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Effect of Heat Treatment on Hardness and Microstructures of AISI 1045

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Abstract. The SAE/ AISI 1045, a type of medium carbon steel, is used most commonly in various structural and element of machines. Sometime, it failed during the in-service, which assumed to be caused by cracking in material as the effect of casting, manufacturing, or heat treatment processes. The current research was developed to find out the effect of hardening and of tempering processes toward hardness, microstructure and cracking. The objectives of the current research are to obtain the effect of cooling rates toward the hardness and cracking and to define a proper cooling media to get a martensite microstructure without cracking of heat resistant products. Results showed that the chemical composition from the spectrometry test confirmed that the specimens were classified as AISI 1045 or JIS S45C. The hardness values properties increased with increase of temperature, except at 1000 ^{o}C. The specimens having the hardness property more than that of ASME II standard were not useable due to its brittle.

Introduction

Pure iron is not used directly as a structural material because it is ductile and weak, and has no significant reaction to heat treatment. The combination of iron, carbon and other chemical elements produces steel which has a higher quality in hardness, strength, and ductility. Carbon, in a steel formation, affects the mechanical properties of the steel. Likewise mostly a heat treatment is based on carbon distribution control. The alloying is basis for the steel heat treatment to be conducted. Iron is the main element in the steel compound, while carbon plays a important role as a hardening agent. The quantity of carbon around 0.80 – 0.90 % increases the strength and the hardness of the steel significantly. Carbon amount up to 4.5% can be found in plain carbon steels, but the strength and the ductility are decreasing, which characterized as building construction steel [1]. Medium carbon steel AISI/ SAE 1045, is commonly used as shaft, bolt, crankshaft, connecting rod, hydraulic tube, pin, roll, spindle, etc which require a higher or at least an equivalent strength from that of XCQ. Nowadays, the AISI 1045 is widely used in the machinability which treated by calcium injection. Having the ability to stand a heat treatment, the medium carbon steel can be annealed at 800^{o}C – 850^{o}C and cooled at room temperature; hardened at 820^{o}C – 860^{o}C then quenched in oil or water; and should the process is continued to a tempering, the temperature to be set at 400^{o}C – 680^{o}C then cooling. However, tempering process at temperature of 150^{o}C – 200^{o}C decreases the residual stress, which minimizes the effect on the hardness. To get the best result, the decarburization from the specimen surface area has to be cleaned up.

The influence of nickel-phosphorus deposits on the corrosion-fatigue properties of AISI 1045 steel after being quenched and tempered had showed by [2]. In according to research report that there was not significant differences the fatigue life between the coated and the uncoated specimens. A further research on layer deposit by using post heat treatment [3] revealed the decreasing of the fatigue behavior from the same material. A study conducted by [4] showed that the microstructure of AISI 4140 steel, containing a higher carbon to that of AISI 1045 steel, was changing due to tempering process. The changing also influenced the mechanic properties significantly.

The phase transformations between BCC steel (ferrite) and FCC steel (austenite) during the heating and cooling process are that which define the microstructure and mechanic properties of steels. Defining an optimum thermo-mechanical process for variety of steel has been studied for many decades [5]. Moreover, the phase transformation rates were controlled by the diffusion of carbon, influenced by the fraction of pearlite in the starting nueclei and the small grain size of the steel microstructures. The higher fraction of pearlite in the microstructure of the AISI 1045 steel resulted in its initial high transformation rate, but its larger grain size, combined with its large patches of allotriomorphic ferrite, resulted in its longer total transformation time [6]. Electroless nickel-plating applied to AISI 1045 steel with and without post-heat treatment (PHT) and cavitation erosion test has been conducted by [7]. The study showed that the electroless nickel-plating with PHT increases cavitation resistance in non corrosive environments, which caused by the adhesion strength of film after PHT. Meanwhile in corrosive environments, the plating with PHT increases anti-corrosion electroless nickel. The objective of the present study is to obtain the effect of cooling rates toward the hardness and cracking and to define a proper cooling media to get a martensite microstructure without cracking of heat resistant products.

Methodology

Preparation. An AISI 1045, medium carbon steel known to have the best hammering ability, was prepared for the specimens. The lab equipment used was the standard machinability, responding well to a heat treatment, which specifications were the hardness after quenching was more than 55 HRC, the strength from 98 (HR) to 120 (WQ) ksi., and the extension from 24% to 18%. Some chemical materials such as HNO_3 and alcohol were used as an etching regent.

