The Effect of Thermo-mechanical Treatment of Substrate Preparation and Carburizing Temperature on The Morphology and Hardness of Carburizing on Low Carbon Steel

Raden Dadan Ramdan[1], Andra Adetia[1] and Rochim Suratman[1]

[1]Faculty of Mechanical and Aerospace Engineering, Institut Teknologi Bandung, Jl. Ganesa no 10 Bandung, West Java, Indonesia, 40132

Email: dadan@material.itb.ac.id

Abstract. Low carbon steel has a lot of applications in daily life because of its excellent properties. Among its excellent properties are good ductility, toughness, formability, and weldability. For the case of application that requires good wear resistant, carbon steel is not sufficient. For this case it is required to increase the hardness of carbon steel, such as by carburizing method. In this method one factor that affects the carburizing layer is metal substrate condition, i.e grain size. Another factor is temperature that could have significant role on the carburized layer characteristics. Therefore the present works focus in the correlation between degree of reduction of cold rolling and carburizing temperature on the carburized layer characteristic. Thermo-mechanical treatment was applied to the specimen with reduction of 0%, 30%, and 80% by mean of rolling before carburizing process. Carburizing processes were carried out at temperature of 850°C, 900°C, and 950°C. Examinations on carburized specimens were conducted by metallography and micro hardness test. The result showed that the specimen of 80% reduction giving the thickest layer and the hardest surface layer. In addition, at temperature of 900°C, the hardest layer was formed with the hardness at 1003 HV. However, the thickest layer was formed at the temperature of 950°C.

1. Introduction

Carbon steel is the most widely applied metals for various applications due to its excellent mechanical properties that combine high strength and sufficient ductility and the relatively good manufacturing ability. However hard coating are normally applied on the steel substrate in order to increase wear resistance characteristic of this metal [1-5] for application that requires excellence of this characteristic. Among of this method is carburizing process, which can be applied in various method of processes [6-10].

