*International Journal of Latest Engineering and Management Research (IJLEMR)*
*ISSN: 2455-4847*
*www.ijlemr.com || Volume 09 – Issue 04 || April 2024 || PP. 40-44*

# Effect of Heat Treatments on the Mechanical Properties of Some Selected Metals (Al, Cu & Zn)

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**Abstract:** Heat treatment is a very important practice in metal working and fabrications as it plays a very serious role in affecting the physical, chemical and mechanical properties of such metals. This study investigated the effect of heat treatments on the mechanical properties of some metals which are Aluminum, Copper and Zinc. There are several heat treatment methods used but this study considered just the normalizing and quenching methods of heat treatment. The chemical composition of the samples investigated were first checked through a PMI test and then the tensile strength and hardness of the metals were measured. The results revealed that the samples of the materials used were almost in their pure forms as the percentage of impurities present were quite negligible. Also, it was discovered that the quenching method was more effective for copper while normalizing method was more effective for zinc. On the other hand, the both methods were not favourable in the improvement of the mechanical properties of Aluminum.

**Keywords:** Normalizing, Quenching, Aluminum, Zinc, Copper.

## 1. Introduction

Metals, are versatile workhorses of industries which have characteristics that can be changed significantly by applying heat treatment, a potent technique. Heat treatment is an important method for changing or adjusting the mechanical, physical, and sometimes chemical properties of metals [1].It can be defined as the process of heating and cooling metals to change their microstructure and to bring out the desired physical and mechanical characteristics of the metals depending on the usage of such metals. The temperatures metals are heated to, and the rate of cooling after heat treatment can significantly change metal's properties [2].Heat treatment has a wide range of effects on metals, and it can be used to modify the material's properties to suit a certain application. In [3], the effect of heat treatment on the mechanical and microstructural properties of tool steel was studied. Some of the properties that could be affected by heat include ductility, hardness, tensile strength, machinability structural change, corrosion resistant, and several others[4].

Some of the heat treatment methods include; annealing – this involves heating a metal at a temperature high above the recrystallization point and then allowed to cool slowly, normalizing – this is almost the same process as annealing but the cooling process is faster because the metal is usually exposed to air to cool the metal [5]. Another is quenching – in this case, after heating up the metal to certain high temperature, the metal is meant to undergo rapid cooling by using quenching medium like, water or oil. Other treatment methods include; tampering, hardening, etc.

For the purpose of this paper, we shall be limiting our study to effect of normalizing and quenching on the following metal; copper, aluminum and zinc. Copper and zinc are d-block elements with atomic numbers 29 and 30 respectively while aluminum is a p-block element with atomic number 13[6]. They are all metals and are good conductors of electricity due to their physical and chemical properties, they have a very wide range of application in industries as well as domestic fields. Copper is the second most abundant metal on earth after iron making up about 1% of the earth crust[7]. It is malleable and ductile, one of its most unique characteristics of copper is its wonderful ability to make alloys with other metals, which makes it a very useful metal to mankind. It is used in construction, electrical wiring, coins, and jewelry industries. Aluminum on the other hand is a soft metal and very malleable. It is a non-toxic metal and it is non-corrosive and non-magnetic. Even though aluminum on its own is not very strong, yet it makes very strong alloys with copper and magnesium[8]. These are lightweight alloys and yet have great strength which makes them find useful application in the construction of automobiles and air crafts. It is also used in construction companies. Aluminum also finds great application in household uses such as cans, foils, kitchen utensils, etc [9]. Lastly, Zinc is about the fourth most abundant metal on earth, making up about 0.2% of the earth's crust. It a hard and brittle metal but can be malleable between $100^{o}C$ to $150^{o}C$ and has a low melting point and boiling point in comparison with other metals and it is fairly non-corrosive[10]. One of the most important uses of zinc is its suitability to be used in Galvanization. A thin layer of zinc coats other metals such as iron. It protects the iron from corrosion. The oxygen in the air reacts with Zinc to form Zinc Oxide, thereby protecting the iron. It is also used in construction, batteries and several others.

