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To cite this article: Achmad Taufik *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **420** 012045

The effect of heat treatment quench-temper and radius bending against hardness hot rolled plate steel

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Abstract. Hardness is a material physical property that needs to be known to apply on steel HRPS. Each treatment given to the HRPS steel can change its physical properties, since the treatment given by the microstructure on steel HRPS will change. This study is carried out by means of a 55 mm and 60 mm bended HRPS steel, which then applied the quench and temper heat. The next step is by analyzing the hardness of a material at each point using Hardness Vickers tester. The hardness value at each point with distance per 1mm is started from the curve point due to bending. Hardness is identified from the nature of the changes indicated by the hardness test data. The results show that, there is an increasing hardness level resulted from the heating level. The quench-temper heat treatment process on the HRPS steel has a clear effect on structural changes and mechanical properties of the HRPS steel. In addition, bending treatment with different angles affects the hardness value on the steel HRPS.

1. Introduction

Steel is accepted globally as an ingredient which is primarily used for the construction of military and non-military vehicles. This is due to features associated with steel, such as high energy absorption properties, high strength, greater notch toughness and high hardness [1-3]. The selection of suitable armor materials for defense applications is essential in terms of improving system mobility and maintaining safety.

Armor steel is protective steel used to prevent damage to an object, an individual, or a vehicle with direct contact of a weapon or projectile, usually during combat, or from damage caused by a potentially hazardous or out-of-control environment. In other words, armor steel is a steel that can protect objects (people or others) against projectile (bullet) attacks, therefore this steel is widely used in military purposes (such as combat vehicles and others). In order to withstand the impact of the projectile, the armor steel is to have a good toughness (which is a combination of strength, plasticity and hardness). One of the steel that has good toughness is Quenched and Tempered Steel or Q & T Steel. The steel in question is obtained by treating heat of quenching and tempering on heat treatable steel. The armor steel ballistic performance is based upon hardness, the higher the hardness the better the ballistic performance. The main considerations in military use are its resistance to penetration, and lightness. The optimum property of armor steel is determined by the toughness and melting strength. Quenched and tempered steels armor steels are widely used in highly stressed structures such as ship hulls and combat vehicle turrets [1].

Q & T Steel is steel produced from austenite hot rolled plate steel (HRP Steel), which is then quenched with a water medium in order to increase the hardness and continued with tempering process to obtain ductility. The result of this process is such steel which has a high hardness and strength. This steel will be labelled as Armor steel.

HRP Steel is a heat treatable steel that can be made by the Indonesians (PT Krakatau Steel). To obtain high hardness and strength, HRP Steel is subjected to heat quenching (i.e. by heating it up to austenite temperature and retained for a while then cooled with water medium), the result is a high hardness steel called Quenched HRP Steel (QHRP Steel). Then QHRP Steel is treated with heat tempering treatment (i.e. by heating it up to a certain temperature below the eutectoid line and retained for a while then cooled with atmospheric air medium) to improve its ductility, the result is a high-strength hardness steel called Q & T HRP Steel or Q & T Steel . However, this Q & T Steel still has non-maximum hardness, due to the unmodified austenite structure into a thorough marten site. In addition, the process of quenching large objects has a lot of constraints on austenite temperature drop, entering the water quencher so that hardness is not maximal.

Quenched steel has the highest strength and hardness limits but low ductility. Distortion occurs during the formation of marten site platelets leading to increased strength and hardness [2]. To maintain the strength of quenched marten site (hard) industrially the tempering is done at temperatures between 150 ºC - 200 ° C [3].

Steel is a polycrystalline substance containing various microstructures such as austenite, marten site and ferrite grain boundaries [4, 5]. Marten site may be formed if the steel is austenitized and cooled at a sufficiently high rate to avoid the formation of ferrite, pearlite and bainite as stated in the Continuous Cooling Transformation Diagram [6,7]. Due to its high hardness, high strength and weight ratio and good toughness, Q & T Steel is widely used in the military [8, 9]. In addition, steel must have good ballistic and mechanical properties (ie combination of strength, plasticity and hardness) [10,11]. The increased hardness is used by a full marten site structure determined solely by carbon content (low-carbon steel), and this is equal to the maximum hardness of steel. [12, 13].

The novelty of this research is the hardness caused by granular changes through the austenite temperature closest to the Ar3 transform line. The problem that arose in this research is how to improve hardness and toughness of hot roll plate steel impact reach ≥ 500 BHN.

2.Method and equipment

In this study, we looked for the cause - effect of each treatment given to Hot Rolled Plate Steel (HRPS). Materials obtained with certificates contained chemical composition in order to maintain the correctness and accuracy of the data. Research material obtained from PT. Krakatau Steel is identical to ASTM A-570 Grade 30-50 which belongs to low carbon steel with 0.29 % C content.

