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The Effect of Austenization Temperature in Surface Hardening Process on Steel Plate as Ballistic Plate

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Abstract. Ballistic resistant plate is a plate that is able to withstand the rate of projectiles. Ballistic resistant plates or armor plates are applied to military vehicles. It requires a combination of hardness, strength and toughness. Surface hardening with heat treatment is carried out to obtain ballistic resistant properties. The article is aimed at increasing the hardness of one of the surface in commercial medium carbon steel. The variation of austenization is done at the temperatures of 700, 800 and 900°C with induction heating and holding time for 3 seconds. The quenching media used 15 litters of oil. Several tests are conducted: The results of surface hardening are observed in microstructure, distribution of hardness is tested by micro vickers, tensile testing and impact testing. Tensile testing in accordance with ASTM E8 standards and impact testing with E 23 standards. The transformation of ferrite and perlite to marten site is obtained on the surface of the plate in the temperature of 900°C. At that temperature, hardness increases on the surface and tenacity can be maintained. In addition, the value of hardness, tensile strength and impact energy were significantly increased. Impact energy as a material requirement for ballistic resistance had been achieved, but hardness and tensile strength still need to be increased.

Keyword: Surface hardness; induction heating; ballistic resistance

1. Introduction

Sovereign countries will always defend and protect themselves from various threats and attacks. In modern defense, a variety of protective equipment is needed to defend firearm attacks. One of the equipment is armor plate. Armor plate can be applied to shields and ballistic-resistant military vehicles. Ballistics is the study of the acceleration of moving objects which is further defined as the study of the behavior of projectile and its impact [1]. Armor material must be high in strength because ballistic endurance is the right combination of various properties such as strength, ductility and formability [2]. Ballistic steel is a complex function of the mechanical properties of steel, such as yield strength, tensile strength, hardness, ductility and impact toughness [3]. Hardness, tensile strength, ductility and impact energy affect the characteristics of projectile holes on a projectile-resistant plate [4]. These properties are gained by combining several plates with different properties through a multilayer plate and can be achieved by surface hardening.

Surface hardening is usually used to increase wear resistance [5]. The result of surface hardening is a hard surface with tough inside. Surface hardening can be done by heat treatment. Specific treatment to obtain surface hardness is induction heating. Induction heating allows fast heat generation for austenisation temperature in the surface, and leaving the core below the austenisation temperature. The procedure is followed by quenching so only the part that has reached the austenite temperature is transformed into hard marten site. Induction heating is affected by electromagnetism and heat transfer. By using simulation, the optimization of induction heating can be achieved [6]. Plate strength can be increased by using induction heating [7]. There are several factors which affect the results of induction heating, especially the heating and cooling procedures [8]. The experiment-verified simulation showed that the transformation of microstructure and the depth of hardening are affected by heating rate and peak temperature [9].
Armor material is not only characterized by high hardness value. High hardness value may result in cracks, shifts and perforation due to projectile impact [10]. The optimum projectile penetration on a high-strength hardened steel armor plate is 555 VHN [3]. A combination of violence and toughness is required. The hardness of the material is used to hold the projectile rate and the toughness of the material is used to absorb the impact energy [11] [12]. The combination of hardness and toughness can be done by making a multilayer plate. The use of multilayer plates is expected to increase the ability of ballistic-resistant construction [13]. Multilayer plate can provide higher ballistic endurance compared to single plate [14]. Two plates are chosen for experiment: plate with high rates of hardness and strength and plate with low hardness and high toughness. The plate with high hardness on the front surface and the plate with low hardness and high toughness have better ability to resist projectile speeds [4]. To increase the impact energy absorption, rubber coating is included in several experiments. In the simulation, the largest absorption of projectile energy is obtained by soft plate with rubber coating [15].
As explained above, another alternative for multi-layered plate is making a single plate with different levels of hardness. Hardening is done on one surface of the plate. Surface hardness will increase strength, while the core toughness is maintained. Surface hardening in structural steel can increase ballistic resistance by more than 20% compared to layered plates or plates with uniform hardness [16].
The use of multilayer plates with different hardness values to resist projectiles has been extensively studied. Hardness and strength are able to withstand the speed of projectiles, while toughness allows the absorption of projectile kinetic energy. However, the use of single-surface hardened plate for ballistic resistance is still limited. This article examines single plates with different levels of hardness on one of its surfaces. Variation on austenisation temperature is established to analyse the microstructure results and mechanical properties to obtain initial data from commercial medium carbon steel suitable for armor.

