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Austempering of DIN CK50 and DIN 62SiMnCr4 In Molten Lead Bath

Raid Kadhim Salim **Adnan Naama Abood**
Technical-College/Baghdad

Abbas Yass Awad
Ministry of Science and Technology

Omar Saad Salih
Technical-College/Baghdad

Barzan Akram Hama
Sulimania Technical College

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ABSTRACT

This work aims to study the ability of austempering DIN CK50 and DIN 62SiMnCr4 steels. Both steels were heated to austenitising temperature and then quenched in a molten metal bath (pure lead) at temperature below the nose of the TTT curves for both steels. Results showed that austempering at 350°C and 400°C for 30 and 15 minutes are the best for above steels respectively, where strength was increased. It was also shown that increasing holding (soaking) time decreases both hardness and strength and increasing elongation percentage. Microstructure examination showed that the majority of microstructures obtained from austempering vary from bainite and pearlite and ferrite for carbon steel to a mixture of bainite, retained austenite and martensite for the alloy steel.

Keywords: Austempering, molten metal bath, bainite, retained austenite, martensite.

التطبيع الأوستنايتي للفولاذ (DIN CK50) والفولاذ (DIN 62SiMnCr4) في حوض منصهر الرصاص

الخلاصة

يهدف البحث دراسة قابلية إجراء التطبيع الأوستنايتي للفولاذ (DIN CK50) والفولاذ (DIN 62SiMnCr4). سخن كلا الفولاذيين إلى درجة حرارة الاستنة ثم التقسيه في حوض منصهر معدني (رصاص نقي) عند درجات حرارية تحت مقدمة منحيات (T.T.T) لكلا الفولاذيين . أظهرت النتائج أن التطبيع الأوستنايتي عند درجة حرارة 350 و 400° والأزمان 30 و15دقيقه هما الأمثل لكلا الفولاذيين وعلى التوالي حيث ازدادت مقاومة الشد . لوحظ أيضا إن زيادة زمن التثبيت يخفض الصلادة ومقاومة الشد بينما تزداد المطيلية. بين الفحص ألمجهري إن البنية الرئيسة الناتجة من هذه المعاملة للفولاذ الكربوني كانت باياnait وبرلايت بينما كانت البنية للفولاذ ألسبائكي خليط من البايانايت والاوستنايت المتبقي والمارتنزايت.

INTRODUCTION

Austempering is an isothermal heat treatment alternative to conventional quenching and tempering, during which the steel is heated to the austenitic phase then quenched to a temperature above martensite start (M_s) with the aim of obtaining bainite instead of martensite . Isothermal transformation takes place until all of the austenite transforms to bainite and then air-cooled. Austempering procedure helps minimization of residual stresses and easier to achieve dimensional stability. Thus, it is easier to produce a structure that is tougher than comparable structures produced by quenching due to the fact that the phase transformation is uniform and the structure contains bainite [1-6]. M. A. Sh [7] showed that the austenitizing temperature controls the carbon content of austenite affects the structure and properties of austempered steel. Austenitizing temperature should be minimum required to heat the entire part to the desired temperature and to saturate the austenite with equilibrium level of carbon. Austenitizing time is affected by chemical composition, austenitizing temperature and section size. The preferred temperature of the quenching bath is generally on the lower side of the bainitic range resulting in the formation of lower bainite which has better mechanical properties than tempered martensite [8-11]. Thermodynamic studies indicate that as transformation temperature lower below 400°C, the kinetic resistance of ferrite diffusion growth is higher than the possible maximum driving force of transformation; the ferrite cannot grow with the growth rate obtained from diffusion. Below 500°C, resistance of ferrite shear growth is lower than the driving force of transformation; therefore below this temperature it is advantageous for the shear growth of the ferrite. At temperature range of 400 – 500°C, the overlap of the growth of two mechanisms appears. When the steels contain silicon at levels above the usual impurity level, it is found to have a significant effect on bainite. It causes the bainite in these metals to contain significant amounts of retained austenite, reduced amounts of carbides, and it changes the type of carbide in the lower bainite from cementite to $Fe_{2.5}C$ (epsilon carbide)[12-15]. S. G. Chowdhury [16] found that the bainitic structure in high silicon steels consists of bainite plates and/or inter-lathe thin films of carbon-enriched retained austenite instead of carbide because silicon strongly retards the formation of carbide, that film was most desirable morphology. The amount of retained austenite present, after quenching from austenitising temperature, depends on the composition, cooling rate, austempering temperature and time. It has been reported that the austenite retention was especially promoted by addition of Mn that stabilized austenite and Si retarded cementite formation.

