The Hardness Analysis of the Martensitic Stainless Steels after Hardening with Variations of Carbon Equivalent and Cooling

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Abstract
Stainless steels are some types of Austenitic, Ferritic and Martensitic. Martensitic types are several types and are one which can be hardened by hardening process, so it can be used for cutting tool or components that require high hardness and corrosion resistance.The purpose of this study was to obtain information about the hardness of martensitic stainless steel type after hardening with variations of carbon equivalent and cooling.The experimental method used was hardening by heating the material up to 1100 ^{o}C temperature, held for 30 minutes, then cooled rapidly/quenching to water, oil and air, then heated to 400 ^{o}C, cooled slowly, the materials before and after heat treatment were tested the hardness of Rockwell C method.The results showed all types of martensitic stainless steels have hardness increased significantly after hardening process ie from about 20 HRC to about 44.7 – 48.9 HRC, based on the carbon equivalent the difference in hardness value was not significant i.e type 410, Ceq = 1.537% (46.9-48.5) HRC, type 420, Ceq = 1.717% (44.5-48.9) HRC, and type 431, Ceq = 2.025% (46.9-47.4) HRC, based on variations of cooling water and oil there is no significant difference, but for air tend to be low ie type 410 (water = 48.5 HRC, oil = 48.8 HRC, air 46.9 HRC), type 420 (water = 48.9 HRC, oil = 47.2 HRC , air = 44.5 HRC) and type 431 (water = 47.4 HRC, oil = 47.7 HRC, air = 46.9 HRC), hardness after tempering down ranges from about 3-7 HRC on all types of martensitic stainless steels .
Keywords: Hardness, Stainless Steel, Hardening, Cooling .

1. Introduction

Martensitic stainless steels are widely used for machining components, either transmission components, or cutting tools. These types of steels include stainless steels that have good hardenability properties that are easy to harden up to high enough to reach about 60 HRC. In the process of hardening required heating, holding and cooling rapidly / quenching process, the speed of heating depends on the furnace, holding depends on the thickness of the work piece, while cooling / quenching depends on the cooling medium. In Cooling medium There are various kinds of salt water, water, oil commonly used. The various cooling mediums mentioned above will have different cooling rates, resulting in different hardness values after hardening. The cooling rate must exceed the critical cooling rate. In addition to which the hardness results are also influenced by carbon content or the equivalent carbon contained in the chemical composition of the material. From the explanation of the description above, it is necessary to research the hardening process on martensitic stainless steels which have different carbon equivalent with variations of cooling, so as to know the optimal hardness of the martensitic stainless steels .

There are 3 types of austenitic, ferritic and martensitic in stainless steel, used for components that require corrosion resistant. For stainless steel identification using 3 digits, the first number determines the group or type of stainless steel

Austenitic Stainless Steel contains not less than 23% of nickel and cromium, for example type 3XX, and 2XX. Stainless steels of this type include non-magnetic and can not be hardened by heat treatment, making it easy to weld. The use of this type of steel is usually for components of process equipment that are corrosion resistant / chemical and heat resistant such as food processing equipment, valve for steam, and others.

Ferritic Stainless Steel contains a lot of chromium in the range of 14 - 27% and less nickel (maximum 0.5%), for example type 405,430 and 446. This type of stainless steel includes magnetic and can not be hardened by heat treatment, making it relatively easy to weld . The use of this type of steel is usually for machine components such as bolts, household appliances, and others.

Martensitic stainless steel contains 11.5% - 18% cromium, for example type 403, 410, 416, 420, 431, 440A, 501 and 502. Type 410 da 416 is the most popular used for turbine blades in the form of castings.

The eqiuvalent carbon content follows the following formula (Source: Harlian Kadir : 1996):

Ceq =% C +% Cr / 10 +% Mn / 6 +% Mo / 10 +% Ni / 20 +% Cu / 40.

For Welding:

Ceq = 0.40 does not need preheat and post heat

Ceg = 0.40-0.60 sometimes need to preheat

Ceq = More than 0.60 need pre and post heat

Ceq can be used to determine the characteristics of metal especially in terms of Weld ability and Harden ability.