2. Method

The material used in the current experiment is commercial medium carbon steel with the chemical composition as shown in Table 1. The experiment used single plates with the size of 100 x 150 mm and 8-mm thickness. One of the surfaces of each plate was heated to experimental temperature using induction heating coil for 3 seconds. The experimental heating temperatures were 700, 800 and 900oC. Once reaching the expected temperatures and holding times, the samples were immediately immersed in 15-liters of cooling oil. The result of plate heating and immersion plates were taken as micro-observation specimens, hardness test specimens, tensile test specimens in accordance with ASTM E8 standard and impact test specimens according to ASTM E23 standard. Microstructure were taken on six points of cross section from the top surface to the bottom. Hardness test was done by micro Vickers method on cross section to determine the distribution of hardness from the top to bottom surface in 20 points with the distance of 0.4 mm from one point to another. The points of microstructure and micro vickers are shown in Figure 1.

Table 1. Chemical Compositions (%wt.)

Material	**Chemical Compositions**
Medium carbon steel	0.4667 %C; 0.5584 %Mn; 0.0556 %Cr; 0.0411 %Ni; 0.2441 %Si; 0.0002 %Nb; 0.0163 %Al; 0.001 %V; 0.0106 %S; 0.0013 %Mo; 0.0016 %W; 0.0195 %P; 0.0577 %Cu; 0.0044 %Ti; 0.0078 %N; 0.0002 %B; 0.0064 %Sb; 0.0003 %Ca; 0.0009 %Mg; 0.0004 %Zn; 0.0108 %Co; Fe balance.

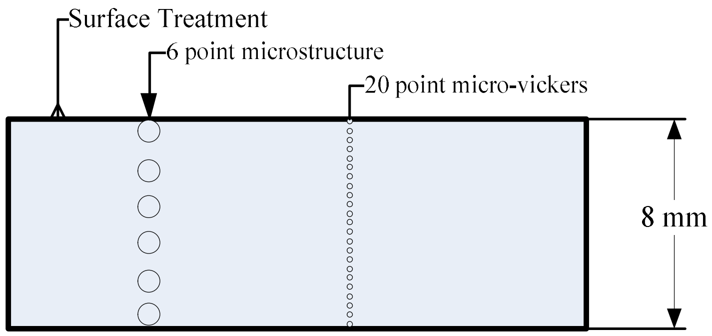


Figure 1. Sampling positions of microstructure and micro-vickers hardness

3. Results and discussion

The material used is the commercial medium carbon steel. The microstructure observations on raw material shown in Figure 2 presented the microstructure of the material with perlite and ferrite phases.

