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ANALYSIS OF THE INFLUENCE OF HOT ROLLED PLATE STEEL TREATMENT USING TEMPER AND QUENCH-TEMPER METHOD ON VICKERS HARDNESS NUMBER ENHANCEMENT

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This paper wants to know the effect of bending radius on the distribution of hardness, grain distribution and microstructure on the surface area of tensile stress and compressive stress after bending, quenching and tempering. Material testing helps determine and analyze material quality. The research was conducted on the bending of Hot Rolled Plate Steel material with a radius of 50 mm, 55 mm, 60 mm, 65 mm and 70 mm with a measurement distance of 1 mm, 2 mm and 3 mm, the highest value was obtained at a radius of 55 mm with a measurement distance of 1 mm. After getting the quench-temper treatment with a holding time of 30 minutes, the value of 498 HV was obtained at a radius of 70 mm with a measurement distance of 2 mm. Hardness test was performed using the austenite temperature of 900 °C, microstructure test results obtained finer grains in the compression area r=2.173 μm and in the tensile area r=2.34 μm. This observation aims to determine the microstructure of the material undergoing a heat treatment process at a temperature of 900 °C with a holding time of 30 minutes using water cooling media. The results of the observation of the microstructure of the test specimens before the quench-temper process showed that the structure of ferrite was more abundant than perlite, but after the quench-tempering process the results showed that there was more perlite than ferrite due to the presence of austenite. The treatment on the transformation of the Ar3 line causes the hardness to change the shape of the martensite microstructure into steel while the thickness of the carburizing layer increases with the increase in the carbonization temperature on the surface of the quenched specimen, resulting in the formation of martensite and residual austenite causing the coating to become hard

Keywords: martensite, ferrite, pearlite, bending, quenching, tempering, microstructure

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1. Introduction

Many researchers study the impact of alloy composition and heat treatment on the mechanical properties of steel, such as macro and micro inspection. Quenching and tempering are one of the mechanical properties of steel to improve steel reinforcement [1, 2]. The results showed that increasing the quenching temperature could increase the grain size of austenite (*dr*), martensite package (*dp*), and beam (*db*). In contrast, the size of the martensite batten (*dl*) is just the opposite. On the other hand, the martensite levels changed from irregular to sequential. The high-angle boundaries (HBs) and low-angle boundaries (LBs) are the prior grain boundaries of austenite, packs, beams, and martensite blades, respectively. The size of the multi-level microstructure was calculated with mathematical models [3, 4]. Armored steel has properties that include comfortable fabrication, wear-service resistance conditions, adequate fatigue, high perforation resistance and ballistic impact. Armored steel is the most well-known alloy used as a protective material. Hardness is an important characteristic of the materials used for tank strategy. The high hardness provided by the armor directly determines the performance of the tank body and the mode of perforation [5]. In addition, toughness is another important property for armored materials having high kinetic energy upon dynamic attack of projectiles, and armored steel can still be developed [6–8]. Armor steel has high strength and hardness to protect conveyances, vehicles, objects, or individuals from direct pressure projectiles, but armor steel in general is still not able to meet the needs for a tank body from the level of hardness and ductility so it is not easy to crack if it gets impact energy [9]. Several studies have shown that the requirements of armored steel as a tank body material are various mechanical properties such as the range of yield and tensile strength values at 1,146–1,463 MPa, various steel hardness at 381–586 VHN, and Charpy impact energy between 19–85 J depending on the tempering temperature [10]. In the research, Quench Tempered Steel materials with high hardness and formability were obtained; that is the nature of the HRPS material, which can be machined, welded, bent with a bending machine, which will be used for tank body materials [11–13].

Why research on bending and quench-tempering needs to be done because steel plate is a versatile engineering material that is widely used today, easy to weld and shape. The use of steel plates is easily seen in a wide range of application aspects, including high-strength structural steel, applications that have high corrosion resistance. This study provides results to be practiced in the manufacturing process, namely increasing the hardness and toughness of the material. The microstructure is more homogeneous due to close bonds between metal atoms, which have an impact on the mechanical properties of the material better.