MATERIALS AND PROCEDUERS

Two types of steels were used in this work, DIN CK50 and DIN 62SiMnCr4 Fig.1-2, with microstructure of pearlite and ferrite . Their chemical compositions are shown in Table 1.

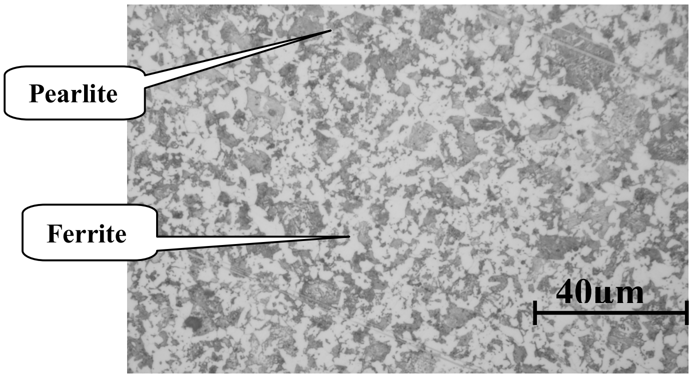

Figure 1: Microstructure of DIN CK50

For heat treating both types of steel rods were cut to a cylindrical shape of 19mm length and 10mm diameter. Tensile test samples were prepared according to ASTM E8M standard. A molten lead (Pb) bath was prepared for austempering since its melting temperature is below the nose of the TTT curve for both steels also it does not react with steel.

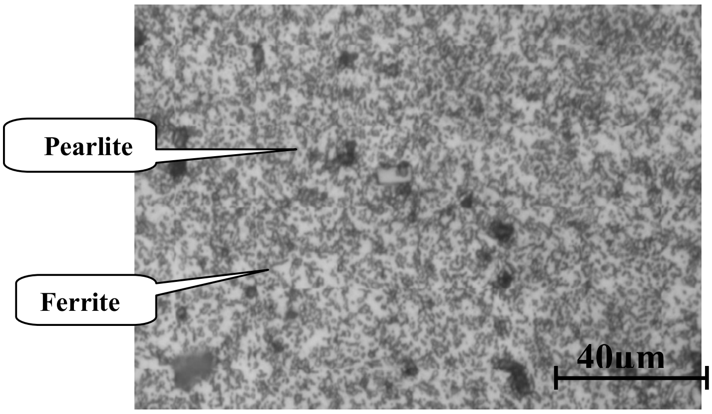

Figure 2: Microstructure of DIN 62SiMnCr4

Table 1: Chemical composition of steels, wt%

Material \ Element	%C	%Si	%Mn	%Cr	%Mo	%Ni	%P	%S	%Fe
Nominal chemical composition DIN CK50	**0.47-0.55**	**0.4**	**0.6-0.9**	**0.4**	**0.1**	**0.4**	**0.04**	**0.035**	**Bal.**
Actual chemical composition DIN CK50	**0.49**	**0.39**	**0.89**	**0.15**	**0.03**	**0.07**	**0.029**	**0.027**	**Bal.**
Nominal chemical composition DIN 62SiMnCr4	**0.58-0.66**	**0.9-1.2**	**0.9-1.2**	**0.4-0.7**	**------**	**------**	**0.04**	**0.03**	**Bal.**
Actual chemical composition DIN 62SiMnCr4	**0.64**	**1.11**	**1.01**	**0.62**	**------**	**------**	**0.023**	**0.013**	**Bal.**

Bainitic and martensitic transformation temperatures (B_s, M_s) were calculated according to the following empirical equations [17]:

B_s = 830-270wt%C-90wt%Mn-37wt%Ni-70wt%Cr-83wt%Mo …….. 1

Where, B_s is the bainitic transformation start temperature (^oC).

