



EXPERIMENTAL STUDY OF THE INFLUENCE OF QUENCHING AND PARTITIONING TEMPERATURE VARIATION ON RETAINED AUSTENITE FRACTION IN AISI 4140 STEEL

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ABSTRACT

Quenching partitioning, the recent heat treatment method, offers a way to enrich carbon in retained austenite at room temperature. This method consists of 4 steps; austenizing, premier quenching, partitioning, and secondary quenching. Afterward, specimen was etched and observed under microscope and x-ray diffraction to obtain microstructure. Retained austenite fraction affected by premier quenching temperature and partitioning temperature was examined. Using this experimental data, the possible forming mechanism was explained and results of mechanical testing was used to verify the influence of retained austenite on mechanical properties.

Keywords: quenching, partitioning, retained austenite, AISI 4140.

INTRODUCTION

Quenching Partitioning is novel heat treatment process of which objective is increase the fraction and carbon concentration of retained austenite phase. Increasing this constituent will improve the toughness of steel because it has good ductility and plasticity. Compared to the conventional method, quenching tempering, this method takes less time and produces tough steel as well as the conventional one.

Quenching partitioning consists of 3 major steps; austenizing, premier quenching, and partitioning. Steel is austenized, by heating over the A3 temperature and hold, to get austenite phase. Hence, steel is quenched between martensite start (Ms) and martensite finish (Mf). During this process, austenite transforms partially into martensite structure, because its unstability at temperature below A1. The amount of austenite which transforms into martensite depends on the quenching temperature. The lower quenching temperature is the more austenite transforms into martensite. After quenching, steel is partitioned with 2 possible options. Steel can be partitioned at temperature below Ms or above the Ms. Partitioning temperature above the Ms will accelerate carbon partitioning from martensite to austenite, but it must be taken at shorter time before the remaining austenite transforms into bainite phase. The other option will make the austenite tend to transform to carbide, if hold for a longer period.

The temperature of quenching and partitioning become very critical, and yet the model has been developed. Edmonds et al has developed the model of retained austenite fraction as a function of quench temperature in plain carbon steel [1]. A. J. Clarke et al has conducted a research to obtain an optimum quenching and partitioning temperature, and partitioning time so that maximum fraction of retained austenite reach maximum [2]. Others researchers has also developed an experimental

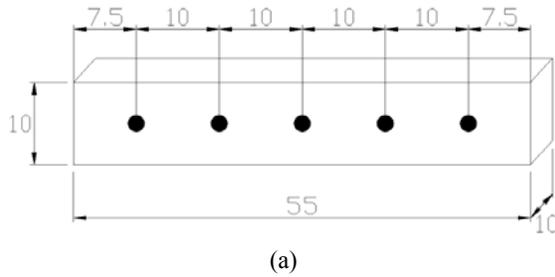
observation of microstructure of sheet steel after quenching partitioning [3-5].

METHODOLOGY

Steel, consisting 0.38% C, 0.88% Mn, 0.95% Cr, and 0.20% Mo, was machined with the dimension is shown at Figure-1. The dimension was used to prevent longitudinal heat transfer so that there was no difference in temperature rate between the center test piece and outer test piece.

Subsequently, test piece was austenized at 885 °C, and then quenched and partitioned at varied temperature. Quenching and partitioning media used in this research was salt bath. Salt bath temperature used in quenching process was varied from 220 °C to 250 °C with increment 10 °C and which is used in partitioning process was varied from 350 °C to 450 °C with increment 50 °C. Quench temperature was chosen based on the model developed by Edmonds showed at Figure-2, and partitioned temperature was picked from experimental data showed at Figure-2.

Optimum retained austenite fraction, for plain steel with 0.4%C, occurs around quench temperature 230 °C, and partition temperature around 400 °C. Holding time of quenching process was 120 seconds and of partitioning process was 10 seconds. Quenching partitioning scheme was showed at Figure-3.

