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Keyword: Ni-Cr-Mo Alloy Steel, mechanical properties, heat treatment, austenisation temperature, holding time, quenching, scale

Abstract

The application of steel products have been widely used and various research have been developed to find a good and appropriate quality of steel and can be produced in the country without have to be imported, for example alloy steels. One of the alloy steels that have been constantly developed is Ni-Cr-Mo alloy steel with additional nickel, chromium and molybdenum which can increase hardness, tensile strength, ductility and toughness. The effect during the production process is at the heating process that causes the formation of iron oxide layer (scale) and the loss of steel weight. Therefore, the selection of heat treatment methods and techniques are required to increase the mechanical properties of steel, such as hardness, tensile strength, and toughness, with the scale is about <5% of steel weight. In the research, the heat treatment was carried out at austenisation temperature of 800°C, 850°C, 900°C and at holding time of 20, 40, 60 minutes, then followed by a rapid cooling (quenching) to improve the mechanical properties of hardness. This research also tested the mechanical properties of steel that consist of hardness test and impact test, and metallographic observation that consist of micro structure observation and scale thickness observation. The micro structure from heat treatment process is martensite, it is due to a rapid cooling (quenching) that rapidly change the austenite phase into martensite. The data showed the highest hardness is 588.35 HVN at 850°C of temperature and 60 minutes of holding time, 8.5 Joules of impact energy, and 91.5 μm of scale thickness. While the lowest hardness is 539.34 HVN at 800°C of temperature, 5 Joules of impact energy, and 47.81 μm of scale thickness.

Introduction

The process of heat treatment in austenisation temperature above the A_3 line in the diagram $Fe-Fe_3C$ phase and followed by a rapid cooling can change the entirely homogeneous austenite structure into martensite structure and will increase the hardness, but the heating process will cause effects such as the formation of iron oxide layer (scale). Scale or crust is an oxide layer that arise due to oxidation reaction between iron elements in oxygen contained in atmosphere in the slab area during the heating process [Poitier, 2006].

The purpose of this tesearch are to know the characteristics and optimum parameters of austenisation temperature and optimum parameters of holding time for heat treatment process in corrosion resistant steel, the thickness of oxide layer (scale), the hardness with water as quenching media, the toughness at room temperature test, and to know the influence of austenisation temperature variation and holding time, toward steel micro structure before and after the heat treatment process.

Austenisation is changing of micro structure of steel into entirely homogeneous austenite, austenisation temperature depends on carbon composition in steel according to diagram $Fe-Fe_3C$ phase. Austisation temperature for hypoeutectoid stell based on the A_3 line. To obtain a full austenite steel, the temperature must be at 30-50°C above the A_3 line [Lakthin, 1977].

Based on the SM handbook vol.4 on heat treating, Andrews equation is formulated as follow:

$$A_3 = 910 - 203\sqrt{C} + 44{,}7\,Si - 15{,}2\,Ni + 31{,}5\,Mo + 104\,V\ \pm 16{,}7°C$$

Description: A_3 : Austenisation tempertaure line A_3 on diagram Fe-Fe3C phase

C : % of *Carbon* composition

Mn : % of *Mangan* composition

Si : % of *Silicon* composition

Cr : % of *Chromium* composition

Ni : % of *Nickel* composition

Research Methodology

The chemical composition test was conducted in chemical laboratory of PT.X by using spectrometer. The purpose of chemical composition test are:

1. to ensure that the carbon steel used is the low carbon steel (≤ 0.3 % C)
2. to know the percentage (%) of alloy elements of Nickel, Chromium, Molybdenum, and other contained alloy elements,

3. to determine the point of austenisation temperature heating (heating above the A_3 line in Fe_3C diagram).

The result of chemical composition test can be seen at the Table 1 below:

Table 1. Data of Chemical Composition of Ni-Cr-Mo Alloy Steel Sample

Element	% of Composition
C	0.2914
Si	0.2297
Mn	1.2431
Cu	0.0304
Ni	0.3219
Cr	0.6239
Mo	0.216
Other alloy	0.0836
Fe balance	96.96