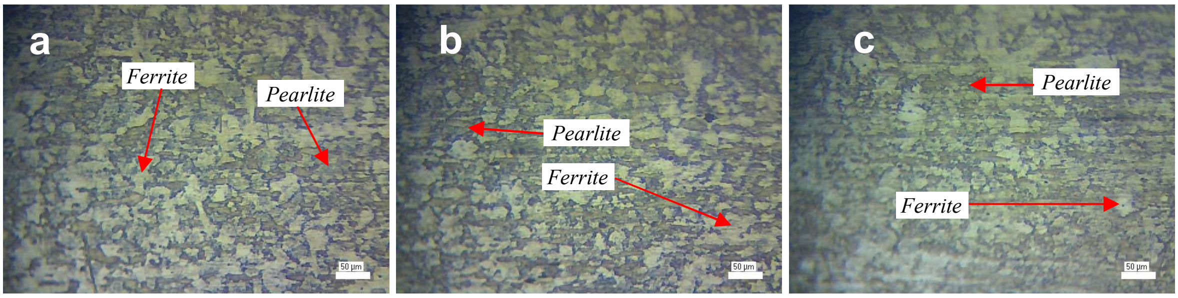


Figure 2. Microstructure of the raw material in cross-section area
(a) upper side, (b) middle side and (c) bottom side

Ferrite and pearlite structures dominated the upper (Figure 2a), middle (Figure 2b) and bottom sides (Figure 2c). The domination of ferrite and perlite structures indicated a low value of steel hardness. The ferrite structure looks brighter, while the perlite structure tends to be darker. This structure of perlite is a laminar between ferrite that ductile and cementite (Fe_3C) the hard and brittle.

The microstructure of the materials which have been austenized on its surface of 700°C temperature for 3 seconds and dipped in the oil media is shown in Figure 3.

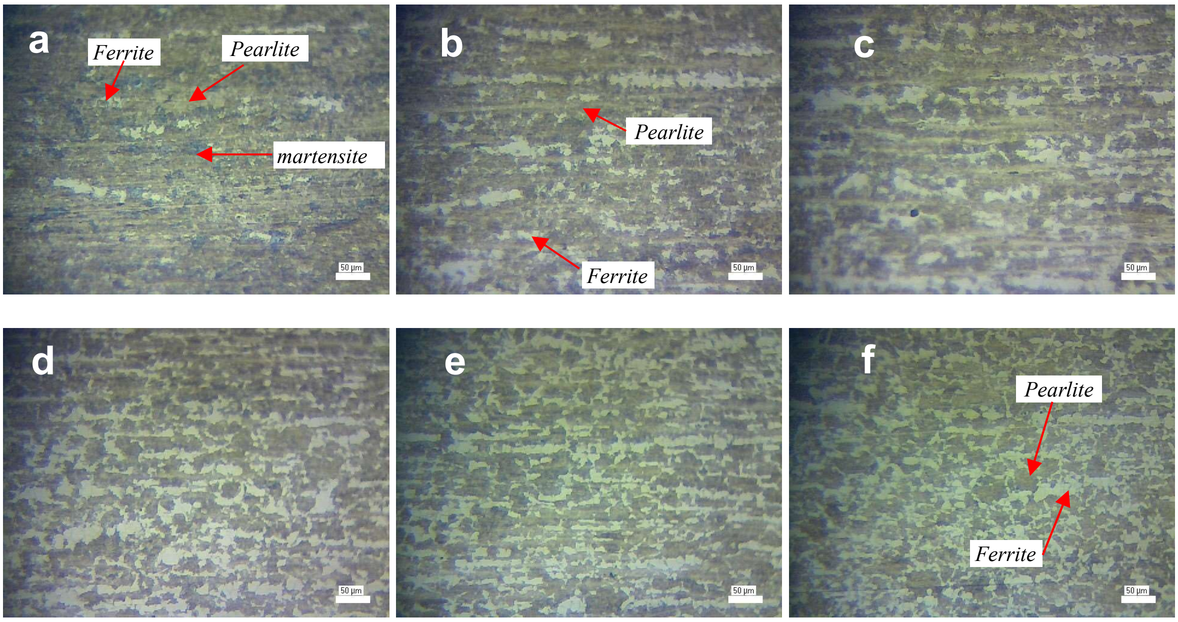


Figure 3. Microstructure of 700°C austenization in cross-section area
(a) point 1, (b) point 2, (c) point 3, (d) point 4 (e) point 5 and (f) point 6.