2. Literature review and problem statement

Hot Rolled Plate Steel (HRPS) is a steel plate rolled with a high temperature of up to 450 °C or recrystallization temperature, which aims to easily change the shape and size of the object, because the metal at high temperatures is more malleable. This material has the advantage of being strong against impact, toughness and the ability to be hardened better when compared to chrome steel [14]. This is indicated by the presence of chemical elements in Hot Rolled Plate Steel (HRPS) with the following contents: elemental silicium (silicon) shows a value of 0.32985 % indicating the silicon content is less than 0.4 %, which has the effect of decreasing tensile stress and increasing critical cooling speed, manganese of 1.41218 %, which has good melting process properties, chrome of 0.55029 % serves to increase tensile strength and plasticity, increase hardness, increase corrosion resistance and high temperature resistance, molybdenum value of 0.19303 % indicates good strength and toughness. Carbon of 0.29342 % as a hardening element, wear resistance, weldability, and toughness, ferro shows a value of 96.7625 %, can increase the hardness and strength properties of steel and 0.27877 % is an element that can increase corrosion resistance, toughness and hardness. But there are unresolved problems related to PT. Pindad (Persero), an industrial and manufacturing company engaged in the manufacture of military and commercial products in Indonesia. One of PT Pindad's Medium Tank products in collaboration with the Turkish defense industry FNSS, which is named Kapalan MT, of which some components are made by PT. Pindad (Persero), mentions the advantages of this tank that it has protection from cannon fire to anti-mines and is equipped with broad combat capabilities ranging from close-range protection for infantry troops to battles between combat vehicles. The sheet metal forming process is very important in a series of Panzer tank body production processes that require materials that have good mechanical properties. The purpose of the carbon steel plate forming process is to change the shape of the workpiece into another desired shape without wrinkling or cracking with low springback. While the notion of formability of a material is the ability of a material to be shaped and plastically deformed without local cracking or thinning. The material requirements for Panzer tanks in general are high toughness and hardness to be resistant to impact and impenetrable by bullets. In particular, this requirement is met by the chemical composition of the material and its mechanical properties. The requirements that must be possessed by armor steel as a tank body material are various mechanical properties, including yield strength and tensile strength in the range of 1,146–1,463 MPa. The hardness of steel varies within 381–586 VHN. The Charpy impact energy varies in the range of 19–85 J depending on the tempering temperature [15]. The initial capability of the HRPS material shows the average yield stress=561.148 MPa and strain=41.21 %. The way to overcome the difficulties is by means of the stages of bending, heat treatment with a temperature of 900 °C then quenching with water to see an increase in the material hardness through the Vickers test, to see the impact energy with the Charpy test method while to see the microstructure of the material with micro photos. [16], knowing the impact of the metal forming process, used the term plastic deformation equation, a process in which the force or load applied to a bent steel plate will permanently deform. [16] showed the results of metal formation were reversible or irreversible depending on the type of material; the size and geometry of the object and the magnitude of the force exerted on the object. The results of microstructural observations show that the applied load causes an increase in grain size and hardness in each bent specimen, as well as quenching and tempering heat treatments. Hot Rolled Plate steel material has limited capabilities when used to make industrial applications, especially tank bodies. The characteristics of the initial material can be improved. To increase the ability of the material, it is recommended to treat the material with the quench-temper method so that it can produce increased strength as expected.

This paper presents a study of springback phenomenon that occurs in sheet metal bending processes. Springback is a sensitive feature in sheet metal forming processes due to the influence of the elasticity of the metal material when the bending load is removed. The main objective of this study was to analyze the effect of the punch angle and radius on springback that occurred in the bending process of carbon steel material St. 60. The punch radius and angle are used as varied parameters.

The problem that arises in steel plate bending determines the optimal bending angle, the ratio of the bending radius/thickness of the steel plate (*r/t*). This is done so that no cracks or defects occur during the manufacturing process caused by shifting between metal atoms due to stresses that occur in the bending process. Residual stress is improved by quench-tempering to obtain better mechanical properties, namely hardness and ductility of the material.