The composition of martensitic stainless steels shown in the table 1 below :

Table 1. Composition of Martensitic Stainless Steels

Type	C %	Cr %	Mn%	Ni %	Si %	P %	S %
410	0,12	12,5	1	-	0,4	1,5	0,105
420	0,25	13-14	1	-	1	0,04	0,04
431	0,2	15-17	1,2	1,25-1,5	0,01	0,04	-

The heat treatment for this type of steel is the same as carbon steel and low alloy steel, the heating is done at temperature 1850^o F (about 1100^{o}C) and Tempering is done at 750 ^{o}F(about 400^{o}C) temperature, Hardness is achieved according to the carbon content it contains.

2. Research Methods

The research is a kind of experiment part of heat treatment and testing of material which is done by destructive test method with science and technology development category in Mechanical Engineering, and the focus of research is the development of infra structure.

The research was conducted at Laboratory of heat Treatment and Testing of Engineering Material, of Mechanical Engineering Department, State Polytechnic of Malang. And Laboratory of Brawijaya University of Malang.

The design of the research is experimental one that is material specimens of martensitic stainless steel diameter 50 mm cut of thick 12 mm , 54 specimen, scheme of experimental design as shown in table 2 below:

Table 2. Experimental Design

Cooling Medium	Hardness After Hardening	Hardness After Tempering
1 Water	Hha1, 1,2,3 Hha2, 1,2,3 Hha3, 1,2,3	Hta1, 1,2,3 Hta2, 1,2,3 Hta3, 1,2,3
2 .Oil	Hho1, 1,2,3 Hho2, 1,2,3 Hho3, 1,2,3	Hto1, 1,2,3 Hto2, 1,2,3 Hto3, 1,2,3
3. Air	Hhu1, 1,2,3 Hhu2, 1,2,3 Hhu3, 1,2,3	Htu1, 1,2,3 Htu2, 1,2,3 Htu3, 1,2,3

The heat treatments process consist of hardening and tempering, Schemes of Hardening and Tempering Process as shown in figure 1 below

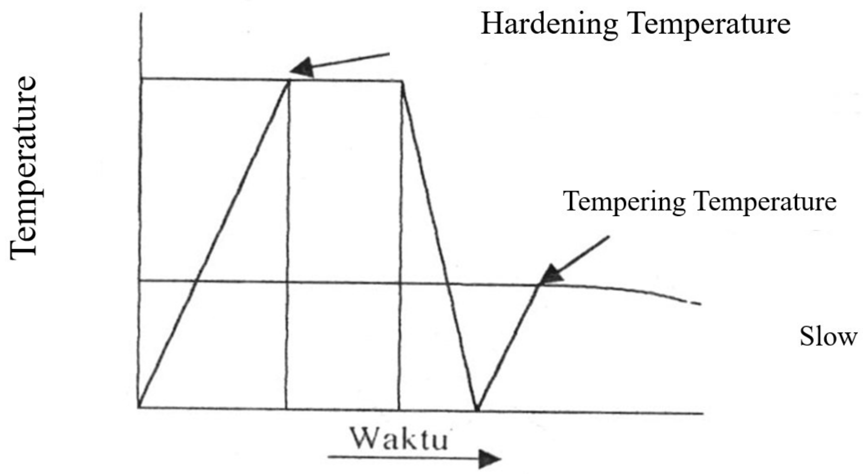

Figure 1. Schemas of Hardening and Tempering Process.

3. Results and Discussion

3.1. Carbon Equivalent.

According by composition of the type martensitic stainless steel and the formula of carbon equivalent :

Ceq. 410 = 0.12% + 12.5/10 % + 1/6 % = 1.537%

Ceq. 420 = 0.25% + 13/10% + 1/6 % = 1.717%

Ceq. 431 = 0.2% + 15/10 % + 1.2/6% + 1.25/20% = 2.025%

3.2. Hardness before Hardening

The Hardness of martensitic stainless steels before Hardening showed on the table 3 below:

Table 3. Hardness Martensitic Stainless before Hardening

No.	Type of Materials	Hardness (HRC)	Average Hardness (HRC)
1	410	20,6 ; 20.4 ; 20,2	20,4
2	420	20,6 ;20,8 ;20,7	20,7
3	431	20,8 ; 21,5, 21,3	21, 2

3.3 Hardness after Hardening process

The data of hardness (HRC) after hardening and tempering process with variation cooling medium can be displayed in graph below :

3.3.1. Martensitic Stainless Steels Type 410

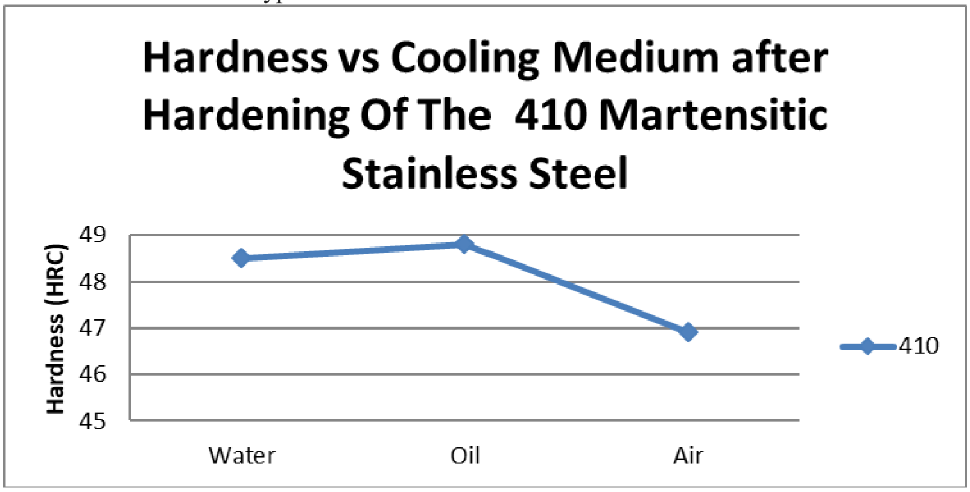

Figure 2. Graphic of Hardness vs Cooling Medium of The 410 Martensitic Stainless Steel.

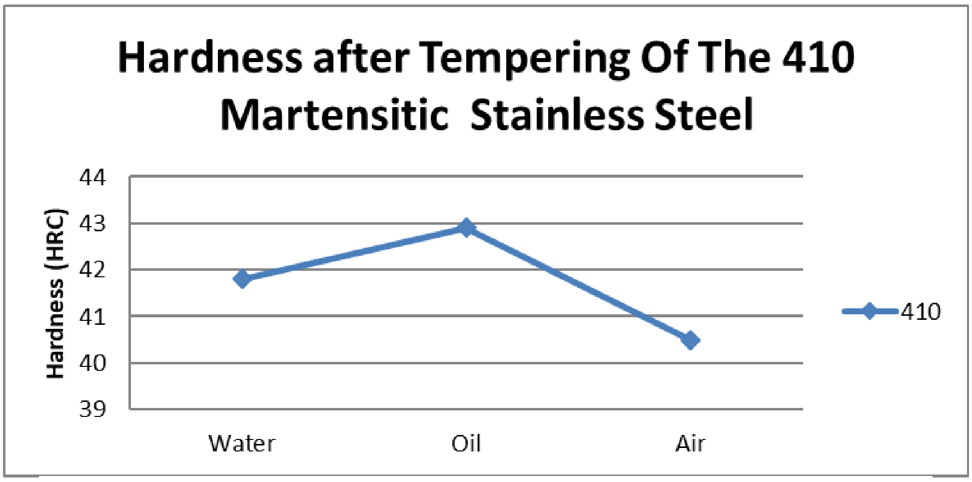

Figure 3. Graphic of Hardness after Tempering The 410 Martensitic Stainless Steel.