M_s =531-391.2wt%C-43.3wt%Mn-21.8wt%Ni-16.2wt%Cr ……… 2

Where, M_s is the martensite transformation start temperature (^oC).

Samples were heated to the austenite region at a temperature of 850^{o}C, soaking at this temperature for 25 minutes. Samples were immediately transferred to the molten bath, holding at this bath for five duration times: 10,15,20,30 and 45 minutes at different temperatures: 350,400,500,550 and 590^{o}C for DIN CK50 steel and 400, 450 and 500^{o}C for DIN 62SiMnCr4 steel ,then air cooled to room temperature. All samples were ground using ASTM grits 120 to 2000 emery papers, polished with Al_2O_3, alcohol washed, dried then etched with 2% nital.

RESULTS AND DISCUSSION

1-Austempering of DIN CK50

The computed value of B_s temperature for this steel (equation-1) is 590^{o}C. It was found that austempering at this temperature increases hardness slightly without noticeable change in other properties. TTT curve of this steel, Fig.3 , shows that this temperature is near to the nose of the curve promoting austenite transformation to pearlite ,fig.4, moreover, the M_s temperature is around 320^{o}C, so the temperature range of 350-590^{o}C was used in austempering. Fig. 5 indicates that austempering at 350^{o}C for 30 minute gives higher hardness with a maximum value of 320HB. The structure results from the isothermal transformation at 350^{o}C for 30 minutes is bainite and some pearlite and ferrite ,fig.6, it is very hard to get full bainitic structure in this type of steel since its TTT curve has a nose close to the left side, when quenching in lead path, pearlite formed at the beginning then the remaining austenite transformed to bainite [17].

After 30 minutes hardness decreases, so at prolonged periods, bainite sheaves losing to their shapes in addition to coarsening. Also tensile strength of this steel (austempering at 30min.) was increased from 748 MPa (as received) to 1056 MPa with an increment of 41%. Elongation percentage was decreased from 22.3 to 14%. Austempering at 590^{o}C did not affect the microstructure and remained pearlite and ferrite, Fig.4.

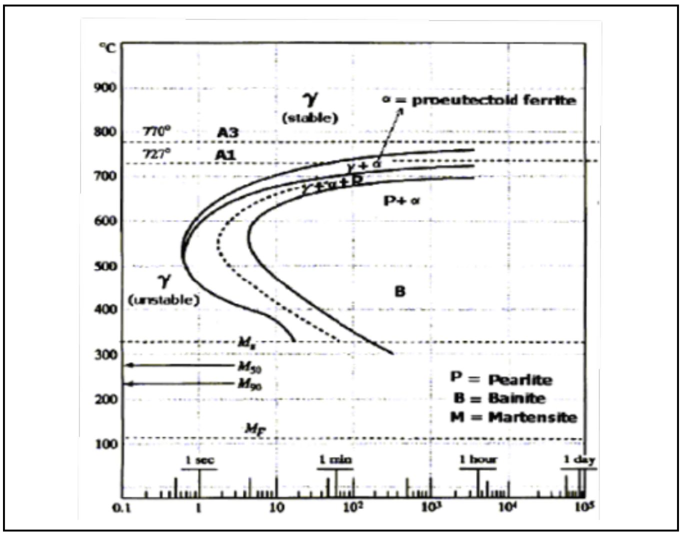

Figure 3: TTT diagram for DIN CK50[6]

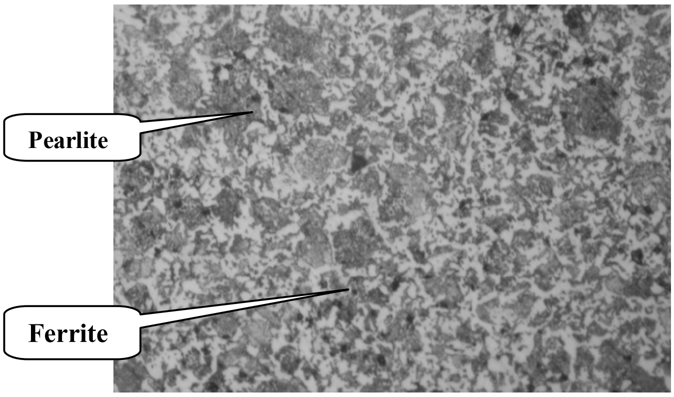

Figure 4: Microstructure of austempered CK50 steel at 590°C for 30 min.

