenching following austempering. As a result, there occurred a decreasing trend in hardness as austempering time increases. Fine grain size, high carbide precipitation and high dislocation density are the main factors that make bainite stronger. These factors increase with decreasing austempering temperature.

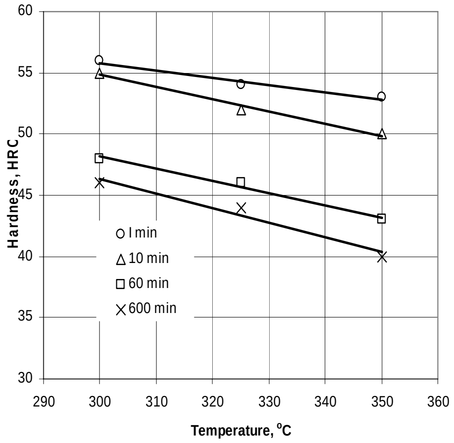

**Fig. 4. Effect of austempering on the hardness**

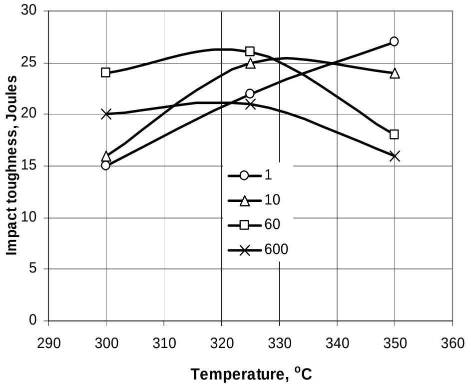

**Fig.5. Effect of austempering on the impact toughness**

The effect of austempering on the impact toughness is shown in Fig. 5. The impact toughness of the original specimens (as received) is 38 joules. As received samples have undergone normalization, quenching and tempering which made the steel tougher than the austempering treatment applied. For austempering time of 1 minute, the increasing trend in toughness values was observed with increasing temperature. The increasing trend of toughness values was also observed for austempering time of 10 minute, 1 hour and 10 hour transformation up to temperature $325^0$C. For austempering time of 10 minute, 1 hour and 10 hour and austempering temperature of 350°C, the toughness values measured were lower than the values obtained at temperature $325^0$C. The important factor that affects the toughness in austempered structures is the packet size. The number of packets increases as the holding time increases. As the number of packets increase, the dimensions of the bainitic colonies decrease. Therefore, there exist more packets with smaller colonies. As a result, more bainite was formed as isothermal holding time increases. Bainite has a tougher structure as compared to martensite. Consequently, it is observed that the toughness of the steel increases as austempering time increases until some point.

### *B. Microstructural Characterization*

The microstructural interpretations of the above mechanical studies are investigated by means of optical and electron microscopy. From the examination of the reference TTT diagram used in this study reveals that the martensite start temperature of the steel is around 280 °C. Therefore, lower bainite is expected to grow at 300 °C. As in Fig. 6, 1 minute isothermal transformation at 300 °C reveals both bainitic and martensitic structures. After austempering at 325 °C for 1 minute, the microstructure displays a mixed structure of bainite and martensite that is obtained. Mechanical tests revealed the same with higher toughness values than the specimens transformed at 300 °C for 1 minute. The structure obtained at 350 °C after 1 minute transformation displays the mixed structure of bainite and martensite. The highest amount of bainite is observed as compared to its counterparts at 300°C and 325°C.