Based on fig.2. it can be seen that of all cooling medium increasing the hardness of 410 Martensitic Stainless Steel, i.e from 20.4 HRC before hardening to become about 46.9 to 48.8 HRC, this is because the micro structure has changed to martensite. When it is viewed by cooling medium variation, the hardness after cooling by oil is 48.8 HRC slightly higher than cooling by water (48.5 HRC), This is possible because the oil cooling medium contains carbon atoms, quenching is carried out at high temperature of 1100^{o}C, so that there are partially carbon atoms that diffuse into the surface material and may increase the hardness of material. Corresponds to the speed of cooling rate, the air cooling medium is lower than cooling rate so that the hardness after quenching by air is lower too. From the above graph fig.3 it can be seen the hardness of 410 martensitic stainless steel decreases after tempering process, i.e from hardness about 46.9-48.8HRC after hardening to became 40.5-42.9 HRC after tempering, because untempered martensite after hardening has become tempered martesite.

3.3.2. Martensitic Stainless Steels Type 420

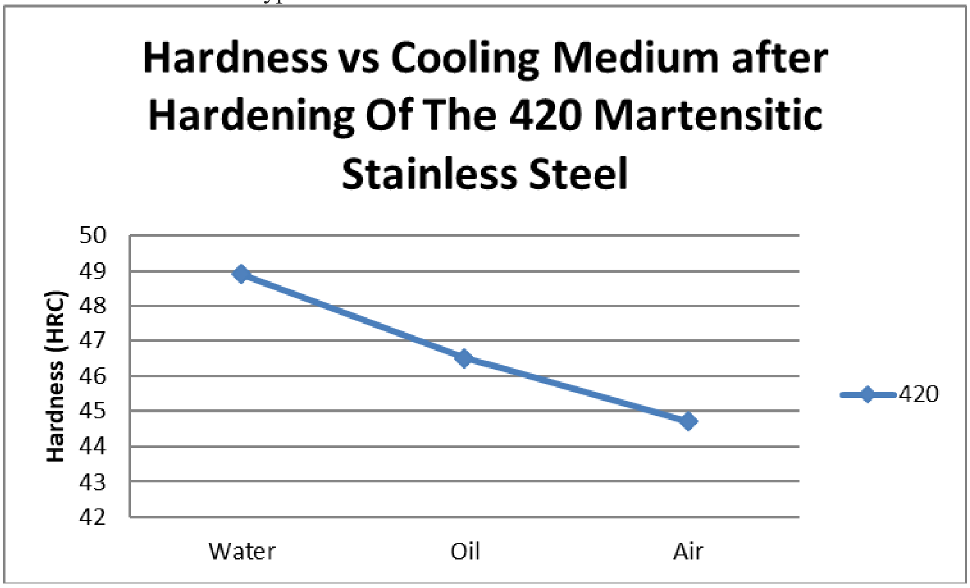

Figure 4. Graphic of Hardness vs Cooling Medium of The 420 Martensitic Stainless Steel.

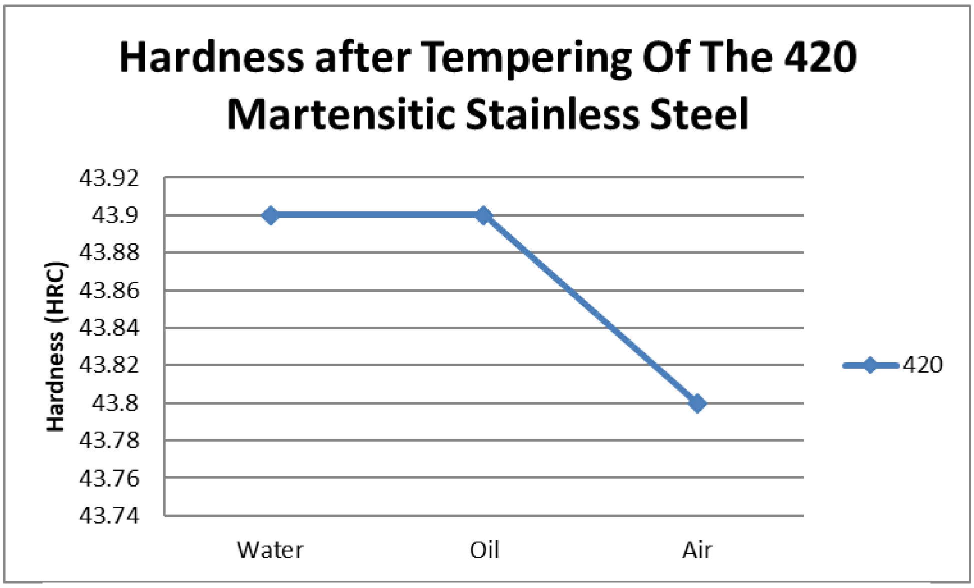

Figure 5. Graphic of Hardness after Tempering The 420 Martensitic Stainless Steel