Procedures. The AISI 1045 steel, a 20 mm diameter of cylindrical rod, was cut for the specimens. The initial tests conducted were chemical composition, tensile test, and hardening test. The hardening process was then applied to increase the metal hardness of the specimens. Two stages were occurred during the process, which were the heating process and then the quenching process in water. In the heating process the temperature was increased to 850 ^{o}C and kept it still for about 30 minutes. The tempering process, re-heating the specimens after the hardening, was intended to decrease the hardness and increase the ductility of the specimens. The process was taken in various temperatures of 900^{o}C, 950^{o}C and 1000oC, with the time control of 60 minutes, 120 minutes and 180 minutes. The last step taken was hardness test and metallographic test based on Van der Voorf procedure [8].

RESULTS AND DISCUSSION

Spectrometry Examination. Based on Standard Chemical Composition AISI 1945 compared to actual based metal or speciment, which was choiced the outer surface element, by using *mass atomic spectrometry*, the composition presented in Table 1.

Table 1. Chemical composition of AISI 1045 standar and Spectrometry examination

Content	AISI 1045 Standar (%wt.)	Spectrometry (%wt.)
C	0.42 - 0.50	0.54
Si	0.15 – 0.30	0.40
Mn	0.50 – 1.00	0.70
P	0.04 Max.	-
S	0.05 Max.	0,03
Cr	-	0.11
Ni	-	0.23
Mo	-	0.06
Fe	balance	balance

Hardness Testing. The result of the initial specimens, before heat treatment, was on average of 290 HV. After the heat treatment with various temperatures and time control, the results showed in Figure 1 and Figure 2.

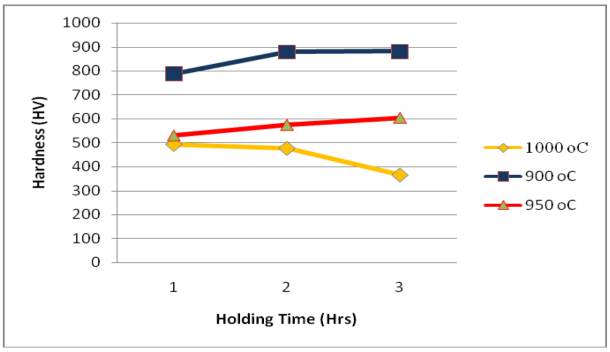

Fig. 1. Holding time vs hardness with different of temperature

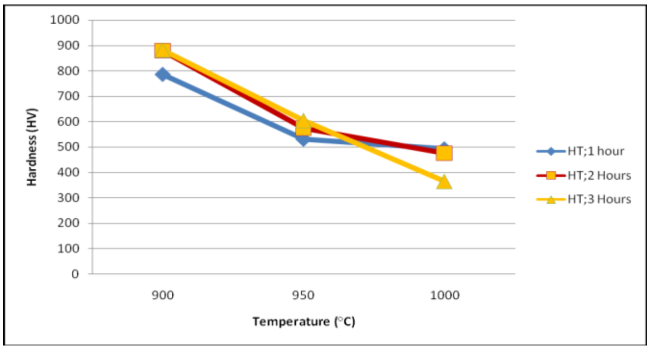

Fig. 2. Temperature vs hardness with different of holding time

Metalography Examination. The metallography examination and the analysis were based on Vander Voorf procedure [8]. The steps were started from specimens cutting to grinding and polishing, etching the surface using the Nital's regent etchant, and generating the microstructure sample under an optic microscope. The examination results obtained from the micrographs with 400X magnifications and 2% Nital's regent etchant (Figure 3–9). An AISI 1045 sample before heat treatment consists of ferrite and pearlite structures (Fig.3), and the same material samples were heat treated on its surface by hardening at 950^{o}C and 1000^{o}C with holding time of 180 minutes, 120 minutes, and 60 minutes respectivelly which obtained the martensite structures. Unfortunately, on all surface structures (Figure 4 – 9), appeared quench cracking. It means the higher heating temperature, the higher quench cracking, but also the higher holding time, the higher quench cracking.

Fig. 3. The microstructure before hardening heat treatment. The ferrite (bright) and the pearlite (dark). 400x, 2%Nital

Fig. 4. The surface structure after hardening at 950^{o}C, holding time of 180 minutes. The crack appear due to cracking quenched. 400X, 2%Nital

Fig. 5.The surface structure after hardening at 950^{o}C, holding time of 60 minutes. The crack appear due to cracking quenched. 400X, 2%Nital

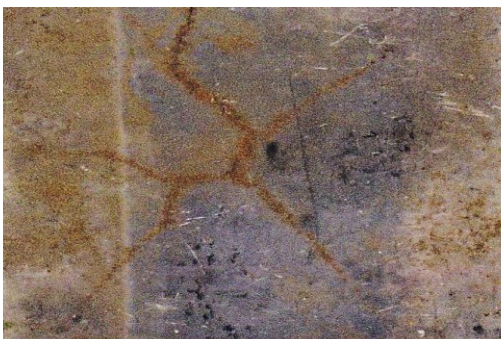

Fig. 6. The surface structure after hardening at 950^{o}C, holding time of 120 minutes. The crack appear due to cracking quenched. 400X, 2%Nital