Carburizing is a method of surface hardening, a method to improve the mechanical properties of metal surfaces. This method is also considered as thermo-chemical treatment since combining of chemical treatment (by diffusing element on the metal surface) and heat treatment processes. This method is widely applied due to relatively low cost of processes involving relatively cheap raw material precursor and the easiness of application as compared with other surface hardening processes.

Based on the above description, carburizing play important role in industries and therefore various attempts have been performed by researchers in order to optimize this method. In the present work,

substrate preparation and carburizing temperature have been selected as variable parameters to be optimized. Substrate preparation has been performed by thermo-mechanical treatment, which is combination between rolling and heat treatment processes. Different degree of rolling reduction is expected to give different microstructure characteristic and thereby giving different diffusion characteristic during carburizing process on the steel substrate. It has been well understood that after forming process, such as rolling, high density of dislocation (a type of metal defect) occurred after this process. This high density dislocation of metals are susceptible for recrystallization that produce finer grain structure, if after forming process is followed with heat treatment at recrystallization temperature of the metals. Different degree of forming process might create different density of dislocation and thereby creating different degree of recrystallization during the following heat treatment that results in different grain size of microstructure of metal. Since during carburizing, carbon enter the metal substrate by diffusion process, and diffusion is predicted occur at the faster rate at the grain boundary, then it is predicted different grain size of the metal substrate might produce different carburizing layer structure. Few researches have been conducted on the topic of the effect of thermo-mechanical treatment on the carburized layer structure, and most of them are working with commercial carburizing resources. The present research utilizing coconut shell charcoal as carbon resources, and therefore the type of carburizing conducted in the present research is pack carburizing process. the On the other hand, different carburizing temperature is also expected to give different diffusion characteristic as well as substrate characteristics during carburizing processes.
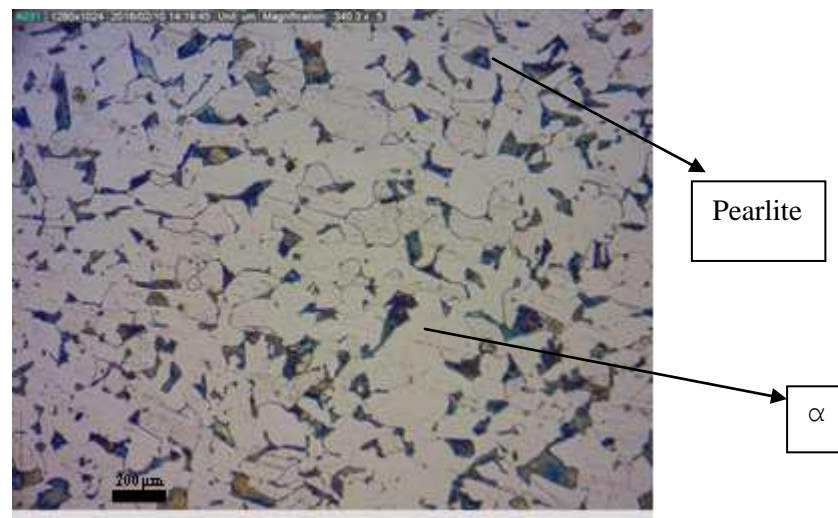
2. Experimental method

