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Effect of Transformation Temperature on Microstructure and Mechanical Properties of Bainite

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ABSTRACT

Fully bainitic microstructure can be obtained by isothermal transformation at temperatures within the range of bainite transformation. Both transformation temperature and time determine the phase fraction, the scale of the resultant microstructure and the carbone content of the retained austenite, which in turn determine the mechanical properties.

In this study, the thermomechanical simulator was used to obtained the fully bainitic microstructure for the high carbon alloy steel (0.78%C) at a different bainite transformation temperatures (200 to 350°C) in order to study the effect of the isothermal transformation temperature on the resultant mechanical properties.

It has been concluded from the detailed analysis of the microstructure, the dilatometric data and the mechanical properties (hardness and tensile properties) that finer bainite and less retained austenite phase fraction can be obtained by transformation at lower temperatures, and that leads to exceptional mechanical properties (Hardness ≈ 660 HV, and Tensile strength ≈ 2 Gpa).

Keywords: Bainite, Isothermal heat treatment, Kinetics, Superbainite.

دراسة تأثير درجة حرارة التحول على البنية المجهرية والخواص الميكانيكية لطور البينايت

الخلاصة

يمكن الحصول على بنية مجهرية من البينايت عن طريق التحولات الايزوثيرمية ضمن مدى درجات حرارة التحولات الطورية الباينايتية، ان درجة حرارة وزمن التحول الطوري يحددان الكسر الحجمي ودرجة نعومة البنية الناتجة وكذلك المحتوى الكاربوني للاوستنايت المتبقي والذي بدوره يحدد الخواص الميكانيكية الناتجة.

تم في هذا البحث استخدام جهاز محاكي للتحولات الحرارية الميكانيكة للوصول الى البنية الباينايتية للصلب العالي الكربون (0.78%C) بدرجات حرارة تحول ايزوثيرمي مختلفة تتراوح من 200 الى 350 م° وذلك لدراسة تأثير درجة حرارة التحول على الخواص الميكانيكية الناتجة.

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لقد تم التوصل من خلال التحليل الدقيق للبنية المجهرية الناتجة وبيانات التغيير في الابعاد وكذلك نتائج فحوصات الصلادة ومقاومة الشد الى امكانية الحصول على بينايت ناعم جدا مع انخفاض درجات حرارة التحول الايزوثيرمي مما يقود الى خواص ميكانيكية عالية (660 صلادة فيكـــرز و≈ Gpa 2 مقاومـــة شد).

INTRODUCTION

Bainite can be regarded as a non lamellar mixture of ferrite and carbides[1-3], it has been known as a phase mixture since the 1930s, it also known that the scale of the structure can be refined by reducing the transformation temperature (Singh and Bhadeshia 1998)[4], and the bainite reaction has a comparatively greater capacity for control[5-11]. Now there is a novel range of steel under development, based on bainite formation at exceptionally low temperature to reduce the scale of the microstructure which enhances both strength and toughness. The microstructure of these alloys is bainitic ferrite and carbon enriched retained austenite[12-16].