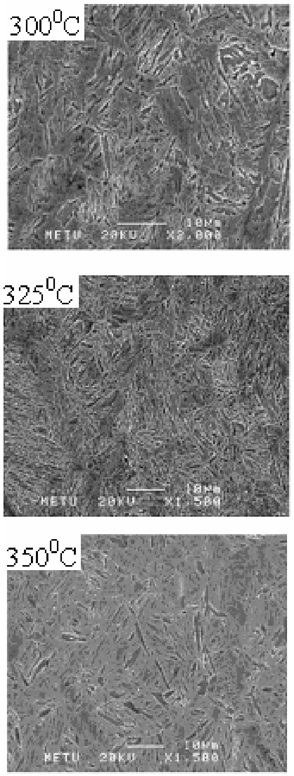

**Fig. 6. Microstructures of austemperted specimens for 1 min**

The structure obtained after austempering at 300°C for 10 minutes of transformation is partially bainitic and partially martensitic (Fig. 7). Bainite sheaves grow parallel to each other and appear as long finger like parallel forms, both light and dark. Martensite also forms because the specimen is quenched after 10 minutes. After 10 minutes of transformation. Elongated bainite sheaves and martensite plates are seen at 325°C. For austempering temperature, the highest amount of bainite is revealed as compared to its counterparts at 300°C and 325°C.

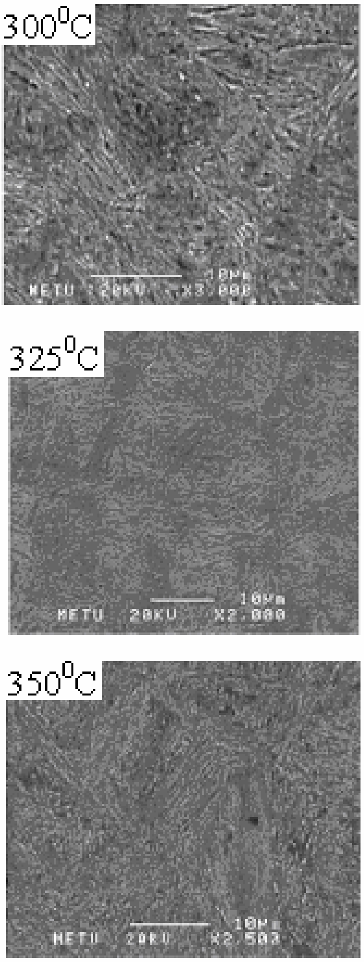

**Fig. 7. Microstructures of austemperted specimens for 10 min**

The structure obtained after 10 hours of transformation displays the acicular shaped bainitic structure (Fig. 8). Although it is hard to distinguish between bainite and martensite at this resolution, bainite is the main constituent here. The microstructure after 10 hours of transformation at 350$^0$C shows finger-like parallel bainitic structure. The microstructure transformed at 350 °C for 10 hours shows that the bainitic structures are deformed and lost its sheaf shape almost completely. Coarsening is also occurred.

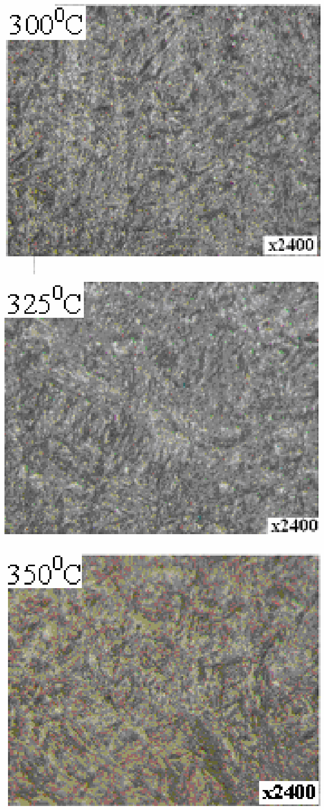

**Fig. 8. Microstructures of austemperted specimens for 10 hr**

## IV. CONCLUSION

All three austempering temperatures produced bainitic structures. Highest impact toughness values are measured at 300 °C and 325 °C for 1 hour isothermal holding period. Hardness decreased with increasing austempering time. On the other hand, as isothermal transformation temperature increased, it was observed that hardness values decreased. The best mechanical properties are achieved when the parts austempered for 1 hour at 325 °C.

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