Metal substrate used in the present research is low carbon steel which is then prepared by thermo-mechanical treatment (TMT) in order to obtain substrate sample with different grain size before carburizing process. TMT processes were performed by combining cold rolling process and heat treatment. There are three type of samples that will be evaluated regarding TMT process, which are sample without TMT, sample with degree of cold rolling reduction of 30% and 80%. After cold rolling process each samples are heated at 625°C for one hour in order to create recrystallization on the cold rolled samples.

After metal substrate preparation, carburizing processes were performed by single quenching method and utilizing solid pack-carburizing method. By single quenching method, two heat treatment cycles have been performed. The first cycle is putting the sample in the container contains solid pack carburizing powder agent and heated at austenization temperature in order to diffuse carbon on the steel substrate and followed with air cooling process. The second cycle is heating this steel sample up to austenization temperature and follow with quenching by immersing the sample in the water. For the first cycle, variations of heating temperature were performed at 850, 900 and 950°C. After carburizing process characterization on the carburized samples were performed. Two main characterizations were performed including micro-vicker hardness test on the cross-section sample and microstructure characterization by using optical microscope on this section. Beside hardness and microstructure data obtained from these two characterizations, it can also be obtained the case depth of carburizing which is related with the kinetic of the process.
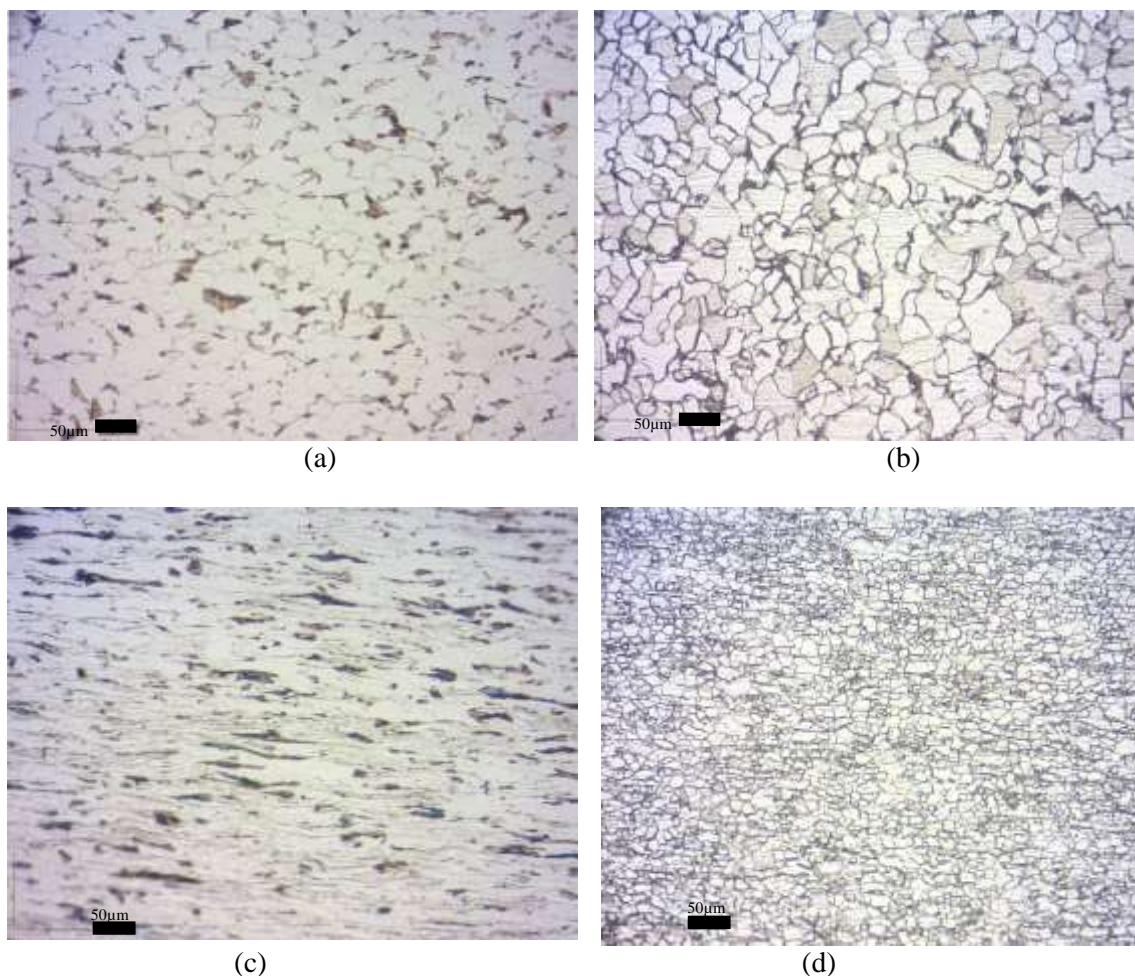
3. Data and Analysis