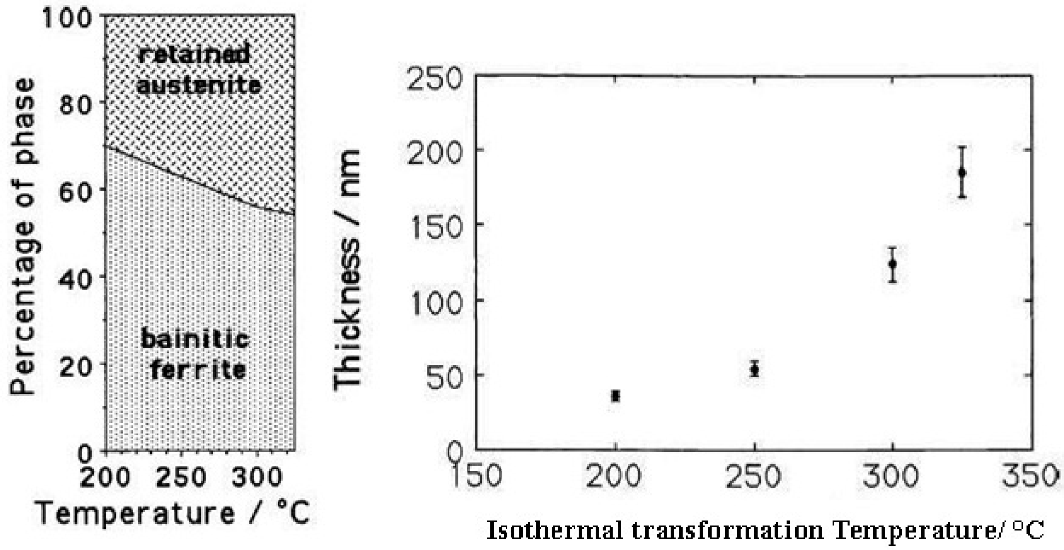
The maximum amount of bainite can be obtained at any temperature is limited by the carbone content of the residual austenite which must not exceed that given by the $\grave{T}_o$ curve, at that point, the enriched austenite can no longer transform into bainite[2, 17] , the carbon content in retained austenite decrease with an increase in the transformation temperature, and that is lead to increase the fraction of retained austenite phase for higher transformation temperature (figure 1-a), a reduction in the scale of the microstructure is also expected (figure 1-b)[2, 15, 18]. In this work, the effect of changing the transformation temperature on the mechanical properties of the resulted bainitic microstructure is studied.

EXPERIMENTAL WORK

The alloy steel used belongs to the class of low temperature bainite[12-16, 19-21] but with cobalt and aluminium added in order to reduce the transformation time from days to hours[22-24]. This is necessary in order to conduct experiments on a thermomechanical simulator. The chemical composition of the steel is given in table 1. Thermodynamic calculations were carried out with MTDATA[25] to determine the austenitizition parameters (figure 2). The calculation shown considered only ferrite, austenite and cementite.

Table (1): Chemical composition in wt %.

C	Si	Mn	Mo	Cr	Co	Al
0.78	1.6	2.02	0.25	1.01	3.87	1.37



(a) (b)

Figure (1): Effect of isothermal transformation temperature on (a) Volume fraction of phases (b) bainitic plate thickness[15].

Bainite formation begins during isothermal transformation at temperatures between 200 to 350 °C and completed when the maximum amount of bainite can be obtained at these temperatures are reached. The isothermal transformation temperatures were selected below the bainite starting temperature,B_s, and above the martensite starting temperature,M_s, (bainite transformation range) . All the heat treatments were carried out in a thermecmastor thermomechanical simulator machine, cylindrical specimens of 8 mm diameter and 12 mm length were austenitised at 1000 °C for 15 min with 10 °C /sec heating rate followed by cooling to variety of isothermal transformation temperatures (250- 350 °C) while the change in diameters were monitored.

Optical microscopy was used to examine the etched microstructures for the samples and reveal the effect of microstructure change with the transformation temperatures on the mechanical properties of the steel. Specimens were ground and polished using standard techniques and etched in 2% nital solution.

The results were supported with Vickers hardness tests which are reported as the average of the at least five tests, the tests were conducted using a 50Kg load.

The Tensile properties were determined at room temperature, the cross-head speed was 0.1 mm. min^{-1} and the elongation is for a gauge length of 10 mm. tensile test samples with 5 mm diameter cross section transformed isothermally as before into the bainitic conditions (3 days at 200 °C, 3 days at 220 °C, 16 hr at 250 °C and 6 hr at 300 °C).

RESULTS AND DISCUSSION

Microstructure characterization and dialometric analysis

Isothermal transformation in the temperature range 200- 350 °C led to the transformation of bainite as illustrated in figures(3, 4 and 5) (experiments were conducted up to 400 °C without leading to bainite).

Figure(3) shows the dilatometric curve of used steel after isothermal holding at 300 °C for 6 hr, in this curve the instance of the bainite transformation kinetics represented in terms of length change, the point where the transformation is almost ended is denoted where there is no more change in the length.