Austenization with heat treatment in 700°C temperature on the plate surface and immersion in the oil media induced transformation in the structure. Perlite is dominated the structure of point 1 (Figure 3a). Perlite structure as the lamination of ferrite and cementite characterized steel hardness. Likewise, the structure of point 2 (Figure 3b) is dominated by perlite as the combination of hard ferrite and cementite layers. Point 3 (Figure 3c), showed decrease in the perlite structure. Lastly, the structures of points 4, 5 and 6 (Figures 3d, 3e and 3f) showed ferrite and perlite as in raw material. The results indicated a structural transformation on the plate surface.
The microstructure of the austenized samples at 800°C temperature are shown in Figure 4. Quenching in oil cause rapid cooling of the austenized surface of the samples.

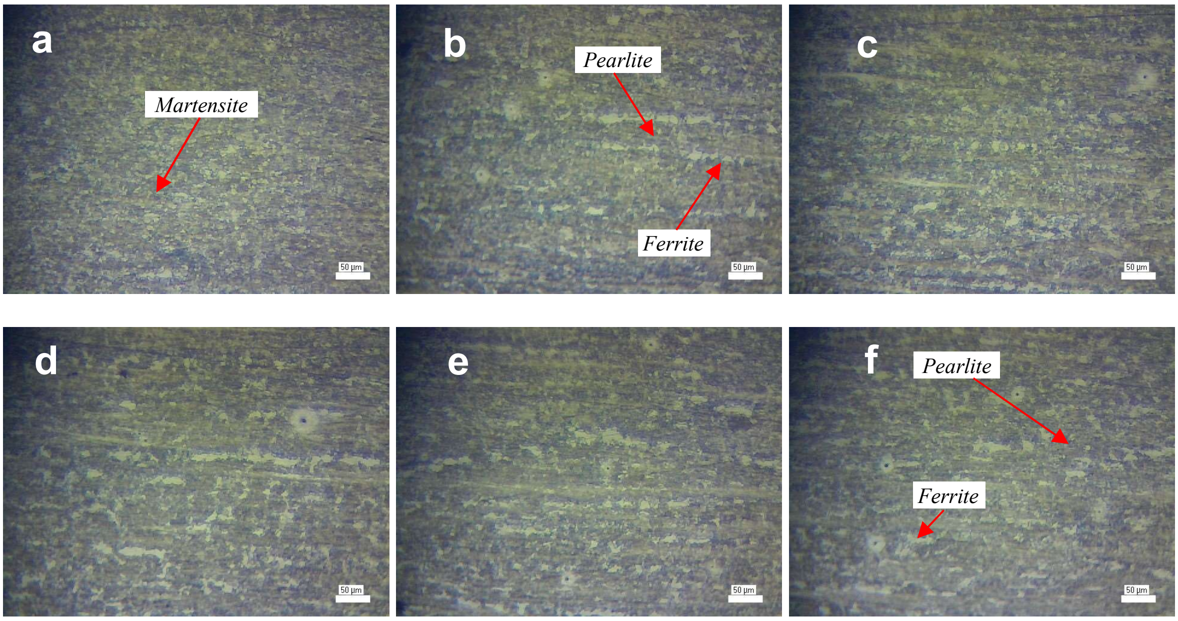


Figure 4. The microstructures of the austenized samples at 800°C temperature in cross section
(a). point 1, (b). point 2, (c). point 3, (d). point 4, (e). point 5 and (f). point 6.

The surface side (point 1) showed the martensite structure (Figure 4a) with dark appearance. This structure has a harder, yet brittle characteristic compared to cementite. Whereas, point 2 (Figure 4b) shows a little amount of martensite, together with the appearance of ferrite and pearlite. Whereas the next points (Figures 4c, 4d, 4e and 4f) are dominated by ferrite and perlite structures.
The microstructure of the austenized samples at 900ºC temperature and quench in the oil media are shown in Figure 5.