Figure 1 shows microstructure of steel sample before treatment, showing ferrite and pearlite structure, characteristic of low carbon steel structure. On the other hand, Figure 2 shows microstructure of steel samples after given thermo-mechanical treatment. Almost insignificant differences with original sample observed for the samples given 30% reduction of rolling and subsequent heat treatment process. However significant microstructure changing observed for the sample given 80% reduction of rolling and the following heat treatment treatment (Figure 2(c) and (d)). After this degree of rolling, it can be seen highly elongated structure, a characteristic of cold formed structured. This structure is heavily deformed and contained much higher density of dislocation as compared with untreated

sample. This condition induces in the massive recystallization during the following heat treatment and results in the fine grain structure as is shown in the Figure 2(d).
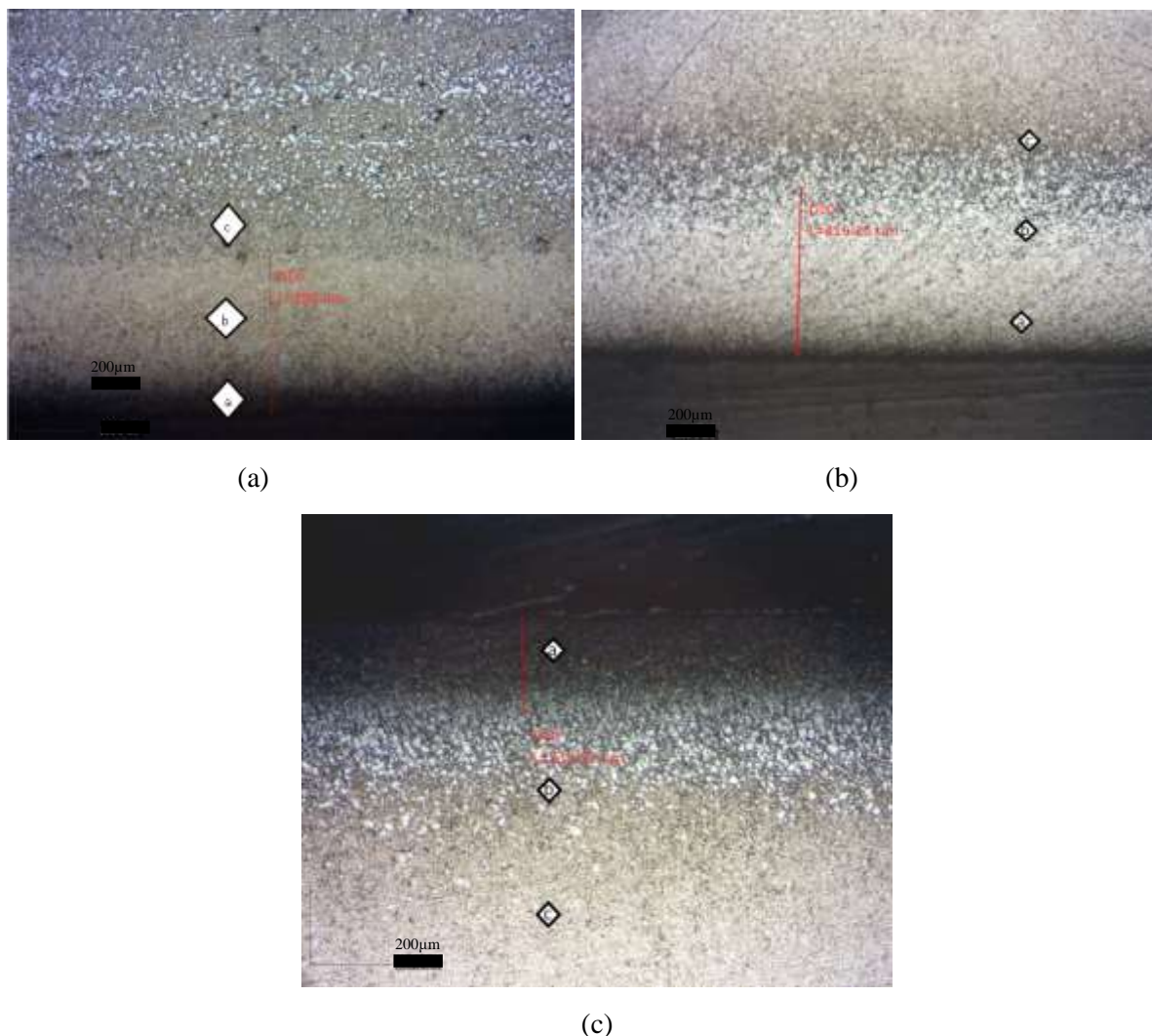

Pearlite

α

Figure 1. Original steel sample microstructure before treatment.

(a)

(b)

(c)

(d)