Figure(4) represents the dilatomtric curves of the same steel after isothermal holding at different temperatures (350 to 250 °C), the dilatometric analysis indicates that the extent of the bainite transformation increased with decreasing temperature. It also shows that greater fraction of bainite is obtained with decreasing the temperature.

This result is demonstrated by the metallographic examination Figure (5) which shows that the transformation remain incomplete even in the early stage of transformation (after 3 days of holding time at 200 °C), but with low austenite volume fraction, transformation at higher temperature shows higher austenite volume fraction. The microstructure in this temperature range consisted of a mixture of just two phases, bainitic ferrite and carbon-enriched retained austenite.

Figure (5) illustrates also the wide variation in microstructure scale, where the microstructure represents the effects of changing the isothermal transformation temperature from 350 to 200 °C, this has resulted a dramatic reduction in the plate size with lowering the transformation temperature.

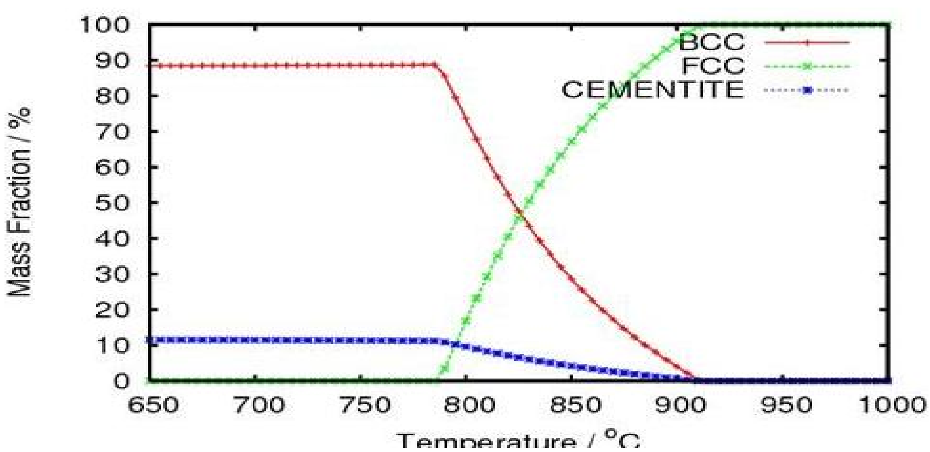
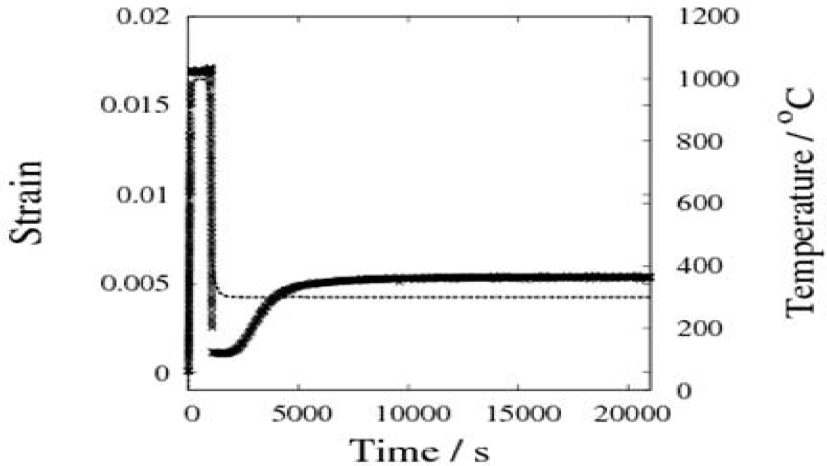


Figure (2): Evolution of eqilibrium phase fraction using MTDATA for used steel. Only fereite, austenite, cementite were allowed to exist.



Figure(3): Dilatometric curve for the isothermal transformation at 300 °C for 6 hr.