Based on fig.4. it can be seen that of all cooling medium increasing the hardness of 420 Martensitic Stainless Steel, i.e from 20.7 HRC before hardening to became about 44.7 to 48.9 HRC, this is because the micro structure has changed to martensite. When it isviewed by cooling medium variation, the hardness after cooling by water is 48.9 HRC higher than cooling by oil 46.5 HRC, and cooling by air 44.7 HRC lower than water and oil, this is possible because the carbon content and cooling rate of water, oil and air. From the above graph fig.5 it can be seen the hardness of 420 martensitic stainless steel decreases after tempering process, i.e from hardness about 44.5-48.85 HRC after hardening to became 41.7-43.9 HRC after tempering, the same at 410 because untempered martensite after hardening has become tempered martesite after tempering.

3.3.3. Martensitic Stainless Steels Type 431

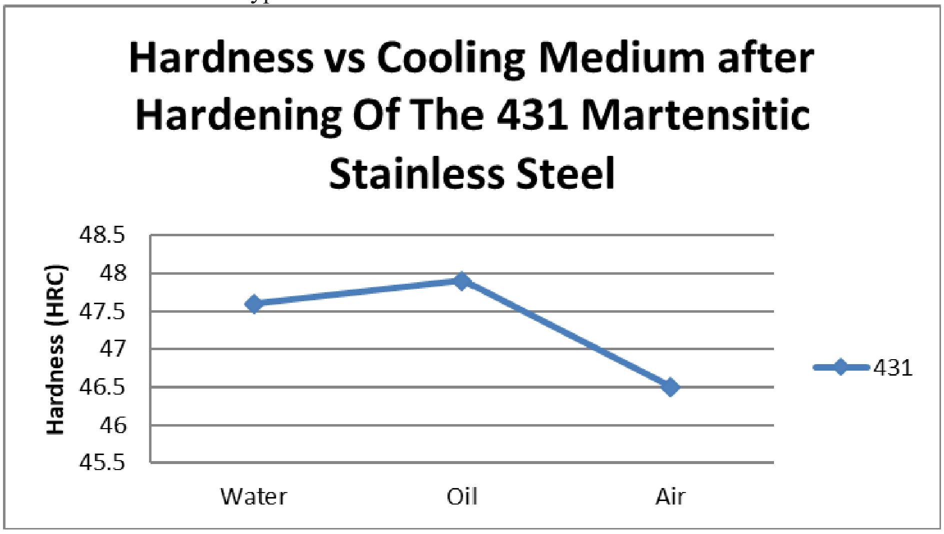

Figure 6. Graphic of Hardness vs Cooling Medium of The 431 Martensitic Stainless Steel.