Fig. 7. The surface structure after hardening at 1000^{o}C, holding time of 180 minutes. The crack appear due to cracking quenched. 400X, 2%Nital

Fig. 8. The surface structure after hardening at 1000^{o}C, holding time of 60 minutes. The crack appear due to cracking quenched. 400X, 2%Nital

Fig. 9. The surface structure after hardening at 1000^{o}C, holding time of 120 minutes. The crack appear due to cracking quenched

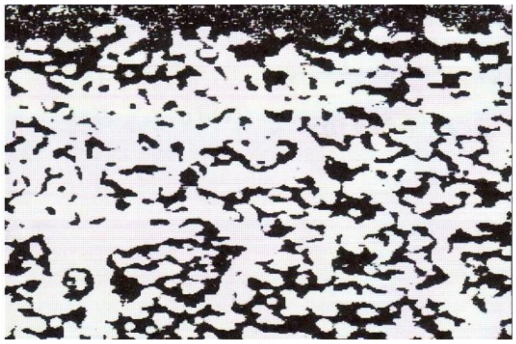

Fig. 10. Decarburization microstructure after hardening at 900^{o}C and holding time of 60 minutes, the thickness of the layer was 265 μ

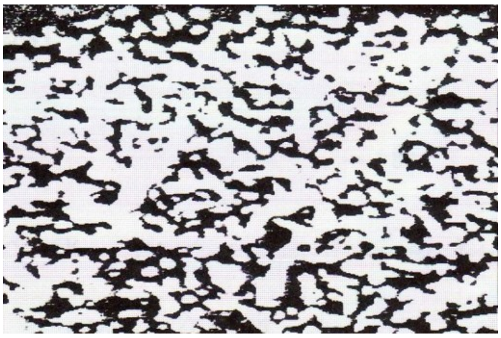

Fig. 11. Decarburization microstructure after hardening at 900^{o}C and holding time of 180 minutes, the thickness of the layer was 305 μ

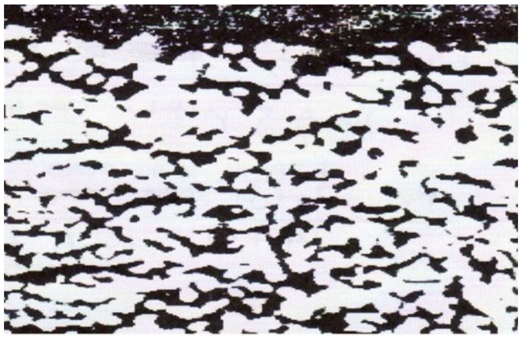

Fig. 12. Decarburization microstructure after hardening at 900^{o}C and holding time of 180 minutes, the thickness of the layer was 345 μ

The higher martensite hardness due to AISI 1045 will be brittle, and during rapid cooling until room temperature, it shall attend the residual stress. If tensile residual stress was higher than the tensile strength, so this material occurred the quench cracking. If these samples examined by The Scanning Electron Microscope with magnification up to 5000X, it may be revealed intergranular fracture. Therefore, quench cracking was very sensitive to external loading, so it must be decreased the carbon content or decarburizing by using tempering process. Decarburization microstructure after tempering produced as shown in Fig. 10–12 that on the top of pictures were a part of sample surfaces. On surface of sample can be measured the layer thickness of decarburazation as tempering product. Carbon trapped during phase transformed from austenite to martensite, and it can be released by heating on AISI 1045 at A_1 line below of Fe_3C – C phase diagram. Releasing carbons, surface structure deformed plastically and releasing the residual stress. Its reason that decreasing hardness and increasing the toughness on material. The measuring results that the carburization layer thickness after tempering process of AISI 1045 at 900^{o}C, 950^{o}C and 1000^{o}C obtained the 304 μ, 350 μ and 418 μ respectively.

Its means that the higher heating temperature, the higher thickness of decarburization layers after tempering.

Summary

Based on the results analysis, the conclusions are taken as the following:

The chemical composition from the spectrometry test confirmed that the specimens were classified as AISI 1045 or JIS S45C and the specimens having the hardness property more than that of ASME II standard were not useable due to its brittle i.e. easy to break. The hardness value obtained based on the Vickers was 84927 HV for HT 900^{o}C, 570 for 950^{o}C and 444 for 1000^{o}C. The hardness values properties increased with increase of temperature, except at 1000 ^{o}C

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