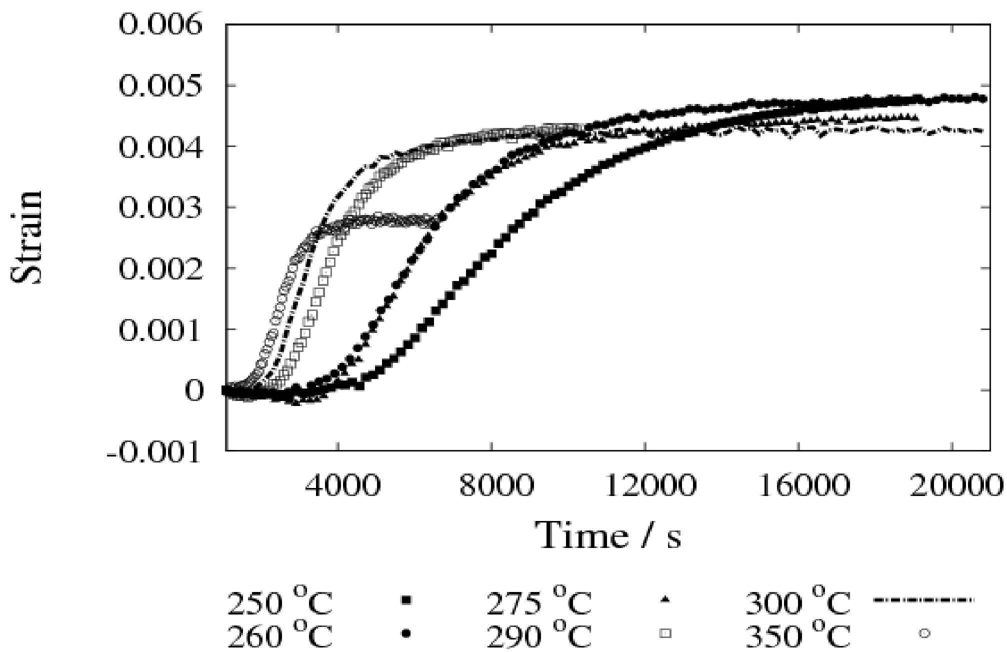


Figure (4): Dilatometric curves for the isothermal transformations at different temperatures.

