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The Influence of Hot Rolled Plate Steel Treatment using Temper and Quench-Temper Method on Vickers Hardness Number Enhancement

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Abstract: The material performance has main features such as hardness, strength and toughness. Steel is the ferrous metal that functions as a fundamental element mixed with several parts. This research to obtain Quench Tempered Steel material with high hardness and analysis radius bending of steel treated by quench and temper methods, the influence of hold time, diameter of steel and impression rim was studied. The result shows that the high value of hardness is 498 HV with a holding time of 20 min which means steel developed has an eminence tensile strength combination, impact strength and satisfactory ductility for structural application.

INTRODUCTION

The structural protection technology uses a protective material such as metal and alloys, polymers, ceramics and composite materials which has the main features of material performance hardness, strength and toughness. Steel is an alloy, ferrous metal that functions as a fundamental element mixed with several parts. It has been used for a long time as a protector because it is low cost and has more strength when combined with good toughness. Many researchers studied the impact of alloy composition and heat treatment on the steel's mechanical traits such as macro and micro inspection. Quenching and tempering is one of steel's mechanical properties treatment to increase steel reinforcement[1, 2].

To see the effect of temperature's quench and temper on multi-level martensite steel and relation amongst microstructure, strength and toughness properties were used the Scanning Electron Microscope (SEM), Electron Backscatter Diffraction (EBSD) and Transmission Electron Microscopy (TEM). The results show that the enhancement of quenching temperature can increase the grain size of the austenite (dr), martensite package (dp) and beam (db). In contrast, the size of the martensite battens (dl) was the opposite. On the other hand, the levels of martensite change from irregular to sequential. The high angle limits (HBs) and low angle limits (LBs) are each prior austenite grain boundaries, packs, beams and martensite blades. Calculating the multi-level microstructural sizes with mathematical models[3-5].

Steel metal has strength, toughness and energy absorption capabilities that can be used to structure protecting from an explosion. Armored steel is the best-known alloy as used as a protective material. Homogeneous armor is one of armored steel which currently used for structural applications. Armored steel has properties that include: convenient fabrication, wear service resistance conditions, fatigue adequate, high resistance perforation and ballistic impact. Hardness is an important characteristic of the material used for tank strategy. The high hardness was given by armor directly determines the performance of the tank and the perforation mode. Many steel studies reveals the relation amongst the hardness matrix and performance steel after contact. Besides, toughness is another essential property for armored materials that have high kinetic energy on the dynamic attack of projectiles and the armored steel can still be developed[6-8].

Armor steel has high strength and hardness to protect conveyance, vehicle, object or individual from direct pressure projectile. In Indonesia, it was made from hot rolled steel which heat-treated by quench and temper treatment. Steel results from Quench and Temper treatment are used for military materials such as main battle tanks and their kind[9]. A requirement possessed by armor steel as a tank body material is a variety of mechanical properties such as the range value of yield and tensile strength at 1146-1463 MPa, various hardness of steel at 381 VHN-586 VHN and Charpy impact energy between 19-85 J depending on the tempering temperature[10, 11]. This research to obtain Quench Tempered Steel material with high hardness and formability; it meant the nature of HRPS material that can be machine-processed, welded, bent with a bending machine which will be used for tank-making materials[12-14]. The novelty in this study based on hot rolled plate steel analysis of the bending and Quench-tempering process gave yield stress results of 561.148 Newton with a strain of 43.82% and after receiving Quenh-temper treatment, the hardness increased by 498 HV and fine grains r 2.341 µm had an impact on microstructure. The ferrite and martensite dulpex is evenly distributed, so that, this material has stronger, ductile and hard properties. Can be applied for industrial needs.

MATERIALS AND METHODS

Material and experimental procedure: Medium carbon steel Hot Rolled Plate (HRP) is used as the material on this research one of abundant yet cheap for industrial use than high carbon steel. The steel has a carbon content of 0.3-0.6% and a manganese content ranging from 0.06-1.65%. This product is more robust than low carbon steel and it is more challenging to forge, weld and cut yet cheaper than high carbon steel[15]. Through heat treatment, the percentage of carbon is increased so steel becomes more robust and hardness but it could be decreasing of melting point and ductiles. This research uses 120×15 mm HRP steel to imitate the material shape which is usually used in the armor industry, as presented in Fig. 1. The HRP steel variants used in this study show the different carbon percentages, affecting the study results (Table 1).