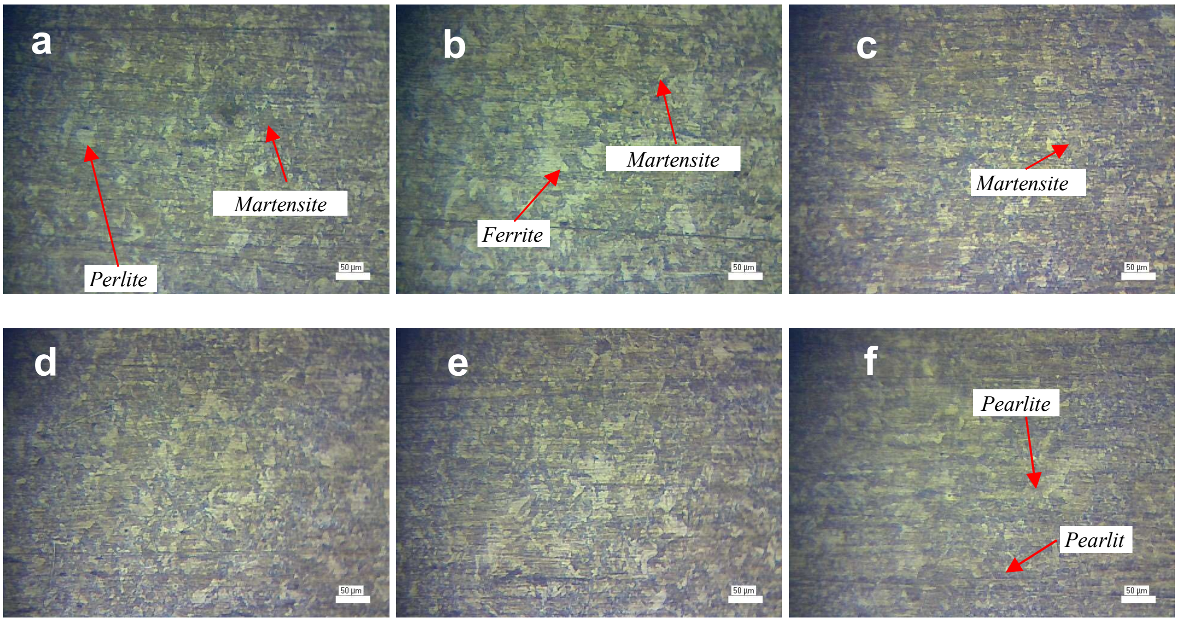


Figure 5. The microstructures of the austenized samples at 900ºC temperature in cross section in cross section
(a). point 1, (b). point 2, (c). point 3, (d). point 4, (e). point 5 and (f). point 6.

Martensite structure dominated the observation points 1 and 2 (Figures 5a and 5b), and partial martensite phase is shown at point 3 (Figure 5c). Whereas, the martensite structure is reduced at points 4, 5 and 6 with visible ferrite and perlite phases. The increase in the austenization temperature of 900ºC caused higher formation of martensite structures on the surface and inner parts of the sample. This is due to the greater conduction heat which entered the plate core, so that the austenization temperature heated the deeper area.
The hardness distribution in the cross section of each austenite temperature variable is shown in Figure 6.