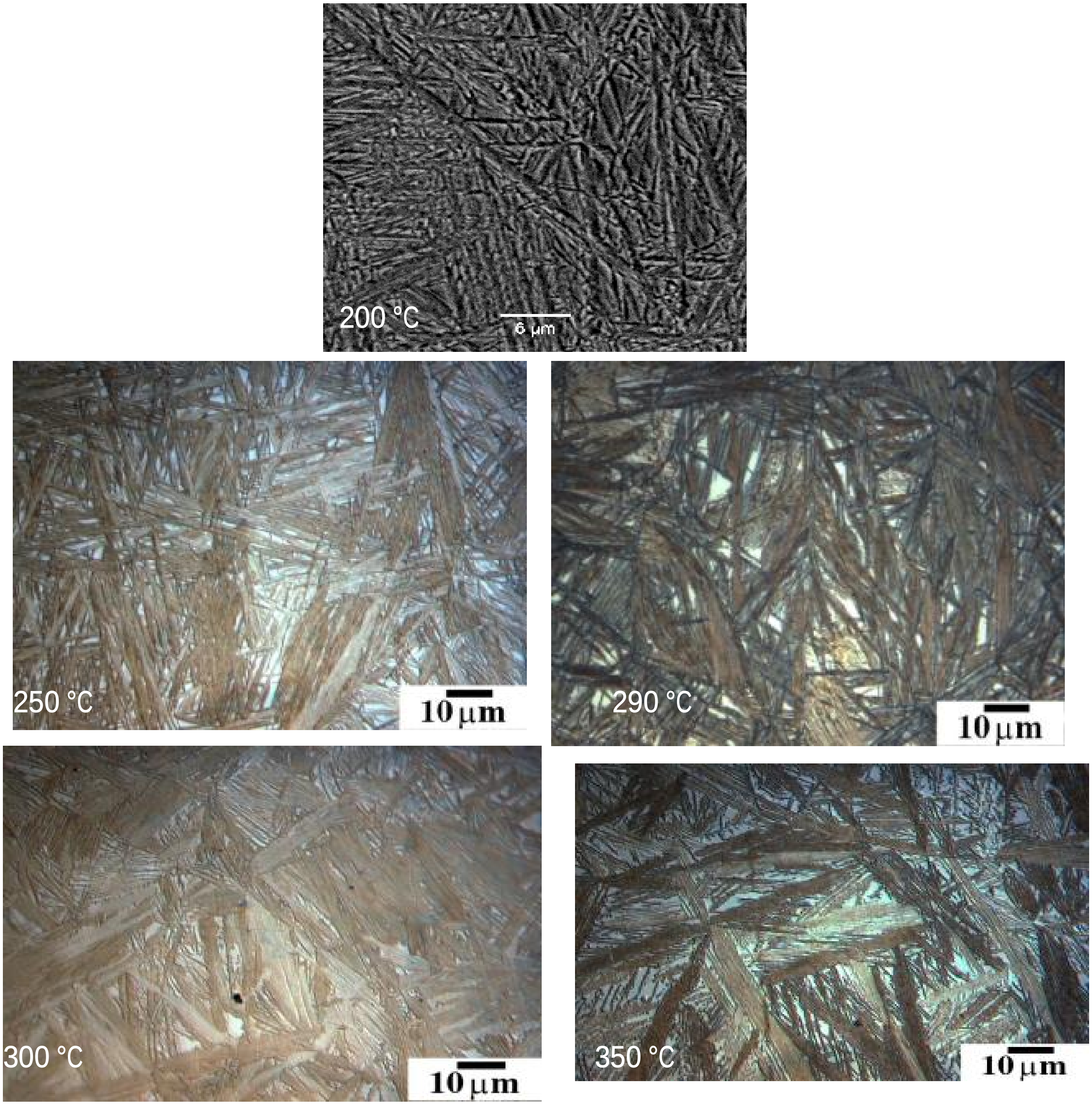


Figure (5): The variation in the microstructure as a function of transformation temperature.

MECHANICAL BEHAVIOUR

Mechanical tests were conducted for the isothermally transformed bainitic steel at room temperature, the results are summerised in tables 2 and 3, and figures 6 and 7.

Hardness

Figure 6 shows the trend of the hardness as a function to transformation temperature, standard deviation of the mesurements. The hardness increases sharply as the transformation temperature is reduced, and that is because of the increase in the corresponding fraction of bainitic ferrite and the sharp decrease in the thickness of the bainite plate.

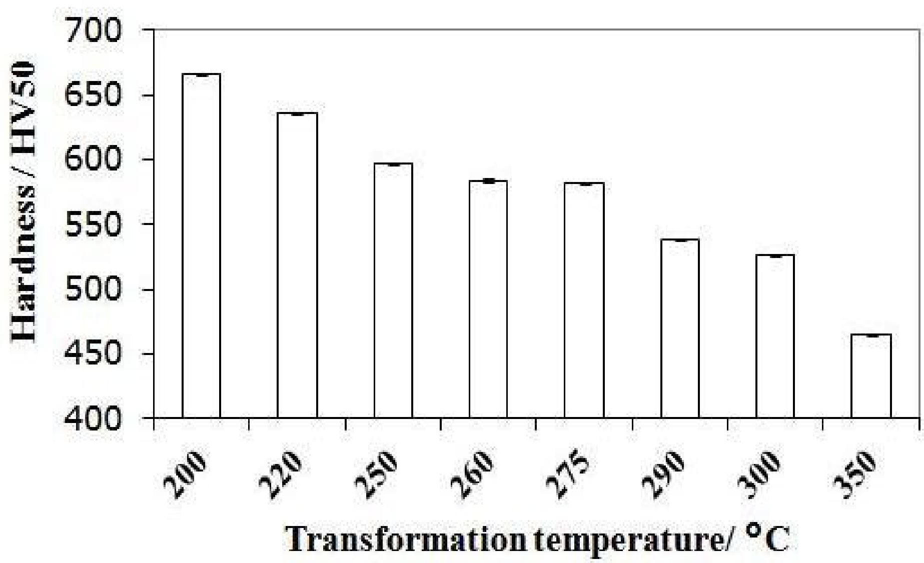


Figure (6): Vickers hardness as function of transformation temperature

Table(2): Hardness Measurements

Transformation temperature/ °C	Hardness/ HV50
200	660±3.6
220	636±4
250	597±9.4
260	584±4.5
275	582±1.3
290	538±2
300	526±5.7
350	465±6.67