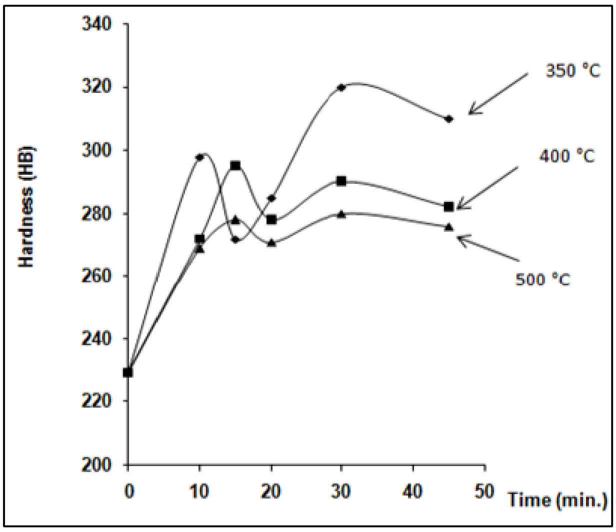

Figure 5: Effect of austempering time and temperature on hardness of DIN CK50

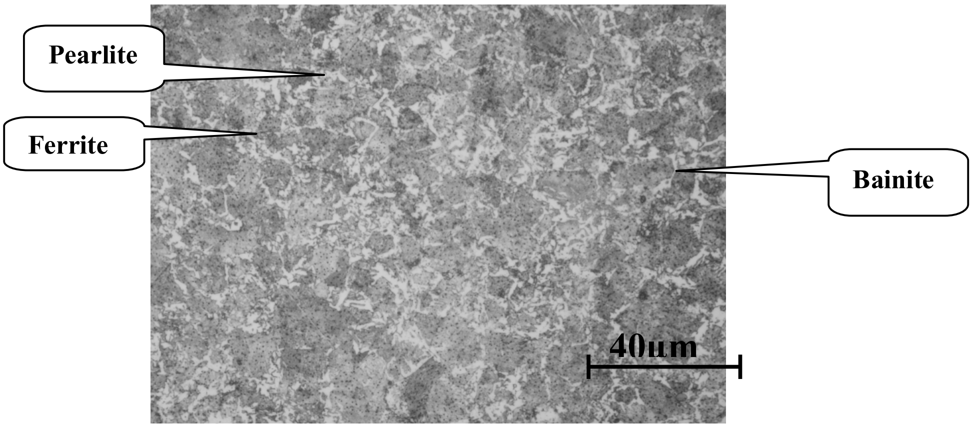

Figure 6: Microstructure of austempered CK50 steel at 350°C for 30 min.