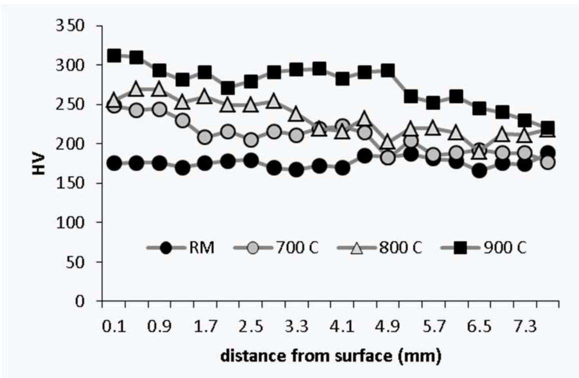
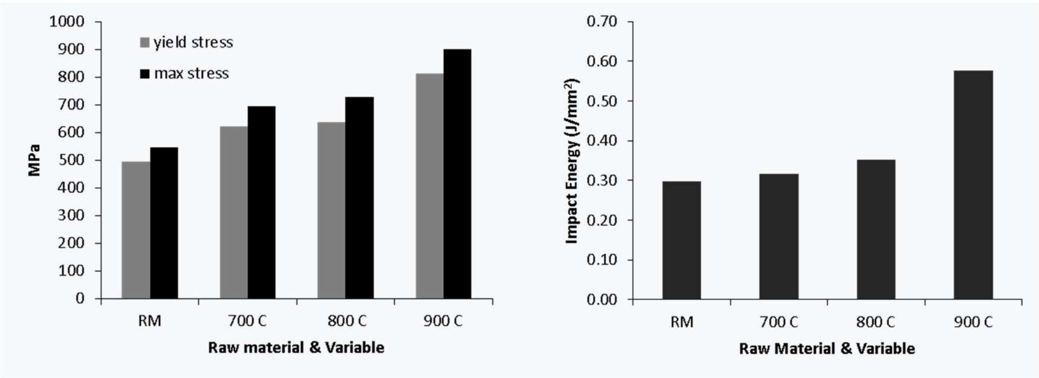


Figure 6. Graph of hardness distribution

The average hardness of raw material is 209 HV. Hardness is evenly distributed across the cross section from top to bottom. Meanwhile, the distribution of hardness in the heated samples was increased on the surface side. The highest hardness value at 312 HV was obtained at 900ºC temperature in the surface area (0.1 mm depth). At all variations in the austenization temperature, the farther the distance from the surface, lower the hardness. It indicates that the transformation in martensite structure on the surface increased the value of hardness. More martensite structures increased the hardness value. Brief austenization on one side of the plate surfaces and immersion in oil can change the surface hardness on one side of the plate, while the hardness of the other sides of the plates is maintained from the raw material. According to [17] [18], the hardness value which is capable of resisting the ballistic speed is around 450 HV, so this result is still unable to resist the projectile speed.

The average tensile strength of raw materials and the variety in austenization temperature are shown in Figure 7.



A b

Figure 7. Graph a). Yield stress, maximum stress and b) impact energy

The average tensile strength, both yield stress and maximum stress, were increased after austenization and quenching. The higher the austenisation temperature, the higher the tensile strength. With oil quench media, the impact toughness is also increasing. This is different from the results of hardening with water media in which the higher the hardness, the higher the tensile strength; but the impact energy is smaller because the material is brittle. The highest impact value of 0.58 J/mm2 is achieved at the temperature of 900ºC austenization.

The highest maximum tensile strength value is achieved in samples at 900ºC austenization temperature of 900 MPa. This value has not been able to hold the projectile rate of 1750 MPa [17]. The test on impact value of the HB500 bullet proof plate showed the result of 0.43 J/mm^2 [19]. Therefore, the impact value obtained in this study with austenisation variable of 900ºC and oil quenching is 0.58 J/mm^2.

4. Conclusion

Based on the experiments results, it can be concluded that the surface of the medium carbon steel plates with 8-mm thickness can be hardened. Ferrite and pearlite phase in the raw material on the transformed surface were transformed into martensitic, especially at austenization temperature of 900ºC. The hardness of the surface can be increased up to half of the plate thickness, while the tenacity of half of the plate is maintained its tenacity at austenization temperature of 900ºC. Based on the initial reverence, the variation of austenization temperature at 900ºC combined with immersing on oil media will produce impact energy sufficient for ballistic-resistant plate properties. The hardness, strength and energy impact have been significantly increased compared to raw material, but the hardness and tensile strength were needed to be increased.

5. Acknowledgment
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