Table 1. Chemical composition of sheet material (mass percent, %)

Al	C	Cr	Cu	Fe	Mn	Mo	Ni	P	Pb
0.0378	0.2934	0.5503	0.0833	96.7625	1.4121	0.1930	0.2787	0.0142	0.0082
S	**Si**	**Sn**	**Ti**	**V**	**W**				
0.0081	0.3298	0.0034	0.0044	0.0147	0.0095				

This research method used was experimental method; making angle of radius bending and heat treatment (Quench and Temper). Quenching is a process of hardening steel by means of a steel heated to austenite limit and then followed by a rapid cooling process through a water cooling medium, oil, or brine, therefore the autenite phase is partially transformed to form a martensite structure. The main purpose of this quenching process is to produce steel with high hardness properties. While tempering is the process of reheating a hardened metal through the quenching process at a temperature below its critical temperature for a certain length of time and slowly cooled. The purpose of this process was to reduce internal stress, change the structure (the structure of micro ferrite austenite into martensite bainite, reduce hardness and increase the ductility of metals, in order to get the right alloy between hardness and ductility of the tested metal.

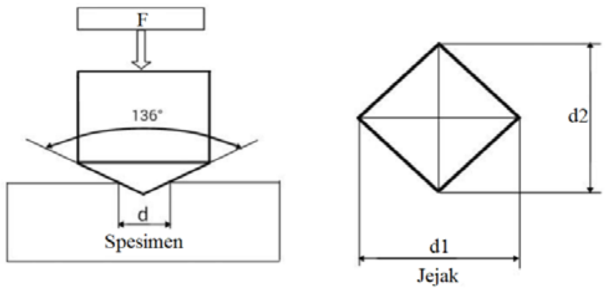


Figure 1. Vickers Hardness Testing

While for hardness testing using vickers method. Vickers micro test is a hardness testing method with relatively small loading that is difficult to detect by Vickers macro method. The principle of testing on Vickers hardness testing method is to emphasize the penetrator on the surface of the test object so that the required loading is also relatively small, ranging from 10-1000 gf. The Vickers hardness test used a square base diamond pyramid crusher and the angles of the interface pyramid were 136^o it is a pyramid-like crusher therefore this test is often called the diamond pyramid hardness test.

Temperature quench used 800 ˚C with 15 minutes holding and water cooling. Whereas the temper temperature was 150 ˚C with 45 minutes holding. Prior to the treatment of bending and heating of the material, the material hardness testing and micrographs are conducted for the purpose of reference to analyze the changes after treatment.

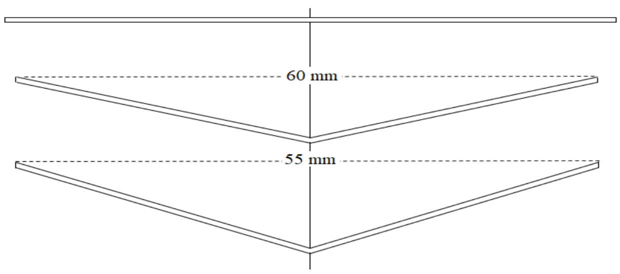


Figure 2. BendingFormation Process

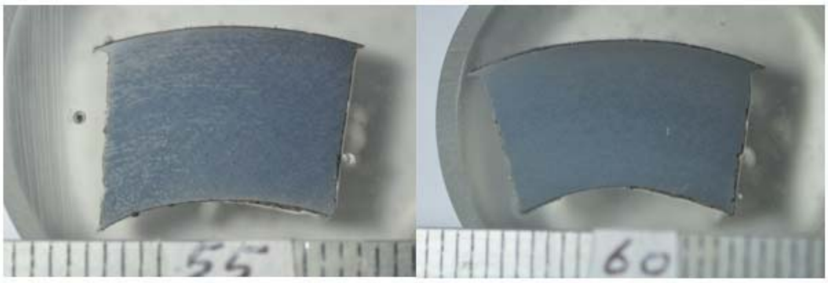
In the preparation of the test, the material was firstly bended within 55 mm and 60 mm radius. After that the hardness was tested for further treatment (heat treatment). The purpose of this direct hardness testing was to find out the gradual change in every given material

IOP Conf. Series: Materials Science and Engineering **420** (2018) 012045 doi:10.1088/1757-899X/420/1/012045

treatment. Then the materials that had been formed were treated with heat treatment of quench, temper and quench-temper.

