



Tensile Strength Analysis of Wire after Annealing and Hardening Using a Hydraulic Tensile Testing Machine

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ABSTRACT

Annealing is a heat treatment of metal with slow cooling to remove internal stresses or to reduce the crystal structure (involves heating above a critical temperature). Hardening is a heat treatment process carried out to produce a hard workpiece. Tensile testing is one of the mechanical tests that most widely used in industry and in education because of the ease of analyzing the data obtained and obtaining information about the mechanical properties of a material. In this study using 304 stainless steel wire with a diameter of 1 mm, aims to determine the maximum load limit, maximum stress and strain. From the annealing and hardening processes, the results obtained after the annealing process 1 obtained a maximum load of 72.7 kg, tension 92.611 kg/mm², strain 0.184, annealing 2 maximum load 75.7 kg, stress 96,433 kg/mm², strain 0.267, annealing 3 maximum load 70.6 kg, tension 8 9.936 kg/mm², strain 0.326. Hardening 1 maximum load obtained 72.5 kg, stress 92.356 kg/mm², strain 0.176, hardening 2 maximum load 73.5 kg, stress 93,630 kg/mm², strain 0.252, hardening 3 maximum load, 73.3 kg, strain 93,376 kg/mm², strain 0.213. And raw material 1 obtained a maximum load of 134.1 kg, stress 170.828 kg/mm², strain 0.022, raw material 2 maximum load 129.4 stress 164.841 kg/mm², strain 0.013, raw material 3 maximum load 128.8 kg, stress 164.076 kg/mm², strain 0.01

Keywords: Annealing, Hardening, Raw Material, Tensile Test

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1. Introduction

Tensile testing is a method used to evaluate the strength of a material by applying an axial tensile load (Askeland, 1985). The results of tensile testing are important in engineering and product design because they provide essential data on material strength. This test is used to determine a material's resistance to a gradually applied static tensile force. During the test, the specimen is subjected to a continuously increasing uniaxial tensile load until failure or fracture occurs.

Annealing is a heat treatment process in which a metal is heated to an appropriate temperature and then cooled slowly, usually inside a furnace. This process is intended to reduce internal stresses, improve ductility, and modify the material's microstructure. For certain steels, annealing involves heating above a critical temperature, holding the material at that temperature for a specified period, and subsequently cooling it slowly in the furnace. The resulting microstructural changes can reduce residual stresses and improve ductility, depending on the material composition and annealing conditions.

Hardening is a heat treatment process used to increase the hardness of a workpiece. The process generally involves heating the material to an appropriate hardening temperature, holding it at that temperature for a sufficient period, and then rapidly cooling it using a suitable quenching medium. In steel, rapid cooling can promote the formation of a hard microstructure, particularly martensite, depending on the steel composition and cooling rate. Hardening is commonly performed to improve wear resistance, strength, and fatigue performance. The resulting hardness depends on factors such as carbon content, austenitizing temperature, holding time, cooling rate, and the hardenability of the steel.

In this study, tensile testing was conducted using a hydraulic testing system to investigate the effects of annealing and hardening on the tensile strength of wire specimens. The material investigated was Type 304H stainless steel wire, and water was used as the quenching medium for the hardening treatment.

2. Methodology of Research

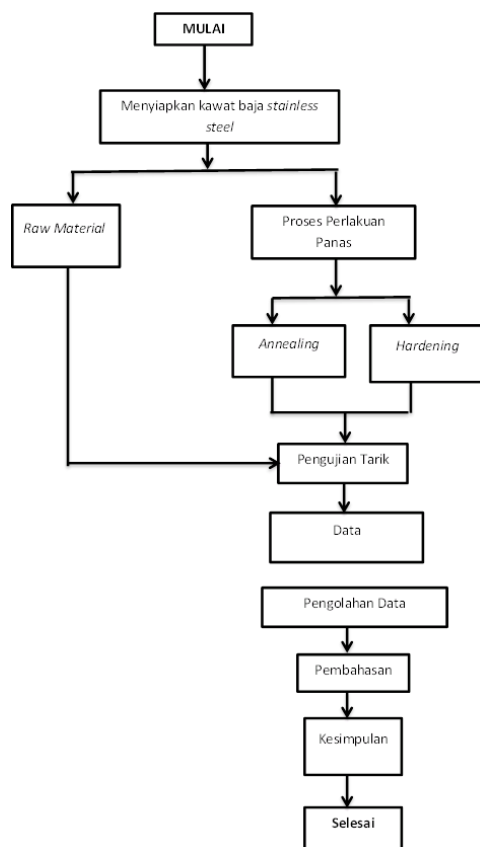


Figure 1. Research Methodology Flowchart

2.1 Research Variables

The research variables consisted of independent and dependent variables. The independent variables were the type of material and the heat treatment applied to the stainless steel wire, including annealing and hardening. The wire diameter was maintained at 1 mm for all

specimens to ensure consistent geometric dimensions during tensile testing.