In [3], the relationship between microstructure and strength and toughness properties was discussed by classical Hall-Petch formula, the results showed that the grain size of the former austenite (*dr*), martensite pack (*dp*) and block (*db*) increased with increasing cooling temperature, while the blade size martensite (*dl*) on the other hand. According to [5], the widely available lightweight composite-based armor is an attractive material due to its wide use in vehicle structures. In this study, the ballistic limit of 500 HB armored armor was determined against 7.62 mm 54R B32 API hardened steel core ammunition. Ballistic boundaries can be predicted quantitatively well regardless of the chosen simulation methodology, but qualitatively some differences are seen during perforation and fragmentation [9]. Structural components in combat vehicles are subjected to dynamic loading with high strain rates during operation. The stress load in the hulls of these vehicles is expected to fluctuate greatly and structural cracking especially in the welds during the service life of these vehicles can lead to catastrophic failure. An attempt was made to study the dynamic fracture toughness of quenched and forged steel with armor grades and the welds made using LHF consumables. Experimental results show that the KId value of joints made by shielded metal arc welding (SMAW) is higher than that of joints made using the flux core arc welding process (FCAW).

3. The aim and objectives of the study

The aim of this study is to determine the effect of the bending radius on the distribution of hardness on the tensile stress side and the compressive stress side after bending, quench-tempering; and microstructure. The result of this study is an effort to develop science and technology that can broaden horizons, and provide information on the importance of the bending ratio of steel plates, quench-temper treatment to obtain the required mechanical properties, namely the HRPS hardness. And it is practically effective for collaboration between academics and practitioners in the material manufacturing field so that they can provide solutions to problems that arise in the industry.

To achieve this aim, the following objectives are accomplished:

– the HRPS steel plate bending process is required for the formation process on the tank body, so the optimum bending radius is selected according to the design. Process phenomena are investigated and analyzed;

– the main purpose of the quenching process is to produce steel with high hardness properties. Heat treatment of quenched steel is expected to change its mechanical properties;

– the purpose of the tempering process is to reduce internal stress, hardness and increase metal ductility. The temperature is below its critical point for a certain time and is cooled slowly;

– study of microstructure to identify and compare experimental results for analysis, samples from bending, quenching, tempering results.

4. Materials and methods of research

Medium-carbon Hot Rolled Plate (HRP) steel is used as the material in this research, one of abundant yet cheaper 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 % to 1.65 %. This research uses 120×15 mm HRP steel to imitate the material shape, which is commonly used in the armor industry. The hardness test step starts from cutting the specimen, placing the specimen on the chuck of the machine, setting the speed of the indenter to 200 m/sec, constant pressing at 1.0 Kgf for 10 seconds. The process of testing 1–10 points of identification of each specimen is repeated until all specimens are tested with R50, R55, R60, R65, R70. Furthermore, testing the microstructure starting from the test object split with a size of 10×10×3.0 mm using wire cutting accompanied by cooling. Sanding the surface of the cleaved test object using sand paper No. 120 to 1500, carried out sequentially from the roughest to the most smooth. In sanding, water is used to wet the sandpaper, which is rotated on a seated sanding machine, the use of water is intended to cool the sanding process so that the heat on the sanded surface does not cause changes in the microstructure. Next, etched 5 ml of HNO_3+95 ml of 90 % alcohol, measuring cup, liquid soap and water to wash the sample to be etched.

5. Results of research on the influence of hot rolled plate steel treatment using temper and quench-temper method on Vickers hardness number enhancement

5. 1. Bending process

Bending process is performed for the purpose of determining the optimum bending angle so that there are no cracks in the plate caused by bending loads.

The result of bending of the R70 mm test object represents another bending radius. Fig. 1 shows the analyzed sample.

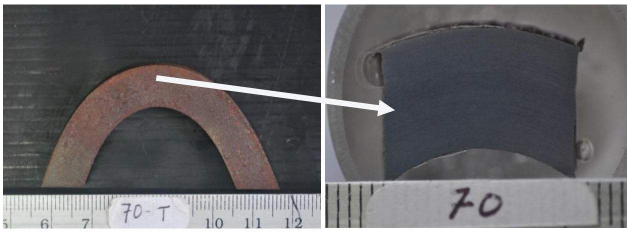


Fig. 1. HRPS R70 bending image microstructure test sample

After the HRPS plate bending process (Fig. 1), the quench and tempering processes are carried out, then the hardness is tested, the results are shown in Tables 1, 2.

5. 2. Hardness test after quenching treatment

The quench process at a temperature of 900 °C was carried out, followed by rapid cooling with water media to obtain the required hardness and ductility.

The results of the Vickers hardness test after quenching are presented in Table 1.