(a) (b)

Figure 3. Material bending radius (a) 55 mm and (b) 60 mm



(a) (b)

Figure 4. Hardness test material sample radius (a) 55 mm dan (b) 60 mm

3. Results and Discussions

3.1. Physical properties of hot rolled plate steel

From the initial identification result on hot rolled plate steel material obtained physical properties of micro photo and hardness of material before given treatment. This initial identification was performed as a reference in analyzing the changes occurring at the hardness value of the material after bending with 55 mm and 60mm angle variations and Quenching (Q), Tempering (T) as well as Quenching - Tempering (QT).

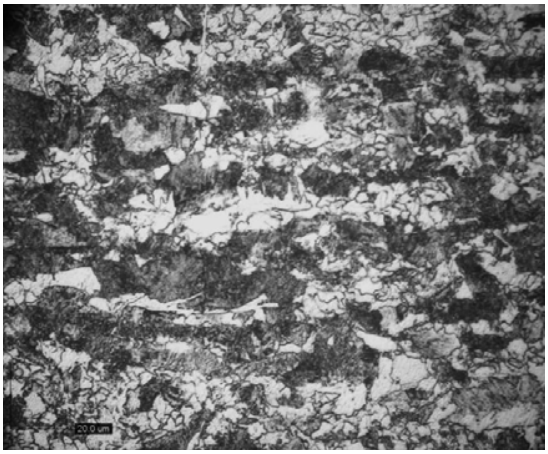


Figure 5. Microstructure hot rolled plate steel

Table 2. Hardness value of *Hot Rolled Plate Steel*

The test object code	VHN
HN_{HRC}	275,220

Hot rolled plate steel material was bended at 55mm and 60mm angles and given tempered, quenching and quenching - tempered heat treatment. Hardness testing was done with different distances that were tested starting from the curve point.

3.2 Effect of radius bending against hardness HRP steel

From the results of research conducted; with different bending angle, the hardness test was conducted with the research data obtained as shown in table 3.

Table 3. Hardness of *HRP steel* with 55 mm and 60 mm bending angle

Distance (mm)	*Hot Rolled Plate* 55 mm	*Steel (HRP Steel)* 60 mm
1	313	283
2	313	276
3	313	260
4	290	257
5	276	245

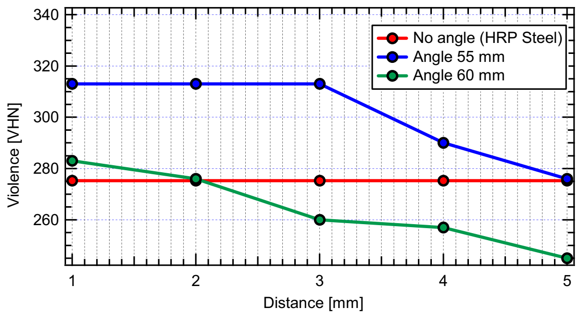


Figure 6. The effect of bending angle toward the hardness of each testing distance

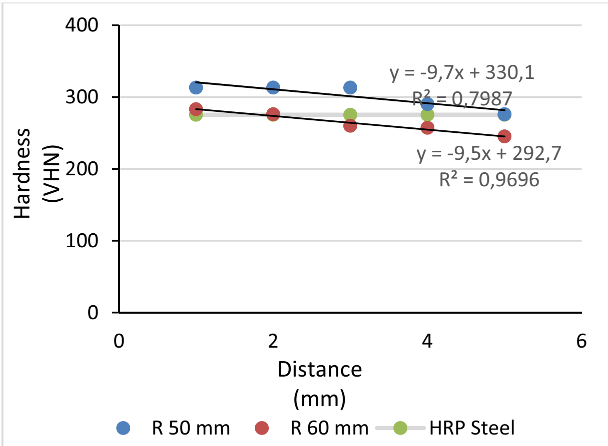


Figure 7. Linear line and bending angle correlation toward hardness

In figure 6 showed a significant change in the value of violence. In the change of bending angle the value of violence was changing. In this study, the bending angle of 60 mm had a lower hardness value than the 55 mm angle. This was because the density of the structure at a radius of 55 mm was denser while in the radius of 60 mm there was damage to the structure due to excessive bending radius. The average with bending treatment in areas near bending (1 mm range) had hardness above the initial hardness data before bending. This was depicted in fig. 6 above; at a distance of 1mm the hardness of radius 55 mm and 60 mm was above the initial hardness value before bending treatment. It also proved that bending treatment could improve structures that could lead to increased hardness. However, that would not constantly improve the hardness value if the bending radius were added. When subjected to excessive treatment of the material, it could damage the important structures contained in the material. As with a radius of 60, it initially possessed a higher hardness than it was before treatment but when tested the hardness with a longer distance away from the curve point the hardness decreased and was under hardness before treatment. Treated excessively, damaging the structure. To find out the structural damage, further analysis needs to be done on the following research that will be done using micro photos.

