

# Comparison of Annealing and Normalizing Cooling in Ferrous Metal Melting to Make Baffle Plates on Strength and Hardness Values Using the Three-Point Bending Method and Rockwell Hardness

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## ABSTRACT

Metal casting is one of the forming processes widely used in the manufacture of industrial components, including baffle plates installed in Babcock and Wilcox type boilers, due to its high flexibility and reliability. The study aims to compare the effects of annealing and normalizing heat treatment processes on the strength and hardness of cast metal baffle plates. The annealing process involves heating the material to a certain temperature followed by slow cooling, while the normalizing process uses air cooling at a controlled rate. The hardness of a material must be known, especially for materials undergoing construction during operation, while the flexural strength represents the maximum bending stress that the material can withstand under external loads without deformation. Hardness was measured using the Rockwell hardness method, and flexural strength was tested using the three-point bending method. The results showed that the average flexural strength of the annealed specimens was 59 kgf/mm<sup>2</sup>, which was lower than that of the normalized specimens at 66 kgf/mm<sup>2</sup>. In addition, the average hardness of the normalized specimens reached 113.66 HRC, slightly higher than that of the annealed specimens at 108.22 HRC. These findings indicate that the normalizing process increases the flexural strength and hardness more effectively than the annealing process.

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## I. Introduction

Baffle plates are made through a metal melting and casting process that generally follows a series of steps. Melting and casting is a manufacturing technique in which metal is melted in a furnace and then poured into a mold cavity that mirrors the original shape of the cast product to be made. The casting process can produce products that are very strong and resistant to friction due to the phase changes that occur when the metal is melted and then cooled.

The metal melting and casting process is a product manufacturing technique where the metal is melted in a melting furnace and then poured into a mold cavity that is similar to the original shape of the casting product to be made [1]. Metal melting and casting processes offer high flexibility and capability/reliability. Therefore, they are the most popular processes for manufacturing components and industrial machinery, such as boiler components, one of which is the baffle plate.

A baffle plate is a plate or dividing wall installed between the water tubes in a Babcock and Wilcox boiler. The baffle plate serves to prevent the tubes from bending (acting as a support). It also acts as a barrier to direct the flow of hot gas upwards, downwards, and upwards again before leaving the chimney. The baffle plate is provided to deflect hot flue gas to maximize heat transfer between the hot gas and the water tubes.



The baffle plate formation process is inextricably linked to the ferrous metal smelting process. Metal smelting involves heat treatment until the metal melts. The molten metal is then poured into a mold and allowed to harden. The final quality of the casting is influenced by the cooling rate, which can affect the mechanical properties of the resulting casting.

The problem object studied in the research with the topic of comparison of annealing and normalizing cooling in ferrous metal melting to make baffle plates is limited only to the research subject which is concentrated on the value of bending strength of baffle plate products against bending loading with the three-point bending method and the hardness value of baffle plate products with the Rockwell hardness test method through annealing and normalizing cooling on ferrous metal melting results.

In general, the purpose of this study is to compare annealing and normalizing cooling in ferrous metal smelting to make baffle plates on strength and hardness values through the three-point bending and Rockwell hardness methods. And specifically, the purpose of this study is to study the magnitude of the bending strength of baffle plate products from annealing and normalizing cooling to bending loading using the three-point bending method bending test and to determine the hardness value of baffle plate products from annealing and normalizing cooling using the Rockwell hardness test method.

## II. Research methods

### A. Baffle Plate

A baffle plate is a plate or dividing wall installed between the water tubes in a Babcock and Wilcox boiler. The baffle plate supports the water tubes to prevent them from bending. It also acts as a barrier to direct the flow of hot gas upwards, downwards, and upwards again before leaving the chimney, maximizing heat transfer between the hot gas and the water tubes.

The cooling rate is the rate at which a material loses heat after undergoing heat treatment. The heat treatment process begins by heating the material and then cooling it. The purpose of heat treatment is to soften the material, change the grain size, modify the material structure, and relieve the stresses in the material after hot and cold working [2].