This research to determine the VHN value, HRP steel was conducted using temper and Quench-temper methods to hold time variations of 10, 20 and 30 min. The cooling medium is room-temperature water. The diameter of steel variants is 50, 55, 60, 65 and 70 mm. The impression rim variations are 1-10 mm, along with Vickers Hardness Number (VHN) results for each impression rim. The impression rim variants present a varying carbon increase and VHN value while the diameter increases the material grain size which may affect the results study (for material properties). The VHN is a hardness test commonly used for metal and alloy. The test procedure applies to a known load surface of the tested material through a known diameter of a hardened

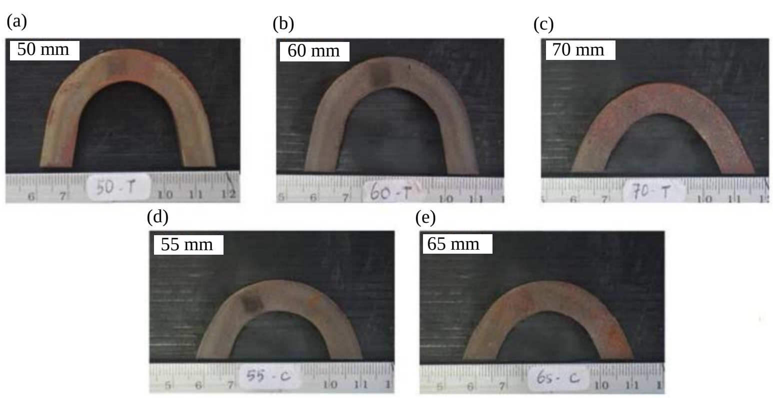

Fig. 1: HRP steel

Table 1: Chemical materials of HRP steel (mass %); PT Krakatau steel

Al	C	Cr	Cu	Fe	Mn	Mo	Ni	P
0.04	0.29	0.55	0.08	96.76	1.41	0.19	0.28	0.02
Pb	S	Si	Sn	Ti	V	W	Zn	Zr
0.008	0.008	0.33	0.003	0.004	0.02	0.009	0.003	0.001

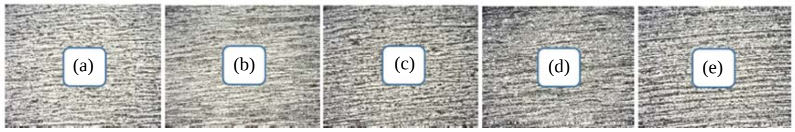

Fig. 2(a-e): Grain size at various R (mm): (a) 50, (b) 55, (c) 60, (d) 65 and (e) 70

Table 2: Hardness value of HRP steel; A research study of Micro Vickers hardness test

Test object code	VHN_1	VHN_2	VHN_3	VHN_4
HN_{HRC}	248.60	278.33	298.73	275.22

steel ball. The results diameter of the tested metal is measured and the Hardness Vickers (VHN) calculated as:

$$VHN = \frac{1.8544\ F}{D^2} \quad (1)$$

Information VHN is Vickers Hardness Number. D is the Width of Vickers indent (mm), F is Load/force indenter pressure (gf).

This study wants VHN results to be <500. Therefore, the maximum test load will be >200 gf but <300 gf (as listed in VHN equation notes). The VHN results of the material used in this study listed in Table 2. Before this research began, the pretreatment and calculation conduct to provide the constant test variable. The grain size Fig. 2 of each Radius (R) value is also listed below.

RESULTS AND DISCUSSION

The first test conduct after tempered treatment which was later called T-HRP steel-the results of this test listed in Table 3 and Fig. 3.