The dependent variables were the cross-sectional area, strain, stress, and tensile strength of the stainless steel wire. These parameters were determined from the tensile test results to evaluate the mechanical properties of the material and assess the effects of different heat treatment conditions on its tensile behavior.

2.2 Materials and Equipment

1. Stainless Steel 304H Wire

The material used in this study was 304H stainless steel wire with a diameter of 1 mm.



Figure 2. Stainless Steel 304H Wire

2. Heating Furnace

A heating furnace was used in this study to heat the stainless steel 304H wire specimens to predetermined temperatures during the heat treatment process. The furnace enabled controlled heating of the specimens to achieve the desired treatment conditions for annealing and hardening prior to tensile testing.



Figure 3. Heating Furnace

3. Hydraulic Wire Tensile Testing Machine

A hydraulic tensile testing machine was used to evaluate the tensile properties of the stainless steel 304H wire specimens. The machine had a hydraulic capacity of 5 tons and was equipped with a digital scale with a capacity of 300 kg to measure the tensile force required to fracture the wire specimens. The recorded force was subsequently used to determine the tensile strength of the specimens.



Figure 4. Tensile Testing Machine

2.3. Heat Treatment Process

- **Hardening Process**

The hardening process was performed on three stainless steel 304H wire specimens. All specimens were heated to a target temperature of 820 °C and held at this temperature for 30 minutes to ensure uniform heating. After the holding period, the specimens were rapidly cooled by quenching them in water. This process was conducted to investigate the effect of hardening on the mechanical properties and tensile strength of the stainless steel wire.

- **Annealing Process**

The annealing process was performed on three stainless steel 304H wire specimens under the same heating conditions. Each specimen was heated to a target temperature of 820 °C and held at this temperature for 30 minutes. Following the holding period, the specimens were allowed to cool gradually inside the furnace. This controlled cooling process was intended to evaluate the effect of annealing on the mechanical properties and tensile behavior of the stainless steel wire.

4. Result and Discussion

The tensile test data were analyzed to evaluate the mechanical properties of the stainless steel 304H wire specimens. The analysis included calculating the cross-sectional area, tensile stress, and strain. The cross-sectional area was determined from the wire diameter, while tensile stress was calculated as the ratio of the applied tensile force to the cross-sectional area. Strain was determined from the ratio of the change in specimen length to its initial length. The following equations were used to calculate these parameters.

1. Cross-Sectional Area

$$A = \frac{\pi}{4} d^2$$

2. Stress

$$\sigma = \frac{F}{A}$$

3. Strain

$$\varepsilon = \frac{\Delta l}{L_0}$$

Using the equation The cross-sectional area, tensile stress, and strain are interrelated parameters used to evaluate the mechanical properties of stainless steel 304H wire specimens. The cross-sectional area is calculated from the wire diameter and is used to determine tensile stress by dividing the applied tensile force by the cross-sectional area. Meanwhile, strain is calculated as the ratio of the change in specimen length to its initial length, indicating the relative deformation during tensile testing. These parameters are used to evaluate and compare the mechanical behavior of the specimens subjected to annealing and hardening treatments.

Table 1. Tensile Test Results

Spesimen	Diameter Awal (d ₀) (mm)	Panjang Awal (L ₀) (mm)	Diameter Akhir (d ₁) (mm)	Panjang Akhir (L ₁) (mm)	Luas Penampang (A) (mm ²)	Beban (F) (kgf)	Tegangan (σ) (kgf/mm ²)	Regangan (ε)
RM 1	1	78	0,95	79,7	0,785	134,1	170,828	0,022
RM 2	1	78	0,95	79	0,785	129,4	164,841	0,013
RM 3	1	78	0,95	79	0,785	128,8	164,076	0,013
A1	1	78	0,75	92,60	0,785	72,7	92,611	0,187
A2	1	78	0,75	98,85	0,785	75,7	96,433	0,267
A3	1	78	0,7	103,5	0,785	70,6	89,936	0,326
H1	1	78	0,75	91,80	0,785	72,5	92,356	0,176
H2	1	78	0,75	97,7	0,785	73,5	93,630	0,252
H3	1	78	0,75	94,65	0,785	73,3	93,376	0,213

The tensile test results presented in Table 1 show differences in the mechanical behavior of the stainless steel 304H wire specimens under different conditions.