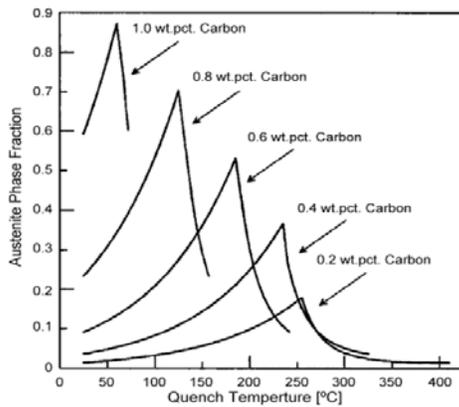


(a)

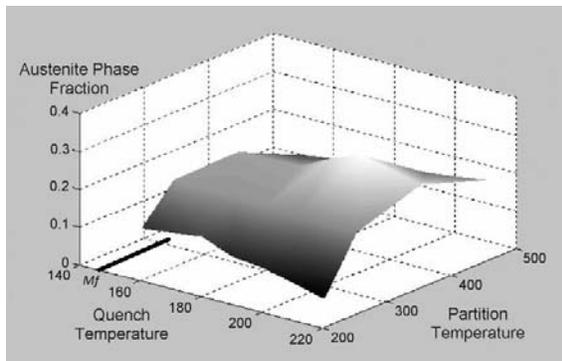


(b)

Figure-1. (a) Dimension of test piece, (b) test piece.



(a)



(b)

Figure-2. (a) Austenite phase fraction as a function of quench temperature [1], (b) model derived from experimental data

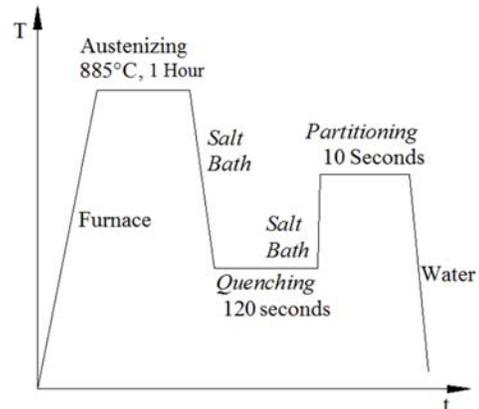


Figure-3. Quenching partitioning scheme.

After quenching partitioning process, test piece was cut and grinded; using silica carbide of which grid increased gradually from 80 to 2000, and polished using alumina powder ($\text{Na}_2\text{O} \cdot 11\text{Al}_2\text{O}_3$). Subsequently, test piece was etched using Kourbatoff no. 4 [6], and observed under light microscope and x-ray diffraction.

DATA ANALYSIS

Results of microscope observation were analyzed to calculate retained austenite fraction. "TA Image" was involved to simplify the calculation process. Table-1 shows retained austenite fraction on each quenches and partition temperature.

Figure-4 showed that quench temperature had significant effect compared to partition temperature. Quench temperature affected the amount of austenite that did not transform into other phases. The higher quench temperature was the more austenite did not transform into others.

During the partitioning process, carbon partitioned from the martensite to austenite because of high strain energy and instability of martensite. The increase of carbon content in austenite increased its stability at room temperature, thus the austenite remained untransformed. Figure 5 shows microstructure of test piece after quenching partitioning process, and there was no fresh martensite. It indicates that retained austenite of which carbon content increased was at stable condition.



Table-1. Area fraction of austenite and martensite in each quench and partition temperature.