Table 1

VHN value of T-HRP Steel after 20 minutes tempered treatment

Distance (mm)	*R* of T-HRP steel				
	50 mm	55 mm	60 mm	65 mm	70 mm
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

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. The Vicker's value after 20 minutes temper treatment written in Table 1 analysis shows that temper treatment affected the mechanical sample properties such as the tensile strength, hardness, and toughness. Tempering hardening increases the specimen hardness, when viewed from the number of Vickers hardness, 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, which reduces the residual compression stress. In this study, heat treatment using quench and temper methods is used to obtain a fine grain structure that is challenging, tough, and has better yield strength. The hardness value of steel specimens accompanied by cooling and pearlite's percentage rate was observed to be higher. One of the phases that become the strengthening of steel is the martensite. The escalation of harshness consequent is by the delay forming of pearlite and martensite on the cooling rate, as shown in (Fig. 2) of the iron-carbon phase diagram. Yield strength values for hardened specimens are observed to be greater than for standard untreated samples.

Based on Fig. 1, the bending radius (*R*) between 60 mm and 70 mm provides a high hardness value of 348 HV at a bending angle of 55 mm with a measurement distance of 1 and 2 mm and low value of 276 HV at 70 mm. This is caused by tempering treatment, so the structure is denser while the damaged form occurs at another radius due to excessive bending. However, the increasing bending radius could damage the important contexture in the material.

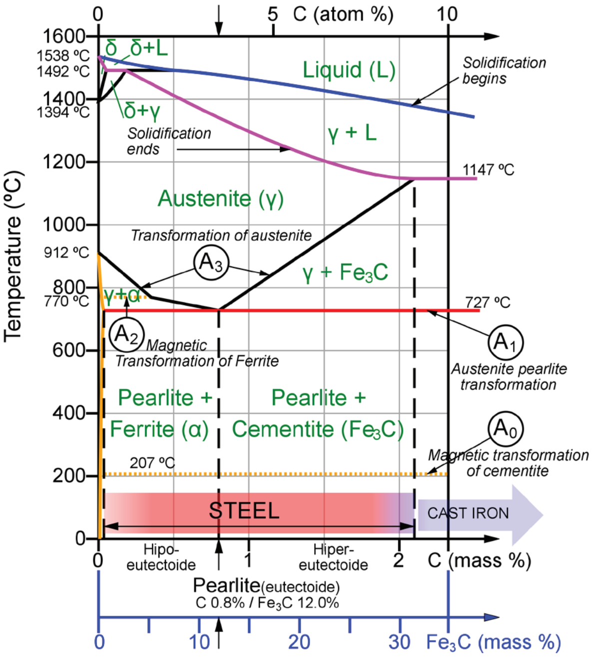


Fig. 2. Phase diagram of carbon steel [17]

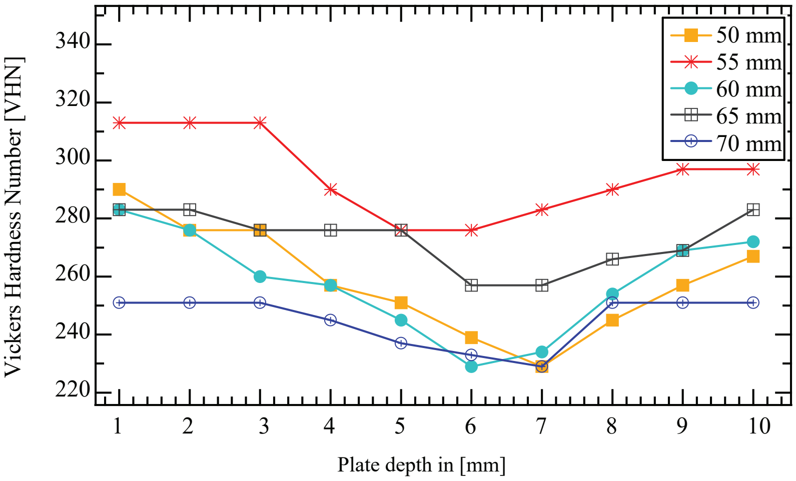


Fig. 3. VHN diagram of regular T-HRP Steel

Table 2 is the result of testing the effect of the bending radius on the hardness of Q-T HRP Steel with different bending radii indicating a significant change in the hardness value. Based on the results of the Vickers hardness test on the Q-T HRPS, the bending radius is obtained:

a) 50 mm, the highest value at a measurement distance of 8 mm and 9 mm in the tensile area with a hardness value of 467 HV;

b) 55 mm, the highest value at a measuring distance of 7 mm in the tensile area with a hardness value of 467 HV;

c) 60 mm, the highest value at a measuring distance of 9 mm in the inner curve with a hardness value of 498 HV;

d) 65 mm, the highest value at a measurement distance of 7 mm to 10 mm in the compression area with a hardness value of 482 HV;

e) 70 mm, the highest value at a measuring distance of 1 mm, 2 mm, and 8 mm up to 10 mm in the bending area of compression and tension area with a hardness value of 498 HV.

Based on the results of the overall hardness test between the bending radius of 50 mm to 70 mm, the highest hardness value was obtained at the bending radius: (*C*) 60 mm with a measurement distance of 9 mm of 498 HV and (*E*) 70 mm with a measurement distance of 1 mm, 2 mm and 8 mm up to 10 mm at 498 HV. At a bending radius of 70 mm, the structure is denser than at a radius of 60 mm, this damages the structure due to excessive bending radius. The average bending treatment in the area near the bending distance of 1 mm, 2 mm and 8 mm to 10 mm has a hardness above the initial hardness data before Quench-Temper, at a measurement distance of 1 mm, 2 mm and 8 mm to 10 mm hardness radius 70 mm above the hardness value after quenching and tempering. It is proved that quench and tempering treatment can improve the structure resulting in increased hardness.

Table 2 gives a diagram result of the hardness value against a plate thickness of 1–10 mm as shown in Fig. 4.

Based on Fig. 1, the bending radius (*R*) between 50 mm to 70 mm provides a high hardness value at a bending angle of 60 mm with a measurement distance of 9 mm at 498 HV and the lowest value at 70 mm at 389 HV. This is due to tempering treatment, so that the structure becomes denser while the damaged shape occurs at another radius due to excessive bending. However, the increased bending radius can damage important contexts in the material.

Table 2

Hardness vs Bending Radius of Q-T HRP Steel

Distance (mm)	Quenched Hot Rolled Plate Steel Q-T HRP Steel				
	50 mm	55 mm	60 mm	65 mm	70 mm
1	389	384	413	413	413
2	385	384	413	389	419
3	413	358	413	401	419
4	413	358	439	389	419
5	413	389	446	403	403
6	413	413	453	395	395
7	413	419	453	407	389
8	413	419	482	419	413
9	413	413	498	439	426
10	413	401	482	439	419

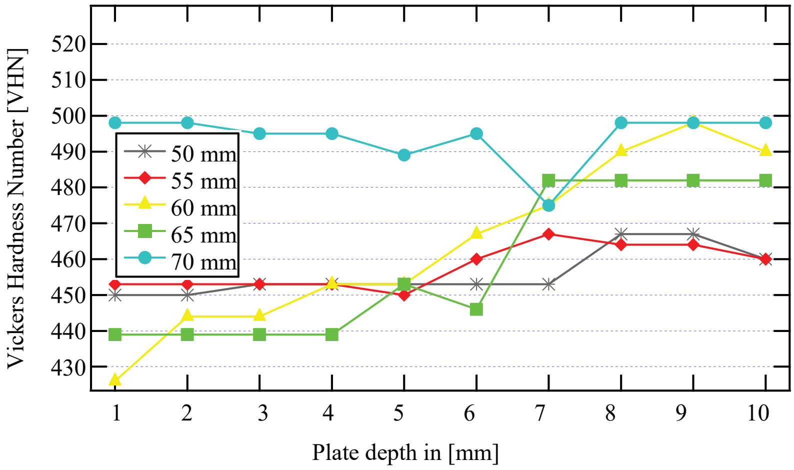


Fig. 4. Microhardness measurement results for the section of sample bending radius (*R*)=50 mm to 70 mm in diagram regular Q-T HRPS

5. 3. HRP Steel microstructure test after Quench-Temper

The tempering process is carried out at a temperature of 150 °C and held for 30–45 minutes to minimize residual stresses that occur due to heat treatment and bending.

5. 4. Microstructure analysis

Microstructure analysis is performed to determine the impact of changes in the structure of the steel plate on the hardness and ductility as application requirements, especially for the manufacture of Panzer tank bodies.