The raw material specimens (RM1–RM3) exhibited the highest stress values, ranging from 164.076 to 170.828 kgf/mm², with relatively low strain values of 0.013–0.022. In contrast, the annealed specimens (A1–A3) showed

lower stress values, ranging from 89.936 to 96.433 kgf/mm², accompanied by higher strain values of 0.187–0.326. These results indicate that the annealing treatment reduced the tensile stress and increased the strain of the specimens, suggesting improved deformation capability compared with the raw material.

The hardened specimens (H1–H3) exhibited stress values ranging from 92.356 to 93.630 kgf/mm², with strain values between 0.176 and 0.252. Compared with the annealed specimens, the hardened specimens showed a relatively narrow range of stress values and generally lower strain values. However, both heat-treated groups exhibited lower stress values and higher strain values than the raw material. Overall, the results indicate that heat treatment significantly influenced the tensile behavior of the stainless steel 304H wire. Nevertheless, further analysis and verification of the experimental data are required to establish the statistical significance of these differences and to clarify the effects of the individual heat treatment processes.

4.1 Discussion of Tensile Test Results for Stainless Steel 304H Wire Specimens

Tensile testing was conducted on three groups of stainless steel 304H wire specimens: raw material, annealed specimens, and hardened specimens. Each group consisted of three specimens, with an initial diameter of 1 mm and an initial length of 78 mm. The tensile test was performed to evaluate the effects of different heat treatment conditions on the mechanical properties of the wire, particularly tensile stress and strain. The results were analyzed by comparing the measured stress and strain values among the three specimen groups to determine the changes in tensile behavior associated with the heat treatment processes.

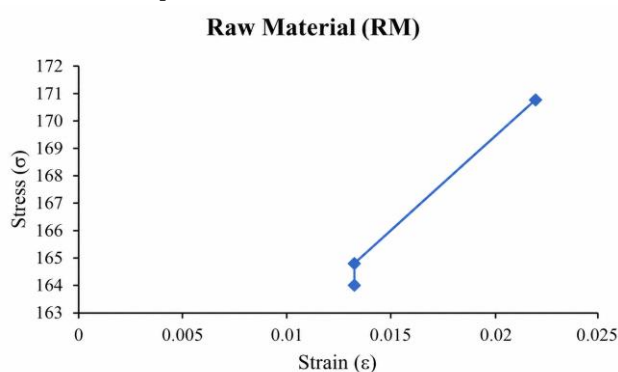


Figure 5 Stress–Strain Curve of the Raw Material

As shown in Figure 5, the raw material specimens consisted of 304H stainless steel wires without heat treatment. Tensile testing was conducted using a hydraulic jack-operated tensile testing machine. The first raw material specimen exhibited a stress value of 170.828 kgf/mm², a tensile strength of 134.1, and a strain of 0.022 mm. The second specimen exhibited a stress value of 164.841 kgf/mm², a tensile strength of 129.4, and a strain

of 0.013 mm. Meanwhile, the third specimen exhibited a stress value of 164.076 kgf/mm², a tensile strength of 128.8, and a strain of 0.013 mm.

4.1.1 Tensile Test Specimen after the Annealing Process

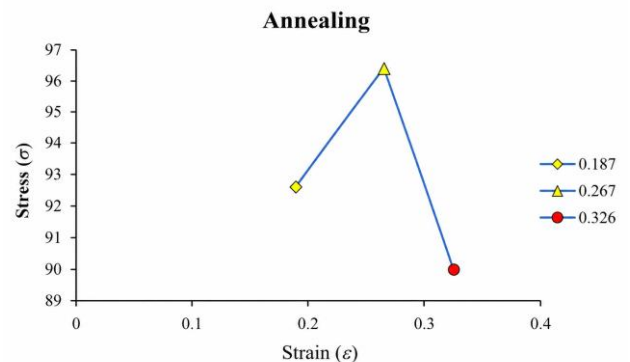


Figure 6. Stress–Strain Curve of the Annealed Specimens

Annealing is a heat treatment process intended to produce coarse pearlite by heating the material to the austenitizing temperature, followed by slow cooling inside a furnace. Based on the experimental results, Figure 6 annealing at 820°C yielded the optimum mechanical properties for the AISI 304H stainless steel wire specimens. The first annealed specimen exhibited a stress of 92.611 kgf/mm², a tensile force of 72.7 kg, and a strain of 0.187 mm. The second specimen exhibited a stress of 96.433 kgf/mm², a tensile force of 75.7 kg, and a strain of 0.267 mm. Meanwhile, the third specimen exhibited a stress of 89.936 kgf/mm², a tensile force of 70.6 kg, and a strain of 0.326 mm.