Quench temperature (°C)	Partition temperature (°C)	Area fraction (%)	
		Austenite	Martensite
220	350	4.38±1.83	95.62±1.83
	400	8.38±2.07	91.62±2.07
	450	8.78±3.70	91.22±3.70
230	350	13.44±3.02	86.56±3.02
	400	12.51±1.09	87.49±1.09
	450	12.94±3.06	87.06±3.06
240	350	15.74±1.70	84.26±1.70
	400	15.45±4.17	84.55±4.17
	450	15.56±2.13	84.44±2.13
250	350	17.76±1.98	82.24±1.98
	400	17.75±2.52	82.25±2.52
	450	17.99±1.71	82.01±1.71

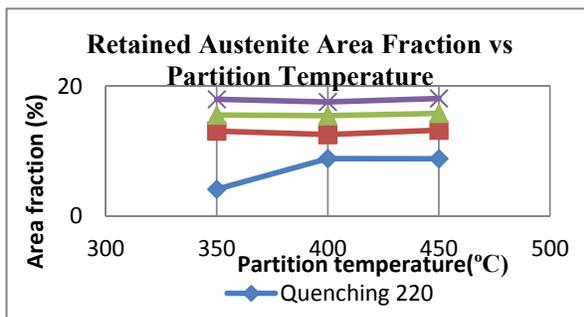


Figure-4. Graphic of retained austenite area fraction as a function of partition temperature at different quench temperature.

As seen in Figure-4, partition temperature did not have significant effect on the amount of retained austenite, but the martensite shape was truly affected. The lath structure of martensite was seen obviously at low partition temperature; on the other hand it lost its shape at higher partition temperature. Figure-6 shows the different of martensite shape at different partition temperature. This phenomenon was caused by the reduction of carbon content in martensite. Carbon's leaving the martensite caused the reduction of martensite strain energy, thus made it lost its shape.

The presence of retained austenite phase was indicated also by x-ray diffraction (XRD) analysis. Small peak at $2\theta=75^\circ$ is a diffraction degree of austenite phase. X-ray diffraction analysis is showed in Figure-7.



Figure-5. Microstructure of heat-treated test piece.



(a)



(b)



(c)

Figure-6. Microstructure of heat-treated test piece at quench temperature 230 °C and at partition temperature (a) 350 °C, (b) 400 °C, and (c) 450 °C.

Increasing carbon content in austenite affects the hardness of this constituent. Micro hardness testing was conducted to verify hardness of each constituent. Results of microhardness testing are showed in Table-2.

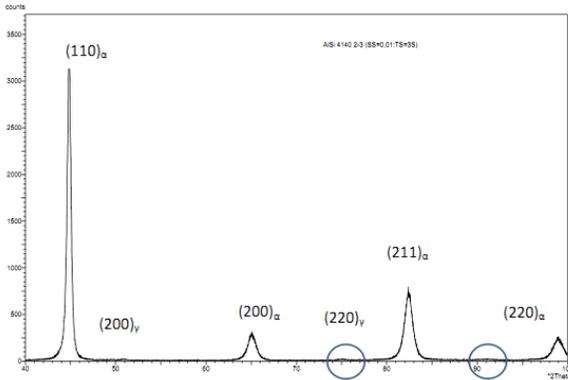


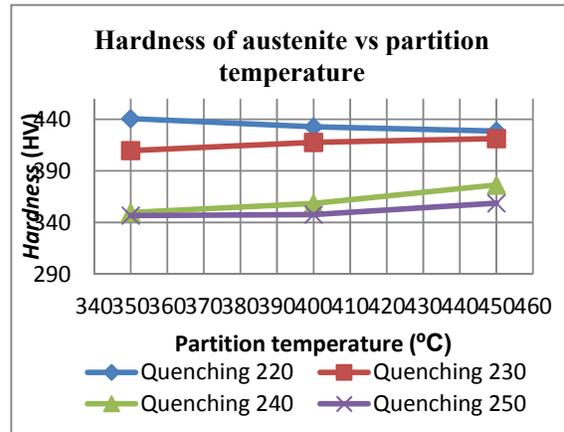
Figure-7. Result of x-ray diffraction (XRD) analysis.

Table-2. Results of microhardness testing in austenite and martensite.