### B. Bending Strength Testing

To determine the bending strength of a material, a flexural test can be performed on the specimen. Bending strength, or bending strength, is the maximum bending stress that can be sustained under external loading without experiencing significant deformation or failure. The magnitude of the bending strength depends on the type of specimen. Bending testing is a system or method for conducting bending tests. This type of bending test has two types: three-point bending and four-point bending. The difference between these two testing methods lies only in the shape and number of points used. Three-point bending uses two points at the bottom that function as supports and one point at the top that functions as a pressure point, while four-point bending uses two points at the bottom that function as supports and two points as pressure points at the top [3].

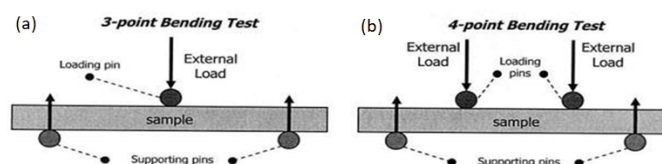


Fig 1. Bending testing process  
 (a) Three-point bending (b) Four-point bending

In this study, mechanical properties were tested using the three-point bending method. The bending test conducted in this study refers to the JIS Z 2248 standard. The three-point bending test is conducted to determine the bending strength of a metal after annealing and normalizing. This test uses a Universal Testing Machine Type MR-5, 10, and 20CT.

Bending testing is a destructive test. Destructive testing is used to determine the strength of metal in a construction. The advantages of using the three-point bending method are ease of preparation of the test specimen and its testing, as well as easier point creation [4]. Standards used in bending testing:

1. JIS Z 2248 is a bending test method
2. JIS Z 2204 is the shape and size of test samples on materials

In the following figure 2 is an image of a bending test specimen.

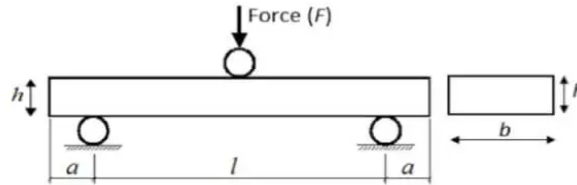


Fig 2. Bending testing specimen

Information:

- B = Material width (mm) = 20 mm  
 L = Material length (mm) = 150 mm  
 h = Thickness/depth of material (mm) = 5 mm

To determine the bending strength resulting from annealing and normalizing cooling using three-point bending testing, the bending strength can be calculated using the following formula:

$$\sigma_b = \frac{3pl}{2bd^2} \quad (1)$$

Where:

- $\sigma_b$  = Bending Strength (Kg-m/cm<sup>2</sup>)      b = Width (mm)  
 P = Load (Kg)      d = Depth (mm)  
 L = Span (mm)

### C. Hardness Test

Hardness testing is one of the many tests used, because it can be carried out on small test objects without difficulty regarding the specifications of the test object. The most widely used test is by applying a certain pressing pressure to the test object with a certain load and by measuring the size of the pressure mark formed on it, this method is called the pressing hardness method [5].

The hardness testing process can be defined as a material's ability to withstand a constant change in load. This means that when a certain force is applied to a test object, the object experiences a decrease due to the load. The hardness of the material can be analyzed by the magnitude of the applied load relative to the surface area receiving the load. Several hardness testing methods are used to assess metal hardness, including:

1. Brinell Hardness Testing Method
2. Vickers Hardness Testing Method
3. Rockwell Hardness Testing Method

The test used in this study was the Rockwell hardness testing method. The following is an image of the Rockwell hardness testing process, which can be seen in figure 3 below:

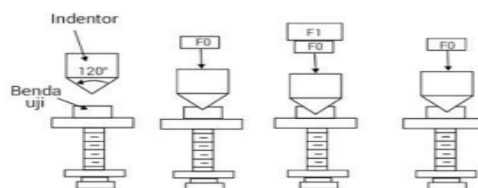


Fig 3. Rockwell hardness testing method

The standard used for the Rockwell hardness test on cast iron is JIS Z 2245. This standard regulates the hardness testing of metals by the Rockwell method, including the test procedure, type of indenter, load, and how to read the test results. To measure the hardness of cast iron, as recommended in the JIS Z 2245 standard. A 1/18" diameter diamond cone indenter and a load of 150 kgf are used on gray cast iron, so the results are accurate and representative for this material.