The sediment phase is soluble, especially the interdendritic gamma-prime deposits, prime carbides and homogenize the microstructure affecting by heat treatment. The second stage is residues and aging heat treatment to obtain the hardening phase's gamma precipitation. Steel can also be hardened by heating it at an austenite temperature for some time, then cooling it more quickly. Vicker's value after 20 min temper treatment writes in Table 4, analysis shows that temper treatment affected the mechanical sample properties such as the tensile strength, hardness and toughness. Tempering hardening increase the specimen's hardness, when viewed from the number of Vickers hardness, caused because carbon does not react longer with oxygen on the cooling rate. Hence, the carbon was trapped in the specimen and forms martensite. Normalization is not softening the steel until the extent of cooling, nor does it restore as much ductility as cooling does. Tempering provides toughness at the expense of hardness to the hardened steel part by reheating at 900°C and cooling it quickly with the tempering process carried out under MF at 150°C, martensite remains stable but which reduces the residual compression stress. In this study, heat treatment using quench and temper methods to obtain a fine grain structure that is challenging, tough and has better yield strength. The hardness value of steel specimens that accompanied by cooling and pearlite's percentage rate was observed to higher. One of the phases that become the strengthening of steel is the martensite. The escalation of harshness consequent by the delay forming of pearlite and martensite on the cooling rate, as shown in Fig. 4 of the iron-carbon phase diagram. Yield strength values for hardened specimens observes to be greater than standard untreated samples.

Based on Fig. 5, the bending radius (R) between 50 mm until 70 mm obtains the high-value hardness at 55 mm of the bending angle with measurement distance 1 and 2 mm of 348 HV and the low value at 70 mm of 276 HV. It causes by tempering treatment, so, a structure denser while the damaged form occurs at another radius due to excessive bending. However, the increasing bending radius could failure the important contexture in the material. Compare Table 3 and 4, the result of the high VHN value of regular HRP Steel at R 55 mm is 313 HV and the VHN value of standard T-HRP Steel is 348 HV. It proves that the tempering (T) treatment could increase dan fix up the hardness structure. After temper treatment for micro-hardness structure, at 20 min and 7 for 30 min, Fig. 6.

Figure 6 shows that temper treatment at ten minutes changes refined grains to coarse and in Fig. 7, the coarse grain pores are getting wider[16]. It showed that less holding time could maintain the hardness of steel and indicates the presence of plastic deformation due to microstructure's transformation, hardness and impact resistance. Furthermore, the enhancement the temper treatment hold time can be damaged the material structure, so, it can diminishes the hardness steel.

The second test conducts after quenched and tempered treatment which was later called QT-HRP steel. The hardness test results at 900°C quenching treatment and 30 min holding times are seen in Table 4 and Fig. 8. The test specimen has increased material hardness toughness, indicating that the material is rigid compared to 20 min in Fig. 5.

Table 4 showed that the bending radius between 50 and 70 mm obtain the high value of hardness test at a measurement distance of 9 for 60 mm bending angel, 1, 2 and 8 mm for 70 mm bending angel that is 498 HV.

Table 3: VHN value of T-HRP steel after 20 min tempered treatment

	R of T-HRP steel (mm)				
d (mm)	50	55	60	65	70
1	272	348	297	313	290
2	272	348	290	305	276
3	274	339	283	309	263
4	274	330	276	297	257
5	257	276	257	305	234
6	239	321	245	269	221
7	239	321	229	269	221
8	248	313	251	279	237
9	266	317	263	313	257
10	276	317	283	313	290

Table 4: VHN value of QT-HRP STEEL after 30 min tempered treatment

	Radius bending of QT-HRP steel (mm)				
d (mm)	50	55	60	65	70
1	450	453	426	439	498
2	450	453	444	439	498
3	453	453	444	439	495
4	453	453	453	439	495
5	453	450	453	453	489
6	453	460	467	446	495
7	453	467	475	482	475
8	467	464	490	482	498
9	467	464	498	482	498
10	460	460	490	482	498