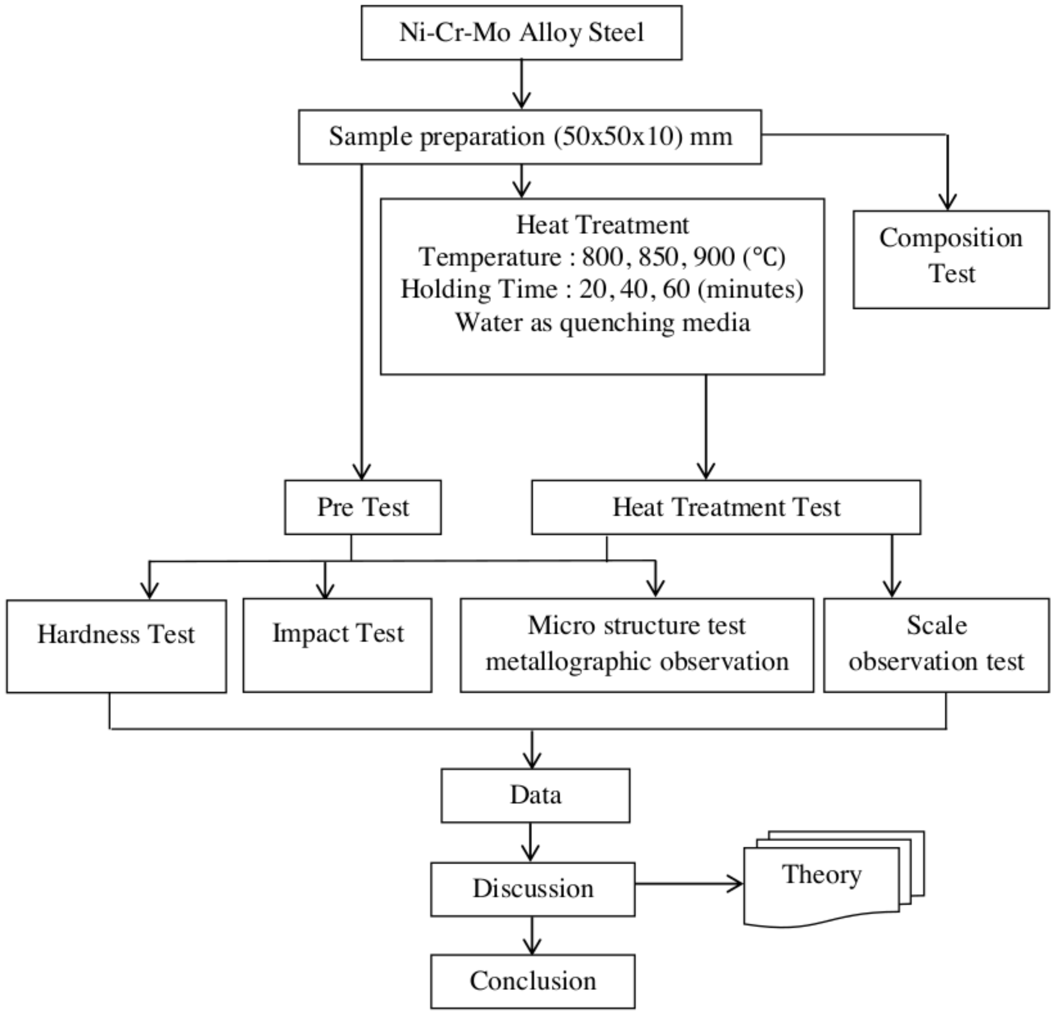

Fig. 1. Research Flow Chart

Result and Discussion

This research has two type of data, namely the preliminary data before heat treatment and the outcome data after heat treatment.

Fig. 2. Phase Structure (a) Ferrite and Pearlite (Before Heat Treatment), (b) Martensite (After Heat Treatment).

During the heating and cooling process, there will be some changes in grain size and micro structure. The result of this research showed HT3 sample heated at 900°C have greater grain size than HT1 sample that heater at 800°Cand HT2 sample that heated at 850°C. The influence of temperature and holding time showed the higher the austenisation temperature given to the lower the materials then the greater the grain size [Zen, 2001]. The greater the grain size, the lower the hardness; because higher temperature may lead to greater grain size, then at 900°C of temperature there was a decline in hardness.

Metallographic observation consist of micro structure observation and scale thickness observation. Figure 4 showed the variation of scale thickness at each temperature and holding time. The scale occurs when the steel exposed to oxidation condition above 570°C; it formed multilayer scale that consist of FeO (wustite), Fe_3O_4 (magnetite), and Fe_2O_3 (hematite); wustite layer is near the surface of steel, magnetite is in middle; and hematite is in the interface of scale-gas [Poirier, 2006].