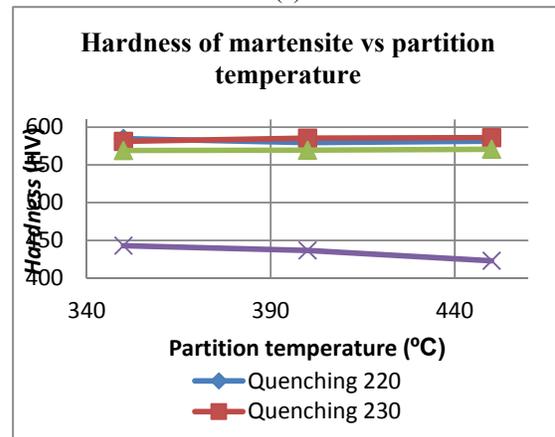
Quench temperature (°C)	Partition temperature (°C)	Hardness (HV)	
		Austenite	Martensite
220	350	441±21.55	585±2.52
	400	433±22.55	579±0.58
	450	429±20.74	581±1.15
230	350	410±24.03	581±1.73
	400	418±2.52	585±1.53
	450	421±11.50	586±2.00
240	350	350±29.02	569±11.00
	400	358±27.54	569±2.89
	450	376±17.62	571±2.89
250	350	347±15.82	443±6.08
	400	348±12.01	437±7.37
	450	359±12.66	423±7.55

As partition temperature increased, more carbon atom partitioned from martensite to austenite. Thus, the hardness of austenite was influenced. At quench temperature 230 °C, 240 °C, and 250 °C, hardness of austenite was increased (Figure-8). This was caused by the increase of carbon atom of austenite itself. On the other hand, this phenomenon did not occur at quench temperature 220 °C. At low quench temperature, amount of untransformed austenite was very little; hence its strain energy was very high. Partitioning acted as strain recovery rather than carbon movement. Strain recovery process reduced the hardness of austenite.

Inversely, partition process declined the hardness of martensite, because of the carbon’s partitioning from martensite to austenite, but it was not significant. This insignificant was caused by the high fraction of martensite, so that carbon which partitioned to austenite was very little; compared to the total martensite. At quench temperature 240 °C, the effect was significant since the highest amount of retained austenite. Martensite would lost much of its carbon content after partitioned to higher austenite fraction, and the effect was significant hardness reduction. Figure-9 shows microhardness testing for each phase.

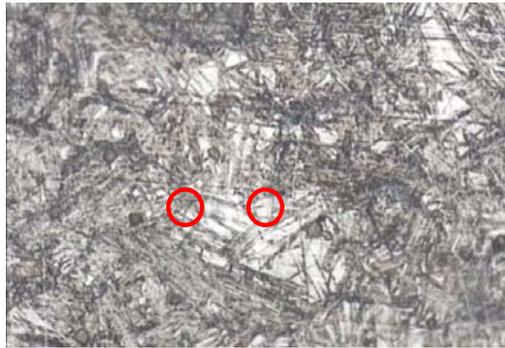


(a)



(b)

Figure-8. Graphic of (a) hardness of austenite as a function of partition temperature and (b) hardness of martensite as a function of partition temperature.



(a)



(b)

Figure-9. Microhardness test for (a) martensite, and (b) austenite.

CONCLUSIONS

Retained austenite fraction during quenching partitioning process depended on quench temperature. The higher the quench temperature was, the more austenite retained. Partition temperature did not affect the amount of austenite fraction, but the hardness of each constituent and shape of martensite was significantly influenced. Higher partition temperature made more carbon partitioned to austenite, thus increased austenite hardness. Furthermore, martensite lost its shape, and its hardness decreased. Optimum retained volume fraction occurred at quench temperature 250 °C and partition temperature 450 °C.

Further work, an alloying effect of quenching partitioning is required to observe quench and partition temperature. Alloying affect the carbide formation, and bainitic structure, so that time and temperature in quenching partitioning will be influenced. Another method for observation as scanning electron microscope will be suitable for obtaining specific microstructure.

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