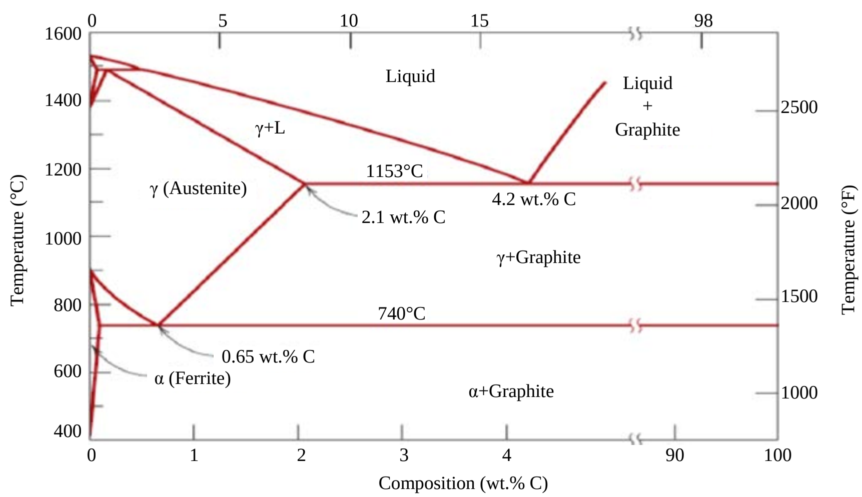

Fig. 3: Iron-carbon phase diagram[15]

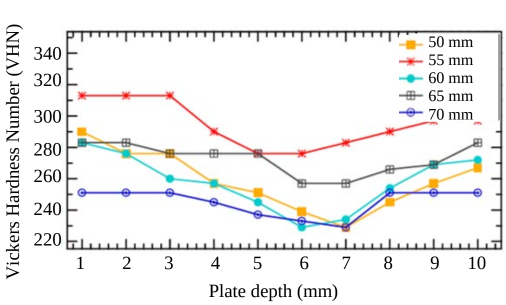

Fig. 4: VHN diagram of regular T-HRP steel

Figure 9 shows that the bending radius 70 mm has a denser structure compared to 60 mm. Compare Table 3 and 4, the result of high VHN value of regular HRP Steel at R 60 mm is 283 HV and at R 70 mm is 251 HV, VHN value of traditional T-HRP Steel R 60 mm is 297 HV and R 70 mm is 290 HV and VHN value of QT-HRP Steel R 60 mm and R 70 mm is 498 HV. It proves that Quench and Temper (QT) treatment could fix up and increased the hardness structure.

Based on Fig. 9, mild grains after 10-20 min of Quench-temper treatment show that the increase of

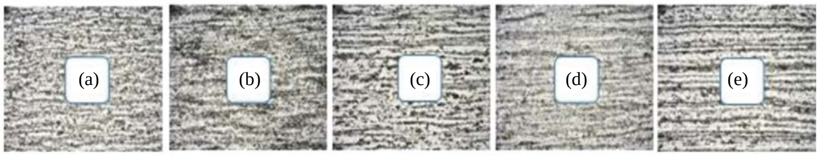

Fig. 5(a-e): Hardness structure of T-HRP steel after 20 min treatment at various R (mm): (a) 50, (b) 55, (c) 60, (d) 65 and (e) 70

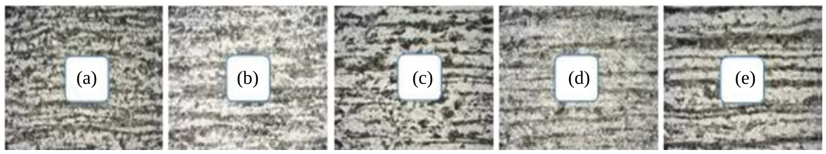

Fig. 6(a-e): Hardness of T-HRP after 30 min treatment at various R (mm): (a) 50, (b) 55, (c) 60, (d) 65 and (e) 70