The results of the final observations of the microstructure of the HRP Steel R70 specimens are presented in Fig. 5 as follows.

Based on the results of the Vickers hardness test on the Q-T HRPS, it was found that the bending angle of:

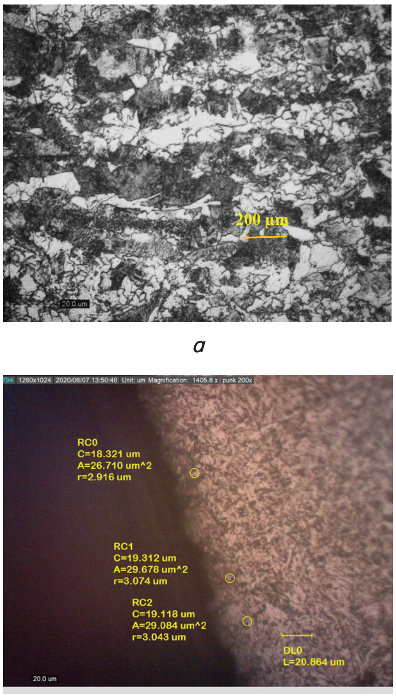
a) 50 mm was the highest value at a measurement distance of 8 mm and 9 mm in the inner curve with a hardness value of 467HV;

b) 55 mm, the highest value at a measurement distance of 7 mm inside the curve with a hardness value of 467 HV;

c) 60 mm, the highest value at a measuring distance of 9 mm in the inner curve with a hardness value of 498 HV;

d) 65 mm, the highest value at a measurement distance of 7 mm to 10 mm in the inner curve with a hardness value of 482 HV;

e) 70 mm, the highest value at a measurement distance of 1 mm, 2 mm, and 8 mm up to 10 mm inner bend with a hardness value of 498 HV.



a

b

Fig. 5. Comparison of HRP Steel Microstructure before and after Quench-Temper with R70: *a* – microstructure before treatment; *b* – after Q – T treatment

The results of the hardness value test show a bending radius of 70 mm, the structure is denser, this is damage to the structure due to excessive bending radius. The average bending treatment in the area near bending (distance 1 mm, 2 mm and 8 mm to 10 mm) has a hardness above the initial hardness data before Quench-Temper. The quenching-tempering treatment can improve the structure resulting in increased hardness. The final result of the microstructure observation shows the difference in the HRPS R70 specimen before and after receiving the quench-temper treatment, where the specimen before receiving the treatment found that martensite grains were more dominant than ferrite, meaning that the specimen showed the properties of elements that were hard, wear-resistant and able to be welded. However, the observation of the microstructure of HRPS R70 after receiving quench-temper treatment showed that martensite was more dominant than ferrite, meaning that the HRPS R70 specimen was stronger and harder, able to be welded and ductile when compared to specimens that had not been treated. This study supports the research conducted by [18] on the process of strengthening martensite that can be achieved in a diffusion-controlled invariant transformation system that can be suppressed by rapid cooling. The martensite strengthening process is basically a temperature change diffusion reaction. The martensite phase is formed from the high-temperature phase, which is held at a temperature lower than the equilibrium temperature of the invariant transformation.

6. Discussion of the results of analysis of Vickers hardness number enhancement

The results of experimental studies on the bending process of steel plates and quench-temper treatment are presented. In this study, the relationship between variables that affect the hardness & ductility of steel plates was determined and whether the microstructure also affects the hardness & ductility.