2- Austempering of DIN 62SiMnCr4

The bainitic start transformation temperature for DIN 62SiMnCr4 is 516°C (equation-2), while the martensite starting temperature is 224°C. According to TTT diagram for this steel (fig.7) the bainite range is between 400-500 °C. Therefore, the selected austempering temperatures for this steel were 400°C, 450°C and 500°C. Fig. 8 shows that austempering at 400°C for 15 minute caused an increase in hardness value from 235 HB (as received) to 429 HB with a structure of lower bainite in addition to some retained austenite and martensite, Fig.9. The alloying elements present in this steel especially silicon stabilized austenite [6]. The hardness increases with increasing austempering temperatures, due to higher volume percentages of less stable retained austenite will get, then it transformed to martensite after quenching to room temperature. Increasing isothermal transformation temperature, also results in obtaining the upper bainite with precipitations of carbides on the boundaries of particular laths. It influences a drop of the retained austenite stability [13]. The reason for this increase in the amount of retained austenite with the increase in the isothermal transformation temperature is the decrease in the driving force for the bainitic reaction. This decrease is caused by the decrease in the temperature gradient [1]. Also, Fig. 8 shows that hardness increase gradually with increase holding time (10 to 15 minute) where, the structure consists of lower bainite , retained austenite and martensite, that because there is not enough time for the bainite to fully grow into the austenite and not enough carbon will move to the austenite to stabilize it, then high amount of remaining austenite transformed to martensite after quenched at room temperature, where retained austenite amount at 10 minutes higher than it at 15 minute, while lower bainite amount at 10 minute is less than that at 15 minute. At 15 minute the structure consists of higher volume fraction of lower bainite from 10 minute, with lower amount of retained austenite, then the structure consist of lower bianite and martensite with small amount of retained austenite, where it was found that austenite existing as layers between bainite sheaves was much more stable than the retained austenite existing between bainite grains [5]. The variation in hardness values decreases after 20 minute because bainite transformation is completed, then less austenite transformed to martensite during quenching following austempering. Generally, austempering of DIN 62SiMnCr4 steel increases values of yield and tensile strength with good elongation. The strength is mainly influenced by the thickness of the bainitic laths, at a lower transformation temperature (400 °C), the bainite laths become finer and close-net, the amount of retained austenite is low, that gives a good combination of elongation and strength, where strength is increased from 775 MPa to 1171 MPa and elongation percentage decreased from 19% to14.6%. The microstructure of the as received DIN 62SiMnCr4 is pearlite and ferrite, it becomes a mixture of lower bainite, retained austenite and martensite when austempered at 400°C for 15 minute, fig. 9. Increasing temperature to 450°C and 500°C decreases the fraction of retained austenite, this behavior can be attributed to the faster bainite transformation kinetics at higher isothermal holding temperatures [13]. Fig.10 shows the structure obtained at 450 °C after 15 minute isothermal transformation. This figure displays the mixed structure of upper bainite and martensite. Typical upper bainitic structures are easy to distinguish.

Regarding the results and hardness test, it is conclusive that this structure contains the upper bainite with martensite.

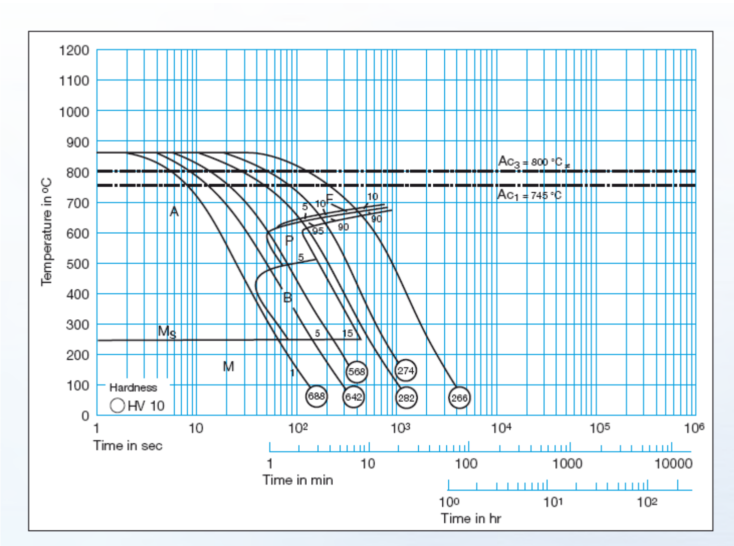

Figure 7: TTT diagram for DIN 62SiMnCr4[16]