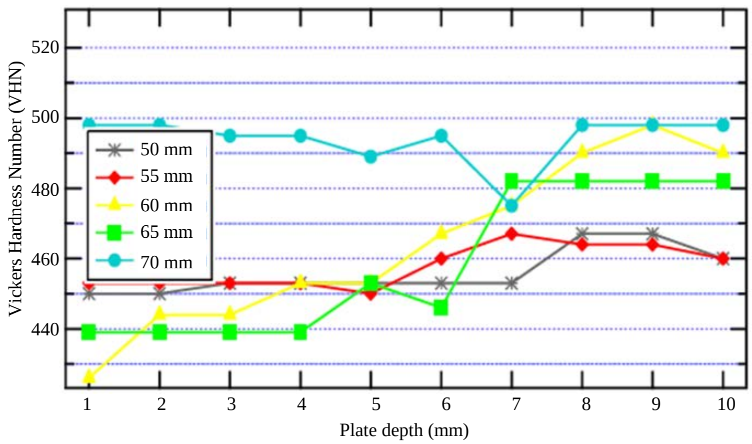

Fig. 7: VHN diagram of regular QT-HRP steel

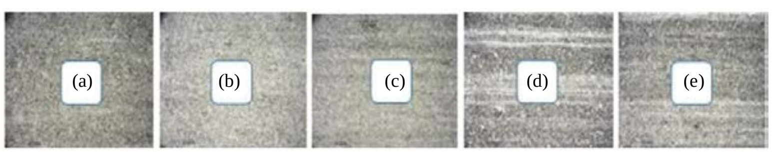

Fig. 8(a-e): Hardness structure of QT-HRP steel after 20 min treatment at various R (mm): (a) 50, (b) 55, (c) 60, (d) 65 and (e) 70

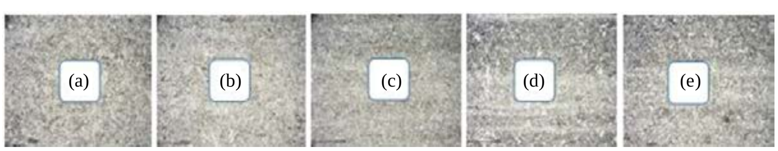

Fig. 9(a-e): Hardness structure of QT-HRP steel after 30 min treatment at various R (mm): (a) 50, (b) 55, (c) 60, (d) 65 and (e) 70

hardness, the grain being delicate due to plastic deformation during bending is eliminated to be changed in the shape and surface irregularities due to strain. Figure 10 shows coarse grain after thirty minutes and the increase in temperature. The result proves that quench and temper treatment had changed the hardness at a 70 mm bending radius which reaches 498 HV, the high value of VHN on QT-HRP compare to T-HRP which indicates the

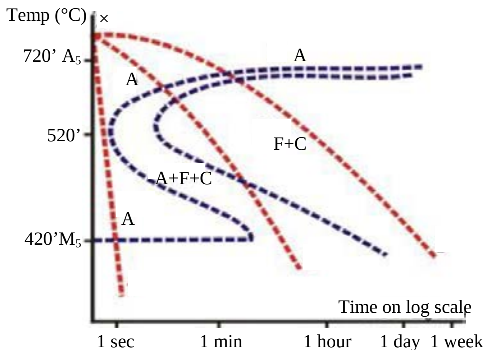

Fig. 10: Curve various cooling rates to obtain microstructure[17]

increase of ductility steel. However, the hardness structure of the material damages by the rise of holding time and temperature, so that, causes deformation back at a particular position. As shown in the effects of quenching and temper microstructure, ferrite has a light color and pearlite has a dark color. The microstructure of the sample's quench and temper processes, the ferrite has undergone recrystallization because the low microstructure of carbon steel was treated by a cooling method with no stress matrix. The deformed structure was thoroughly homogenized at 900°C, moreover consists of refined ferrite grains and during the slow cooling process the pearlite can more distribute between temperature's austenitizing and the final micro room. Figure 8 shows the Hot Rolled Plate Steel (HRPS) experiment microstructure carried out by a cold working process, namely bending the HRPS (bending) then quenching and tempering the specimen to improve the steel properties. The samples that were treated indicate that they affected the original austenite grain's form and measurement strongly. The piece shows a pearlite matrix in which short graphite flakes have hard properties. Steel can also be hardened by heating it to the austenite temperature for some time, then cooling it as shown in Fig. 11. The microstructure curve formed is martensite which is very hard.

CONCLUSION

Tensile stress on the surface caused by bending, quench and temper affects the hardness value. The highest value is 498 HV with a holding time of 20 min. Due to the hardness distribution of the area due to the atomic density caused by atomic displacement during plastic deformation due to the process's influence. Heating, obtained from the position of the bending radius R = 70 mm.

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