In Rockwell hardness testing, hardness measurements are directly performed by a machine, and the machine immediately displays the hardness number of the material being tested. This method is faster and more accurate. The load and indenter used vary depending on the test conditions. The indenter used is usually a hardened steel ball and a diamond cone. The test is carried out by first applying a minor load (preliminary load) of 10 kg, after which the pointer is set to zero on the black scale, and then given a major load (main load) ranging from 60-100 kg for the steel ball indenter and 150 kg for the diamond cone indenter. The following is an image of Rockwell penetration, which can be seen in figure 4.

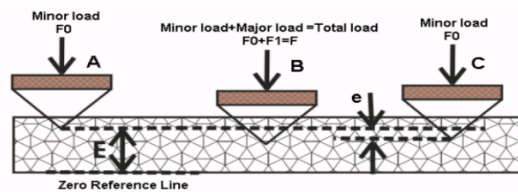


Fig 4. Rockwell penetration

Information:

$F_0$  = initial load (Kgf)

$F_1$  = additional load (Kgf)

$F$  = total load (Kgf)

$e$  = increase in penetration depth

$E$  = Indenter constant 0.002 mm

The Rockwell hardness scale consists of red and black colors, designed to accommodate the commonly used B and C scale tests. The red scale is for ball indenters, while the black scale is for diamond cone indenters. The B hardness scale is used for testing medium-hardness materials such as low-carbon and medium-carbon steels. The C scale is used to measure the hardness of very hard metals.

To be able to determine the hardness value resulting from cooling, annealing and normalizing using Rockwell hardness testing, the hardness value can be calculated from the indentation depth [6]. experiments with diamond cones, Rockwell hardness can be calculated using the formula:

$$HRC = \frac{a+b+c}{3} \quad (2)$$

### III. Method

#### A. Material

The materials used are test specimens, which are samples taken from an object for testing purposes to obtain information about the mechanical properties and characteristics of the material. The following is an image of a sample taken from an object after annealing and normalizing, as seen in figure 5.

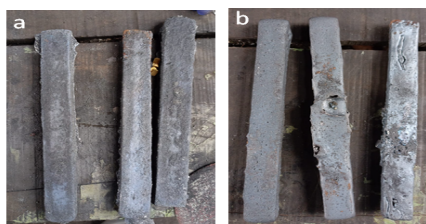


Fig 5. Resulting specimens for testing  
 (a) Annealing specimen (b) Normalizing specimen

The test specimens are then shaped according to the standard dimensions established for each type of test to ensure consistency and accuracy of the test results. The following are the standard dimensions for bending strength testing, as shown in figure 6. The standard dimensions for Rockwell hardness testing are shown in figure 7.

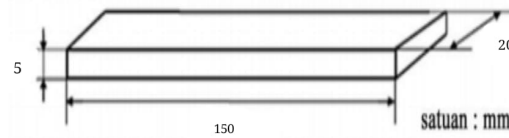


Fig 6. Dimensions of the JIS Z 2204 standard bending test specimen

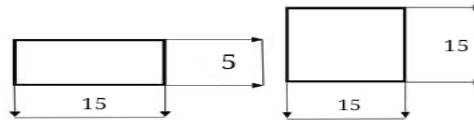


Fig 7. Dimensions of the Rockwell hardness test specimen standard JIS Z 2245

## B. Tools

### Universal Testing Machine

This test uses a universal testing machine type MR-5, 10, and 20 CT, which is used in the testing process to determine the mechanical properties of a material, specifically to obtain the material's strength value accurately and systematically. The following is an image of the universal testing machine, which can be seen in figure 8.

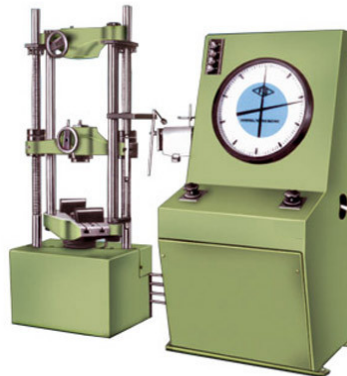


Fig 8. Universal testing machine tool

### Rockwell Hardness Tester

This hardness test uses a Rockwell hardness tester Type MATSUZAWA 8781, which is used to determine the mechanical properties of a material, specifically in obtaining the hardness value of the material accurately and systematically. The following is an image of the Rockwell hardness tester, which can be seen in figure 9.