Figure 2. Microstructure of (a) Cold rolled sample at 30% reduction, (b) 30% cold rolled sampled plus annealing, c) Cold rolled sample at 80% reduction, (d) 80% cold rolled sampled plus annealing.
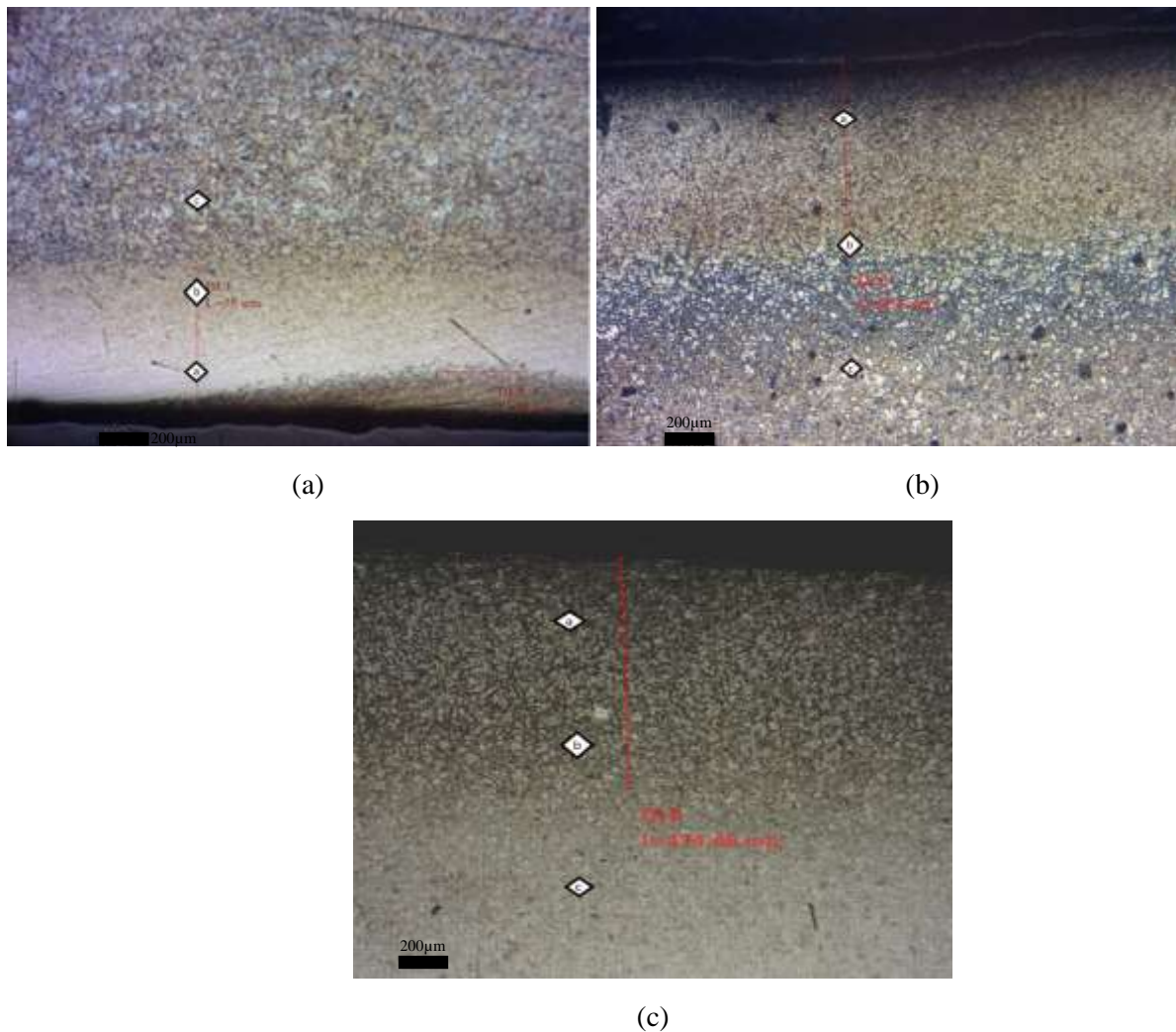
Figure 3 shows cross-section microstructure of sample without thermo-chemical treatment preparation, after carburizing process. Point a,b and c in the figures are points where hardness test performed on the samples, and points a is the outermost points of the carburized layers in each figure. Carburized layer is considered as the layer with minimum hardness of 550 HV, and therefore sample that carburized at 900°C shows the thickest layers. In addition from Table 1, it can be seen that this sample also having the highest hardness at the outermost point (poin a) of measurement.

On the other hand, Figure 4 shows cross-section microstructure of sample prepared with 30% cold rolling and heat-treatment process. Refer to Table 2, it was obtained that sample carburized at 950°C having hardness above 550HV at point c, and therefore have highest thickness of case depth. However, the highest hardness at the outermost layer position is shown by the sample carburized at 900°C.