The discussion in this paper is a study of the quench-temper treatment of HRPS materials, the results are as follows: as shown in Fig. 5, light grains after ten and twenty minutes of quench-tempering treatment showed that with the increase in hardness, the grains became finer due to plastic deformation during bending and removed deformation and surface unevenness due to strain. It then shows coarse grains after thirty minutes of increasing the holding temperature. The results showed that the quench and tempering treatment changed the hardness at a bending radius of 70 mm, which is up to 498 HV, a higher VHN value in QT-HRP compared to T-HRP, which shows an increase in steel ductility. Therefore, it is recommended to use a bending radius of R70 mm as a manufacturing product application. However, the structural hardness of the material is damaged due to the increase in holding time and temperature, causing it to deform back to a certain position. As shown in the cooling effect and tempering microstructure, ferrite has a light color, and pearlite has a dark color. The microstructure of the sample quench and temper process, ferrite has been recrystallized because the low carbon steel microstructure is treated by the quenching method without a stress matrix. The deformed structure was thoroughly homogenized at 900 °C, additionally consisting of fine ferrite grains and during the slow cooling process, the pearlite could be more distributed between the austenitizing temperature and the final microspace. Fig. 5 shows the microstructure of the Hot Rolled Plate Steel (HRPS) experiment, which was carried out with a cold working process, namely bending the HRPS then quenching and tempering the specimen to improve the steel properties. The treated samples showed that they strongly influenced the shape and grain size of the original austenite. The section shows a pearlite matrix in which the short graphite flakes are hard. Steel can also be hardened by heating it to austenite temperature for some time, then cooling it, as shown in Fig. 2. The microstructure curve formed is martensite, which is very hard. The achievement of this research objective is beneficial from the theoretical aspect, which is an effort to develop science and technology that can broaden horizons, build an integrative mindset and important information related to the flexural ratio, quench and temper treatment to obtain the required HRPS hardness value as a body tank material produced by PT. PINDAD. While the applicable aspects of the results of this study are useful as a means of collaboration between academics and practitioners in the field of manufacturing production to obtain solutions in the field. The method that will be used to repair the tank body depends on the quality of the work expected, the equipment owned, the type of damage that occurred and the value/price of the product.

The limitations of this study are the different testing sites and high costs. This research is very good to be developed because one of the obstacles is PT Krakatau Steel as one of the main players in the national strategic industry that contributes maximally to the country. Based on Fig. 5, *a*, *b*, the fine grains can be seen after ten to twenty minutes of quench-tempering treatment. According to [13], this shows that with increasing hardness, the grains become finer due to plastic deformation during bending is removed, so that there will be changes in shape and surface irregularities due to strain. Fig. 5, *b* shows the coarse grains after thirty minutes and the increase in holding temperature. The results proved that the quench and tempering treatment changed the hardness at a bending radius of 70 mm, which reached 498 HV. According to [14], the high value of VHN in QT-HRP compared to T-HRP indicates an increase in steel ductility. However, the increase in holding time and temperature can damage the structure of the material because the plate has elastic properties so that some of the deformation will slightly return at a certain position.

This study focuses on the optimum bending process and quench-temper treatment to produce steel structures with the expected hardness and ductility according to the application requirements.

7. Conclusions

1. Based on the results of the bending test described above, one of the fundamental problems in the design process of machine components or equipment must pay attention to the principle of flexural loading on the material. The stresses that occur in the loading of the bending moment M caused by the load P are normal stresses and shear stresses. The magnitude of the normal stress that occurs varies with increasing distance from the neutral axis. Bending load causes strain, this affects changes in the microstructure associated with the bending process of the material.

2. Based on the results of the Quenching HRPS (Q-HRPS) hardness test with a bending angle of 60 mm, there is a significant change in the hardness value of the Q-HRPS specimen at a measurement distance ranging from 1 mm to 10 mm. The results of the test values obtained the highest hardness value at a bending angle of 60 mm with a measurement distance of 9 mm at 498 HV. This is because the structure at a radius of 60 mm is denser while at the other radius there is structural damage due to excessive bending radius.

3. Based on the results of the Vickers hardness test on the QT HRPS, it was found that the bending angle of 70 mm was the highest value at a measurement distance of 1 mm, 2 mm, and 8 mm up to 10 mm bending with a hardness value of 498 HV. This shows that the structure is denser, there is a change in the structure due to different bending radii. The average bending treatment in the bending area (range 1 mm, 2 mm and 8 mm to 10 mm) has a hardness above the initial hardness data before Quench-Temper. The quenching-temper treatment can improve the structure resulting in an increase in hardness.

4. The final results of microstructure observations showed that there was a difference in the HRPS R70 specimen before and after being quench-temper treated, where in the specimen before being treated it was found that martensite grains were more dominant than ferrite, meaning that the test object showed hardness, wear-resistant properties and can be welded. However, observation of the microstructure of HRPS R70 after receiving quench-temper treatment showed that martensite was more dominant than ferrite, meaning that the HRPS R70 specimen was stronger and harder, able to be welded and ductile when compared to unwelded specimens.

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