Fig 9. Matsuzawa Rockwell hardness test

### C. Activity Plan

Bending strength testing activities:

1. Prepare flexural testing equipment, such as a universal testing machine used for flexural strength testing using the three-point bending method.
2. Carefully measure the dimensions of the test specimen, such as width, height, and length, as these are critical parameters for accurate flexural strength calculations.
3. Place the test specimen in the universal testing machine in the correct position and adjust the loading position accurately.
4. Apply the load carefully and gradually to avoid errors. Continue applying the load until the test specimen breaks or fractures.
5. Record the maximum load the test specimen can withstand before breaking as the primary data for the flexural strength test.

Hardness test activity:

1. Prepare the Rockwell hardness tester according to testing standards.
2. Check that the surface of the test specimen is flat and free from dirt or dust, so that test results are not affected by surface conditions.
3. Place the specimen in a stable and precise position on the anvil of the Rockwell hardness tester to ensure proper contact between the indenter and the specimen surface.
4. Select a Rockwell testing scale appropriate for the material type and thickness of the specimen, then carry out the test procedure according to the testing standards.
5. Apply a load through the indenter automatically by the instrument and record the Rockwell hardness value displayed on the measuring clock after the load is applied and released.
6. Perform at least three tests on different areas of the specimen to obtain an average hardness value, thereby reducing measurement errors.

## IV. Results and Discussion

### A. Bending Test

From the results of the three-point bending test conducted using 3 samples for each type of cooling, the maximum strength data of the specimens was obtained from the test results for each type of cooling. Therefore, the bending strength can be calculated from the test specimens used according to the data shown in table 1 as follows.

Table 1. Observation of impact test results

No.	Cooling Type	$L_b$ (mm)	$L_t$ (mm)	b (mm)	d (mm)	$F_{max}$ (Kgf)
1	Annealing Process	150	100	20	5	195
2		150	100	20	5	185
3		150	100	20	5	210
1	Normalizing Process	150	100	20	5	190
2		150	100	20	5	240
3		150	100	20	5	230

1. Calculating the bending strength of a baffle plate product from ferrous metal smelting through annealing can be done using the following formula:

- a. Calculating the bending strength of specimen 1

$$\begin{aligned}
 \sigma_b &= \frac{3PL}{2bd^2} \\
 &= \frac{3 \cdot 195 \text{ Kgf} \cdot 100 \text{ mm}}{2 \cdot 20 \text{ mm} \cdot (5 \text{ mm})^2} \\
 &= 58,5 \text{ Kgf/mm}^2
 \end{aligned}$$

b. Calculating the bending strength of specimen 2

$$\begin{aligned}\sigma_b &= \frac{3PL}{2bd^2} \\ &= \frac{3 \cdot 185 \text{ Kgf} \cdot 100 \text{ mm}}{2 \cdot 20 \text{ mm} \cdot (5 \text{ mm})^2} \\ &= 55,5 \text{ Kgf/mm}^2\end{aligned}$$

c. Calculating the bending strength of specimen 3

$$\begin{aligned}\sigma_b &= \frac{3PL}{2bd^2} \\ &= \frac{3 \cdot 210 \text{ Kgf} \cdot 100 \text{ mm}}{2 \cdot 20 \text{ mm} \cdot (5 \text{ mm})^2} \\ &= 63 \text{ Kgf/mm}^2\end{aligned}$$