(a)

(b)

(c)

Figure 3. Microstructure of sample prepared without treatment after carburizing at (a) 850°C, (b) 900°C, (c) 950°C.
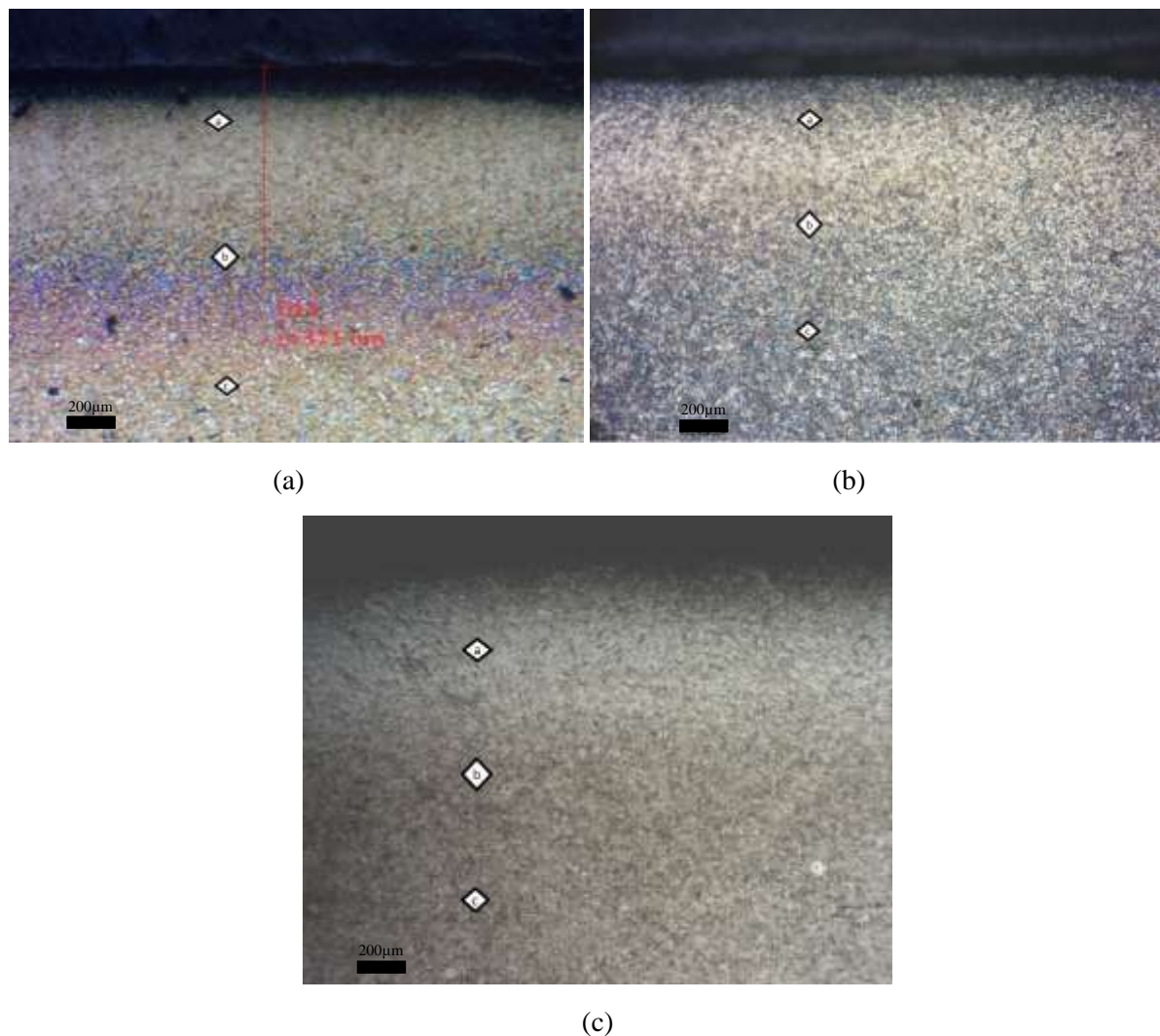
Table 1. Hardness of carburized samples, samples prepared without thermo-mechanical treatment