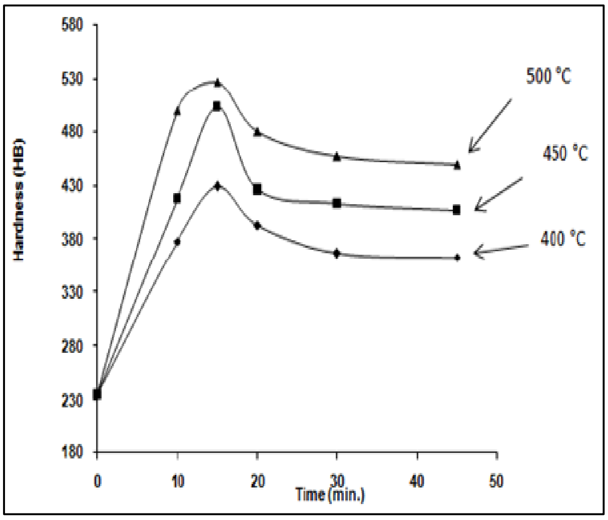

Figure 8:Effect of austempering time and temperature on hardness of DIN 62SiMnCr4

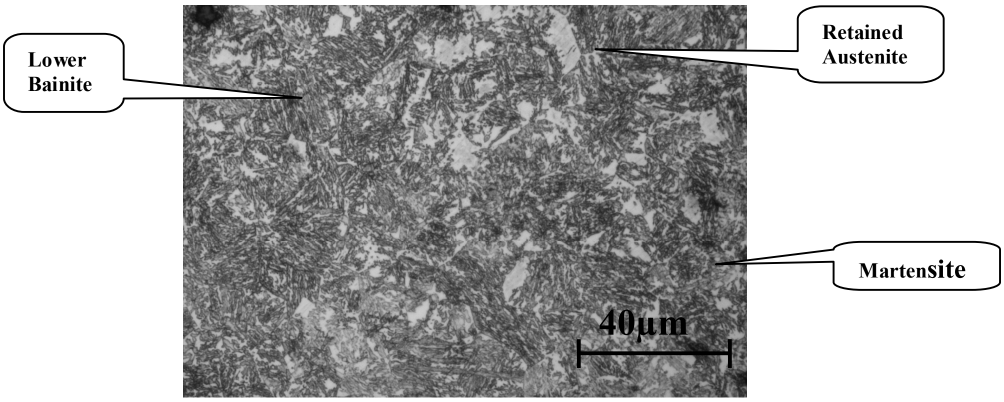

Figure 9: Microstructure of austempered spring steel at 400°C for 15 min.

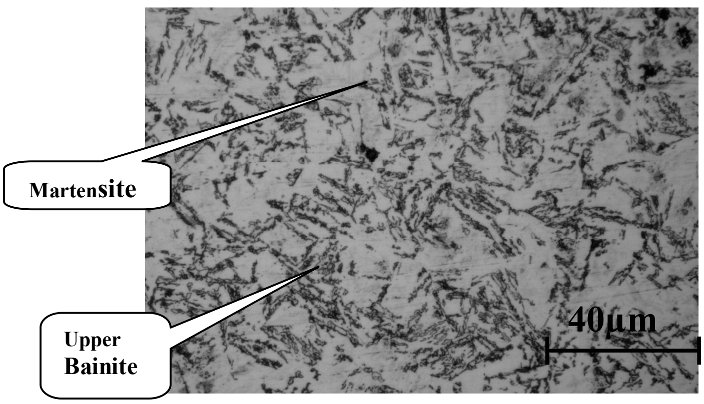

Figure 10: Microstructure of austempering spring steel at 450°C for 15 min.

CONCLUSIONS

1- DIN 62SiMnCr4 steel has higher ability to be austempered than DIN CK50 steel.
2- Optimum austempering temperature for DIN CK50 and DIN 62SiMnCr4 is 350^{o}C and 400^{o}C respectively.
3- Optimum isothermal transformation time is 15 minutes and 30 minutes for DIN CK50 and DIN 62SiMnCr4 steels respectively.
4- Bainite-Pearlite and ferrite mixture is the final microstructure of the austempered DIN CK50 while it is a mixture of bainite, retained austenite in addition to some martensite for the austempered DIN 62SiMnCr4.
5- Presence of carbon and silicon make austempering easier in obtaining bainitic structure with both types (upper and lower).
6- Increasing alloying elements (especially silicon) increase amount of retained austenite.
7- Increasing holding time decreases hardness for both steels.

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