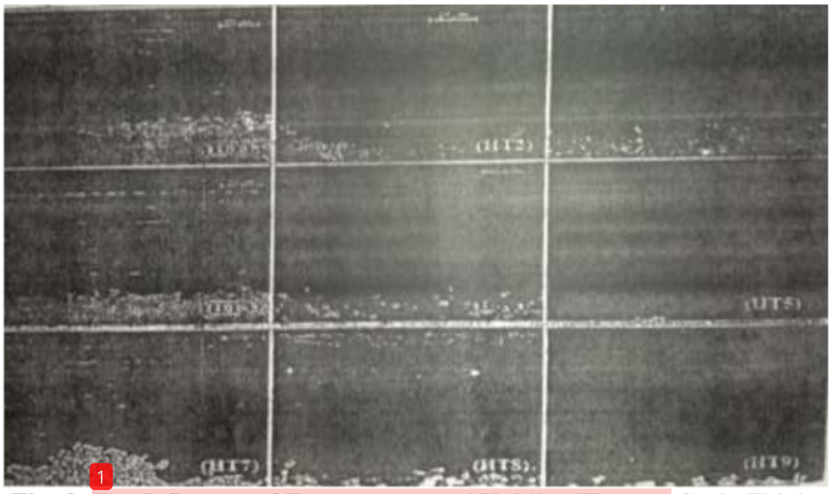

Fig. 3. The Influence of Temperature and Holding Time on Scale Thickness

The scale layer structure in HT 3C sample is thicker than other sample, but due to the increasing of oxide thickness then the appearance of oxide scale optically dominates than the metal base. The correlation between temperature and holding time and scale thickness can be seen in figure below.

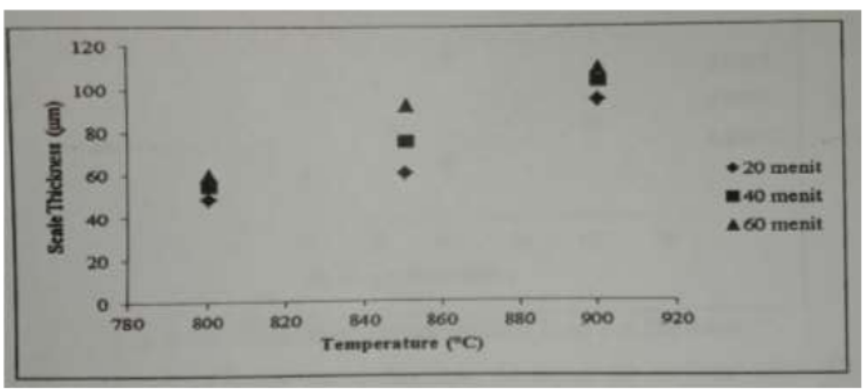

Fig. 4. Result of Scale Thickness

Figure 4 showed the the increase of temperature and holding time influenced the increase of scale thickness. This is due to the tendency of metals to react with oxygen driven by the decrease of free energy that follows the formation of oxide [David, 2005]. In line with the increase of temperature and holding time which influence the scale thickness, then the increase of temperature and holding time also influenced the lose scale. The mass loss occurred because the scale will result the loss of metal about one (1) to five (5) percent or more and the possibility of surface defects in rolling process [William, 1983].

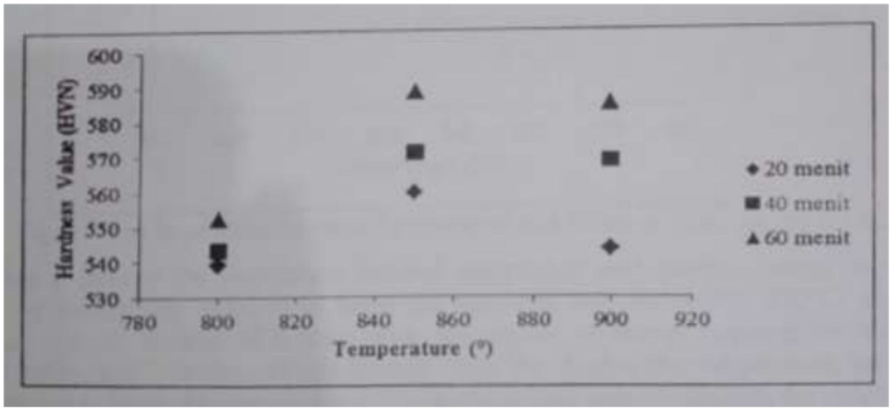

Fig. 5. The Correlation between Temperature and Hardness

Figure 5 showed the correlation between temperature and hardness. The graph showed the increase of hardness at 850°C of temperature and the decrease of hardness at 900°C of temperature. It is in line with the result of micro structure on the previous figure 4 that the large the grain size, the lower the hardness. The smaller the grain size, the better the hardness value [Reed-Hill, 1994].