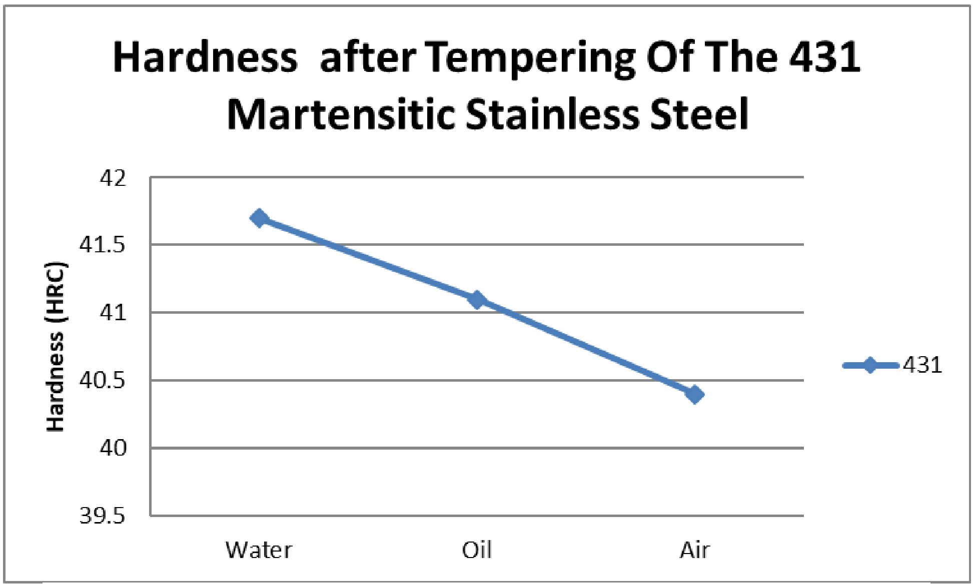

Figure 7. Graphic of Hardness after Tempering The 431 Martensitic Stainless Steel

Based on fig.6. it can be seen that of all cooling medium increasing the hardness of 431 Martensitic Stainless Steel, i.e from 21.2 HRC before hardening to become about 46.7 to 47.9 HRC, this is because the micro structure has changed to martensite. When it is viewed by cooling medium variation, the hardness after cooling by oil is 47.9 HRC slightly higher than cooling by water (47.6 HRC), this is possible because the oil cooling medium contains carbon atoms, quenching is carried out at high temperature of 1100^{o}C, so that there are partially carbon atoms that diffuse into the surface material and may increase the hardness of material. Corresponds to the speed of cooling rate, the air cooling medium is lower than cooling rate so that the hardness after quenching by air is lower too. From the above graph fig.7 it can be seen the hardness of 431 martensitic stainless steel decreases after tempering process, i.e from hardness about 46.9-48.8 HRC after hardening to become 40.4-43.9 HRC after tempering, because un tempered martensite after hardening has became tempered martesite.

3.4. Discussion

From the explanation above it can be seen that of all types of martensitic stainless steels (type 410, type 420, type 431) and viewed by cooling medium the hardness increase after hardening from about 20 HRC to became about 44.7-48.9HRC and it decreases after the Tempering process, i.e from hardness of about 44.7-48.9 HRC after hardening to become 40.4 -42.9 HRC (type 410), 41,7-43,9 HRC (type 420) and 40,4-43,9 HRC (type 431). When it is viewed by cooling variation, the hardness for stainless steel type 420 increased from water to oil and slightly decreased from oil to air, i.e water cooling (41.7 HRC), oil (43.9 HRC) and air (43.8 HRC) decrease of hardness after Tempering between 3 - 7 HRC. But for stainless steel type 410 and type 431 the value of hardness tends to increase in oil cooling and decreases for air cooling for (ss 410) 40.4 HRC for water, 42.9 HRC for 40.5 for medium air for (type 431) 43.9 HRC for water, 41.1 HRC for oil and 40.4 HRC for air, when compared with graphs in the hardening process the pattern is the same only different unequal hardness. This is because in the tempering process the micro structure does not change its atomic arrangement, it is changed from untempered martensite to tempered martensite.

4. Conclusion

1. Of all types of martensitic stainless steels they have increased significant hardness after hardening process. The hardness is about 20 HRC (before the hardening) to become about 47 HRC (after the hardening).
2. Based on the carbon content of equvalen the difference of hardness value is not significant i.e type 410 (46,9 - 48,5) HRC, type 420 (44,5-48,9) HRC, and type 431 (46,9-47,4) HRC
3. Based on the variation of the cooling medium, for water and oil there is no significant difference in the value of hardness, while the cooling of the air tend to be low, i.e type 410 (Water = 48.5 HRC, Oil = 48.8 HRC, Air = 46.9 HRC) For type 420 (Air = 48.9 HRC, Oil = 47.2 HRC, Air = 44.5 HRC), and for type 431 (Air = 47.4 HRC, Oil = 47.7 HRC, Air = 46.9 HRC) .
4. For the results of the Tempering Process the decrease in hardness ranges from about 3-7 HRC with the same as chart pattern the Hardening Process.

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