TENSILE STRENGTH

The tensile properties of the studied steel with the composition shown in table 1 were measured as a results of applying different isothermal transformation temperature (200, 220, 250, 300 °C), the transformation time were in all cases sufficient to ensure the cessation of the bainitic reaction. Figure 7 shows the stress- strain curves which is summerize the mechanical behaviour of this bainitic microstructers at room temperature, the deformation is generally characterized by continuous yielding because the microstructure include soft phase such as blocks of retained austenite; the figure shows also that the yield stress increased significantly with decreasing the isothermal transformation temperature as the retained austenite content decreased. It is also evident from the figure that most of plastic deformation is uniformaly distributed along the gage length of the samples, with a minor tendency to neck in early stage of deformation, and as expected the total elongation (TE) increased significantly from 0.33 to 19.2% with increasing the isothermal transformation temperature from 200 to 300 °C, as the retained austenite content increased (table 3); at 200 °C transformation temperature condition, the steel possessed a relatively low austenite volume fraction and that can explain the very low elongation obtained.

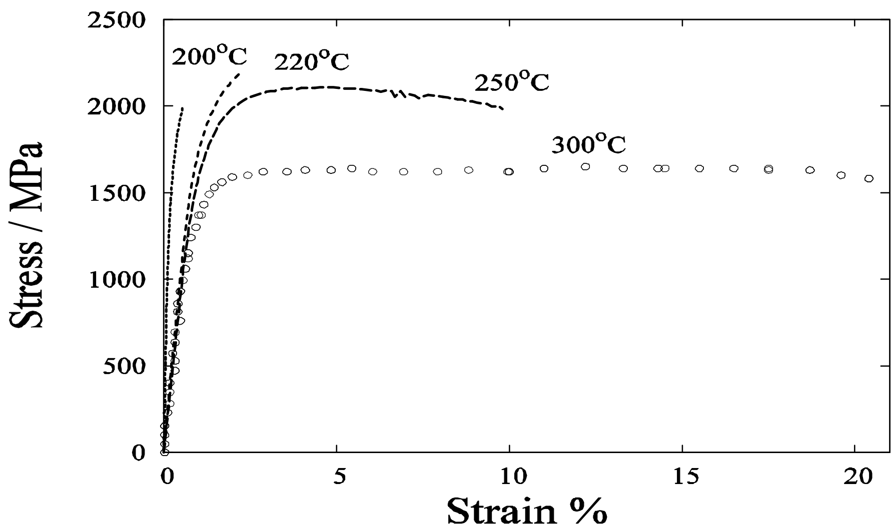


Figure (7): Stress- strain curves of used steels transformed into bainite at different temperatures. The cross-head speed was 0. 1 mm. min^{-1}, the elongation is for a gauge length of 10 mm.

Table (3): Tensile properties at room temperature, σ_y is the yield strength (0.2% proof strength), σ_u is the tensile strength and %Elong. the total elongation.

Heat treatment	σ_y **MPa**	σ_u **MPa**	**%Elong.**
3 days at 200 °C	1880	1996	0.33
3 days at 220 °C	1755	2210	1.25
16 hr at 250 °C	1620	2110	8.7
6 hr at 300 °C	1283	1640	19.2

CONCLUSIONS

Bainitic microstructures obtained by isothermal transformation at temperature rang from 200 to 350°C were tested in order to characterize the effect of changing the isothermal transformation temperature on the resulted mechanical properties, this attempt lead to the conclusions that:

- decreasing the transformation temperature extent the bainite transformation and increase the volume fraction of the bainite obtained, finer bainite can be obtained by transformation at lower temperatures (200°C)
- The achievement of very fine scale of the bainite can lead to exceptional mechanical properties which are combinition of strength and ductility (Hardness ≈ 660 HV (50kg), and Tensile strength ≈ 2 Gpa) which is not normally available in affordable steels. The strength comes from the fine scale of the structure whereas the ductility is associated with the texture of the austenite and the bainitic ferrite.

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