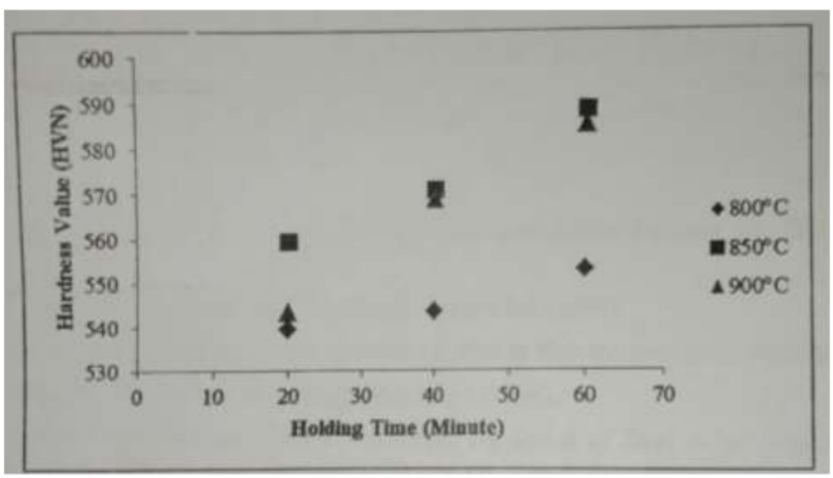

Fig. 6. The Correlation between Holding Time and Hardness

In figure 6 showed the longer the holding time, the higher the hardness value. The highest hardness value was obtained at 60 minutes of holding time and 850°C of temperature. The increase of hardness in the length 0f 20 minutes of holding time is about 13.55-14.32 HVN.

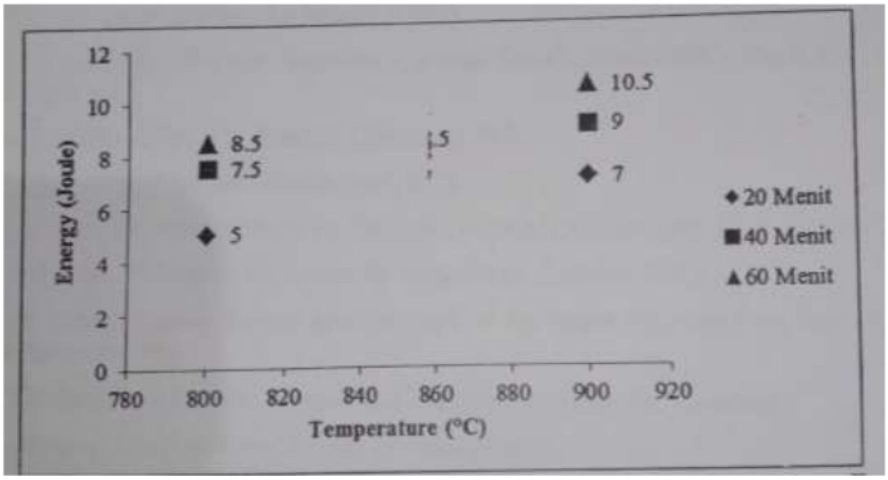

Fig. 7. The Correlation between Temperature and Holding Time on Impact Energy

Figure 7 showed the correlation between temperature and energy. Energy in this context refers to the energy that required to break the specimen test. At 800°C, 850°C, and 900°C of temperature and 20 minutes of holding time, the amount of energy required are respectively 5 Joules, 7 Joules, and 7 Joules. At this holding time, the higher the temperature, the greater the energy required to break the specimen test. Due to the greater energy required, the samples are more resilient because the great value of impact energy [Widya Mukti S, 2007].

Conclusion

From the research of the influence of austenisation temperature and holding time on Ni-Cr-Mo alloy steel before and after heat treatment at 800°C, 850°C, 900°C of temperature and 20, 40, 60 minutes of holding time, it can be concluded that:

1. The micro structure before the heat treatment are ferrite and pearlite, while after the treatment is the formation of martensite phase.
2. After the heating process, there were compound scale that consist of FeO (wustite), Fe_3O_4 (magnetite), and Fe_2O_3 (hematite). The lowest scale thickness is 47.81 μm at 800°C of temperature and 20 minutes of holding time, while the hihest scale thickness is 108.86 μm at 900°C of temperature and 60 minutes of holding time.

3. The optimum austenisation and holding time to obtain mechanical properties is at 850°C of temperature and 60 minutes of holding time. The highest hardness value is 588.35 HVN, and the toughness impact energy is 8.5 Joule.

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