In analyzing figure 7, by reviewing the change in distance of the hardness test there had been a significantly decreased trend. This was due to the bending treatment done could change the material structure, henceforth the structure would move and assemble into the region of the curve because the bending treatment had a force which made the material structure moved tothe center bending so that the bending area had denser density than the area far from the bending. As a result of this treatment, the farther the area in direct contact with the bending treatment, the hardness would be lower.

3.3. Effect of heat treatment against hardness HRP steel

Basically, from the theory derived from the previous research, with the heat treatment given to a material could improve the physical and mechanical properties of the material. However, by providing too excessive heat treatment on materials could also damage the properties of the material. In the present study, the HRP steel material which was bended with a radius of 55 mm and 60 mm was given a heat treatment to improve its material properties especially the hardness property. There were three heat treatment models carried out namely, temper, quench and quench - temper.

Table 4. HRP Steel hardness with heat treatment

Treatment	**Distance (mm)**	***Hot Rolled Plate Steel (HRP Steel)***	
		55 mm	**60 mm**
Bending	1	313	283
	2	313	276
	3	313	260
	4	290	257
	5	276	245
Tempered	1	348	297
	2	348	290
	3	339	283
	4	330	276
	5	276	257
Quenching	1	384	413
	2	384	413
	3	358	413
	4	358	439
	5	389	446
Quenching - Tempered	1	453	426
	2	453	444
	3	453	444
	4	453	453
	5	450	453

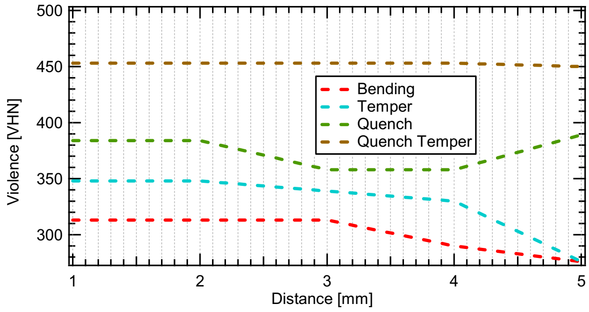


Figure 8. Hardness with heat treatment at 55 mm bending radius

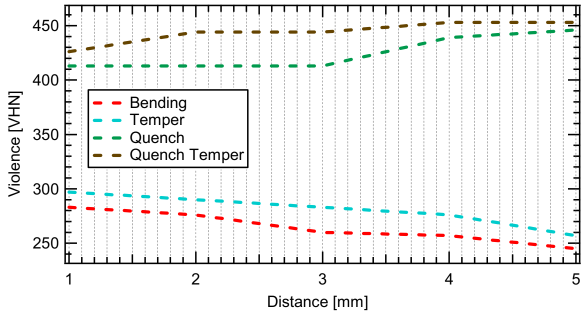


Figure 9. Hardness with heat treatment at 55 mm bending radius

Figure 8 showed the effect of heat treatment on HRP Steel against hardness. The average value of hardness after heat treatment was above the hardness value before heat treatment. Theoretically, heat treatment could change such a structure that previously had austenite structure with the heat treatment quench and temper, then the structure turned into austenite.

The heat treatment with forced cooling (water) might produce martensite structure on the material. In addition, this martensite structure caused such material to have high hardness as it was shown in figure 7; after being bended with the radius of 50 and then was given by temper, quench and quench-temper resulted higher hardness value. The highest hardness was obtained by the combative treatment between quench and temper. It was due to a double heat treatment of quench heat treatment forming a martensite structure which then was proceeded with tempering process to give time to the moving martensite structure occupied the empty space. Therefore, the martensite structure would be bonded to the other which caused the density of the martensite structure denser. This was the cause of the quench-temper heat treatment process to have higher hardness.

In addition to improving the structure of the bending area, heat treatment also improved structures in areas far from the treatment of bending. This can be seen in figure 8 of the quench and quench-temper lines. As depicted in the figure both processes kept the stability of hardness ranging from 1 mm to 5 mm. Even the hardness value was close to linear. With the high heating time and rapid cooling, the structure in the area away from the bending treatment was attracted to the bending area would move back and formed a new structure; the martensite. While in the quench-temper process; the trend was closer to linear. This was due to the so evenly spread martensite structure that the hardness value in the material was not much different from the hardness at the starting point.

4. Conclusion

All in all, from the analysis result of the test data it was said that the effect of radius bending and heat treatment on the material affected the value of hardness in the material. Learning from the results of the current study, a bending radius that could be used was a 55 mm bending radius with quench-temper heat treatment. Since this treatment has a higher hardness value than any other treatment that has been done in this study.

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