Samples	Hardness at point a (HV)	Hardness at point b (HV)	Hardness at point c (HV)
Carburized at 850°C	641	566	296
Carburized at 900°C	847	706	407
Carburized at 950°C	660	557	282

(a)

(b)

(c)

Figure 4. Microstructure of sample prepared with 30% cold rolling+heat treatment, after carburizing at (a) 850°C, (b) 900°C, (c) 950°C.

Table 2. Hardness of carburized samples, samples prepared with 30% cold rolling+heat treatment

Samples	Hardness at point a (HV)	Hardness at point b (HV)	Hardness at point c (HV)
Carburized at 850°C	782	566	327
Carburized at 900°C	914	762	517
Carburized at 950°C	724	710	608

In addition Figure 5 shows cross-section microstructure of sample prepared with 80% cold rolling and heat-treatment process. Hardness data at the points of measurements shown in this figure are tabulated in the Table 3. Interesting facts are observed here that both samples carburized at 900°C and 950°C are having hardness above 550HV along their cross-section points, which means the case depth is along the cross-section of both samples. However, sample carburized at 900°C still showing highest hardness at its outermost side.

(a)　　　　　　　　　　　　　　　　　　　(b)

(c)

Figure 5. Microstructure of sample prepared with 80% cold rolling+heat treatment, after carburizing at (a) 850°C, (b) 900°C, (c) 950°C.

Table 3. Hardness of carburized samples, samples prepared with 80% cold rolling+heat treatment

Samples	Hardness at point a (HV)	Hardness at point b (HV)	Hardness at point c (HV)
Carburized at 850°C	805	724	316
Carburized at 900°C	1003	825	587
Carburized at 950°C	813	782	636

Table 4 summarized the effect of degree of rolling on the hardness of carburized layer at each carburizing temperature. It can be seen from this table that sample with degree of rolling at 80% show

highest hardness at each carburizing temperature. This condition is considered related with the microstructure condition of these samples which having finest grain structure as is shown in the Figure 2. Finer grain structure provide more massive diffusion path during carburizing process and therefore results in the more compact carburized layers than the coarser grain structure.

From this research, surface hardness of the steel substrate obtained after the carburizing process due to the formation of martensite structure at the surface as shown in the Figure 3,4 and 5. The steel substrate which having low carbon content is normally cannot be hardened by heat treatment since transformation to martensite structure is difficult for the low carbon steel. During carburizing process, carbon is diffused into the surface of the steel, and therefore increases carbon content at the surface. This condition change the hardenability of the steel surface, and transformation to martensite structure become possible by heat treatment process. In addition, it was also obtained that carburizing temperature at $900^{o}C$ applied in the present research shows highest hardness at each degree of rolling condition. This condition suggests that there is optimum temperature to obtain highest hardness of carburized layer. High temperature is required in the carburizing process in order to provide diffusion energy for carbon into the steel surface. However, high temperature also accelerates other mechanism that imparts the softening of steel, such as grain growth process. Therefore it is important to determine and select the optimum temperature, in order to obtain the best character of steel substrate after the carburizing process

Table 4. The effect of degree of rolling on the hardness of carburized layer at each carburizing temperature

Carburizing temperature (^{o}C)	Hardness at degree of rolling (HV)		
	0%	30%	80%
850	641	782	805
900	847	914	1003
950	660	724	813

4. Summaries

The present research focuses on the effect of thermo-mechanical treatment as substrate preparation and carburizing temperature on the carburized layer. Carburized layer with the thickness of hundreds micrometer have been obtained after the process. It was observed that highest hardness obtained for the samples cold rolled at 80% degree of reduction. On the other hand, temperature of $900^{o}C$ gives the optimum carburizing temperature (regarding hardness properties) from the range temperature applied in the present research.

5. References

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