4.1.2 Tensile Test Specimen after the Hardening Process

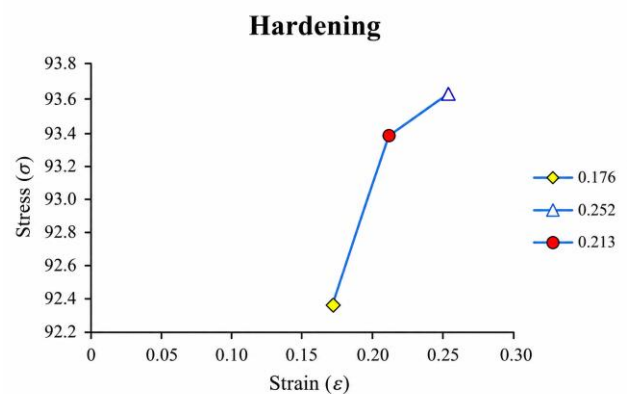


Figure 7. Stress–Strain Curve of the Hardened Specimens

Hardening is a heat treatment process performed to increase the hardness of a workpiece. In steel, hardening is generally carried out by heating the material to a temperature above its critical temperature, holding it at that temperature for a specified period, and then rapidly cooling it through quenching, typically in water.

The experimental results showed that hardening at 820°C Figure 7 produced the optimum mechanical

properties among the tested AISI 304H stainless steel wire specimens. The first hardened specimen exhibited a stress of 92.356 kg/mm², a tensile force of 72.5 kg, and a strain of 0.176 mm. The second specimen exhibited a stress of 93.630 kg/mm², a tensile force of 73.5 kg, and a strain of 0.252 mm. The third specimen exhibited a stress of 93.376 kg/mm², a tensile force of 73.3 kg, and a strain of 0.213 mm.

4.1.3 Comparison of the Material Before and After Heat Treatment

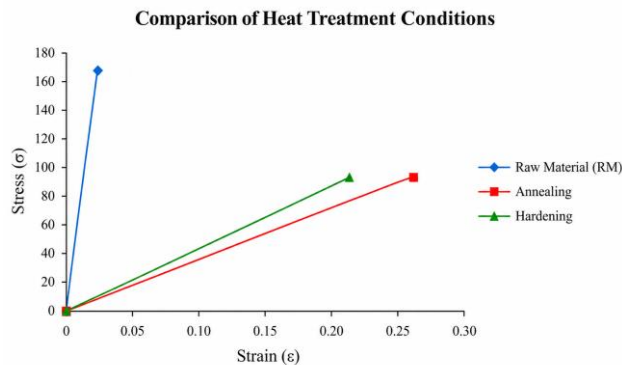


Figure 8. Comparison of the Material Before and After Heat Treatment

Based on the test results obtained from the stainless steel wire specimens before and after heat treatment, changes in mechanical properties were observed, particularly in the measured hardness-related values. Both specimens cooled slowly in a furnace without water quenching (*annealing*) and specimens rapidly cooled using water as the quenching medium (*hardening*) exhibited lower measured values than the untreated specimens. These changes were also influenced by the heat treatment temperature and cooling conditions.

The test results Figure 8 showed that all heat-treated specimens exhibited lower values than the untreated specimens. The first, second, and third untreated specimens recorded values of 170.828, 164.841, and 164.076 kgf/mm², respectively.

For the specimens subjected to annealing, the first specimen recorded a value of 92.611 kgf/mm², the second specimen 96.433 kgf/mm², and the third specimen 89.936 kgf/mm². Similarly, the specimens subjected to hardening exhibited values lower than those of the untreated specimens. The first hardened specimen recorded a value of 92.356 kgf/mm², the second specimen 93.630 kgf/mm², and the third specimen 93.376 kgf/mm².

4. Conclusions

The tensile test results for AISI 304H stainless steel wire specimens subjected to annealing and hardening at 820°C showed variations in yield stress, tensile force, and strain. For the annealed specimens, the highest values were recorded in the second specimen, with a yield stress of 96.433 kg/mm², a tensile force of 75.7 kg, and a strain

of 0.267 mm. Meanwhile, the hardened specimens exhibited the highest yield stress and tensile force in the second specimen, reaching 93.630 kg/mm² and 73.5 kg, respectively, with a strain of 0.252 mm. Overall, the annealed specimens exhibited higher maximum yield stress and tensile force than the hardened specimens.

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