2. Calculating the bending strength of baffle plate products from ferrous metal melting through normalizing cooling can be done using the following formula:

a. Calculating the bending strength of specimen 1

$$\begin{aligned}\sigma_b &= \frac{3PL}{2bd^2} \\ &= \frac{3 \cdot 190 \text{ Kgf} \cdot 100 \text{ mm}}{2 \cdot 20 \text{ mm} \cdot (5 \text{ mm})^2} \\ &= 57 \text{ Kgf/mm}^2\end{aligned}$$

b. Calculating the bending strength of specimen 2

$$\begin{aligned}\sigma_b &= \frac{3PL}{2bd^2} \\ &= \frac{3 \cdot 240 \text{ Kgf} \cdot 100 \text{ mm}}{2 \cdot 20 \text{ mm} \cdot (5 \text{ mm})^2} \\ &= 72 \text{ Kgf/mm}^2\end{aligned}$$

c. Calculating the bending strength of specimen 3

$$\begin{aligned}\sigma_b &= \frac{3PL}{2bd^2} \\ &= \frac{3 \cdot 230 \text{ Kgf} \cdot 100 \text{ mm}}{2 \cdot 20 \text{ mm} \cdot (5 \text{ mm})^2} \\ &= 69 \text{ Kgf/mm}^2\end{aligned}$$

The specimen testing was carried out using gray cast iron with annealing and normalizing cooling with dimensions designed in accordance with the JIS Z 2204 standard for bending loading, so that the results of the material testing obtained an average flexural strength value from annealing cooling of 59 Kgf/mm<sup>2</sup>, and for normalizing cooling obtained an average flexural strength value of 66 Kgf/mm<sup>2</sup>.

## B. Hardness Test

From the results of hardness testing on specimens carried out using the Rockwell hardness method using 3 samples for each type of cooling.

The value of each indentation is obtained, namely the top point (a), middle point (b), bottom point (c), using a Diamond cone indenter and a load of 150 kg. Then the specimen hardness data is obtained from the test results on each type of cooling, so that the calculation of the Rockwell hardness can be calculated from the test specimen used according to the data that can be seen in table 2.

Tabel 2. Rockwell hardness testing observations

No.	Cooling Type	Burden (Kg)	Experimental Data		
			a	b	c
1	Annealing Process	150	108	109	108,5
2		150	109,5	106	108
3		150	107,5	109,5	108
1	Normalizing Process	150	107	113,5	112,5
2		150	114	118	119
3		150	118	117,5	108

1. Calculating the hardness value of the baffle plate product from the melting of ferrous metal through annealing cooling can be done using the following formula:

- a. Calculate HRC hardness on specimen 1

$$\begin{aligned}
 \text{HRC} &= \frac{a+b+c}{3} \\
 &= \frac{108 + 109 + 108,5}{3} \\
 &= \frac{325,5}{3} \\
 &= 108,5 \text{ HRC}
 \end{aligned}$$

- b. Calculate HRC hardness on specimen 2

$$\begin{aligned}
 \text{HRC} &= \frac{a+b+c}{3} \\
 &= \frac{109,5 + 106 + 108}{3} \\
 &= \frac{323,5}{3} \\
 &= 107,83 \text{ HRC}
 \end{aligned}$$

- c. Calculate HRC hardness on specimen 3

$$\begin{aligned}
 \text{HRC} &= \frac{a+b+c}{3} \\
 &= \frac{107,5 + 109,5 + 108}{3} \\
 &= \frac{325}{3} \\
 &= 108,33 \text{ HRC}
 \end{aligned}$$

The test was carried out using gray cast iron with annealing and normalizing cooling with dimensions designed according to the JIS Z 2245 standard for penetration. So the average Rockwell hardness value obtained from annealing cooling was 108.22 HRC, and for normalizing cooling the average Rockwell hardness value was 113.66 HRC.

## V. Conclusion

The results of this study are to study the comparison of annealing and normalizing cooling in ferrous metal smelting to make baffle plates on strength and hardness values through the three-point bending and Rockwell hardness methods with destructive test types.

The purpose of this study is to determine the value of the flexural strength of baffle plate products on ferrous metal smelting results through annealing and normalizing cooling with the three-point bending method. and to determine the value of the hardness of baffle plate products on ferrous metal smelting results through annealing and normalizing cooling using the Rockwell hardness method:

1. The average value of bending strength that can be withstood by baffle plate products with annealing cooling is 59 Kgf/mm<sup>2</sup>. And the average value of bending strength with normalizing cooling is 66 Kgf/mm<sup>2</sup>.
2. The average Rockwell hardness value for the baffle plate product under annealing cooling is 108.22 HRC. The average Rockwell hardness value for normalizing cooling is 113.66 HRC.

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