The normalizing heat treatment method refines the grain structure of Aluminum, thereby enhancing its mechanical properties like strength, ductility and toughness [11]. On the other hand, the method can improve the mechanical and wear properties of Zinc, making it more suitable for specific application s that required enhanced strength and durability[12]. Subjecting copper to normalizing heat treatment, its grain structure is improved which gives rise to increase in its strength, ductility and toughness.

## 2. Materials and Method

Firstly, the individual materials were copper, aluminum and zinc were gotten from steel village in Port Harcourt, Rivers state Nigeria. The samples of the materials used were collected and prepared. The surface of the materials measured was smoothened and polished with a sample grinder. This step is done to eliminate any existing dirt and roughness from the sample surface being measured so as to avoid measurements errors.

### 2.1 Positive Material Identification (PMI)

This is used to analyze and identify material grade and alloy composition for quality and safety control. A rapid, non-destructive method, positive material identification is performed on a wide range of components and assets, and provides a semi-quantitative chemical analysis. This test was done with the use of an Oxford instrument XRF spectrometer (model X-MET 7000 and model X-MET 7500). The spectrometric analysis of the materials was carried out to determine its chemical compositions.

### 2.1.1 Hardness and Tensile Testing Procedure

The surface of the materials measured was smoothened and polished with a sample grinder. This step is done to eliminate roughness of sample surface being measured so as to avoid measurements errors. The hardness tester was verified by using standard test block for calibration. It was first used to test the standard test block downwards vertically for three times, the arithmetic average value is compared with the value of standard block test. Pushing the loading-tube downwards until contact is felt. Then allow it to slowly return to the starting position. Lastly, pressing the impact device supporting ring on the surface of the sample firmly; the impact direction was vertical to the testing surface. The sample was tested by pressing the release button on the upside of the impact device. The sample was tested three times and the average value was taken.

### 2.2 The Heat Treatment Processes

### 2.2.1 Quenching Heat Treatment

This process is done by heating the metal in a furnace to a temperature close to its melting point and cooling it in a cooling medium, water was used as a cooling medium here. The aluminum and copper metals were heated from room temperature of 30°C to 450°C while zinc was heated from room temperature of 30°C to 250°C. This temperature was maintained in the furnace for 15mins before it was brought out with a tong and immediately quenched in water.

### 2.2.2 Normalizing Heat Treatment

It involves the process of heating a metal to a temperature just below it melting point, holding at that temperature for a few minutes and bringing out to cool at atmospheric temperature. This process was done on representative on the samples. While the aluminum and copper metals were heated to 450°C from room temperature, zinc was heated to 250°C from room temperature and maintained for 15mins. After that, they were all released from the furnace to cool at atmospheric temperature.

## 3. Results

### 3.1 Positive Material Identification (PMI) Test

The PMI test gives the chemical composition of the metals and the record of the chemical composition of the metal is shown in the images below;

| Name | Class | Date | Time | Duration |
|---|---|---|---|---|
| CALEB | Alloy_LE_FP | 07/02/2023 | 10:47:10 | 15.5 s |

| **Element** | Al % | Si % | Fe % | Co % | Zn % | Pb % |
|---|---|---|---|---|---|---|
| | 99.03 | 0.72 | 0.15 | 0.05 | 0.02 | 0.02 |
| ± | 0.637 | 0.112 | 0.011 | 0.006 | 0.003 | 0.003 |

Grades: AA-1100 (0.03), Al-I000 (0.21)
Reference:

Fig. 1: PMI Result for Aluminum

| Name | | Class | | | Date | | Time | | Duration |
|---|---|---|---|---|---|---|---|---|---|
| CALEB | | Alloy_LE_FP | | | 07/02/2023 | | 10:47:37 | | 15.6 s |
| **Element** | P % | Fe % | Co % | Zn % | Y % | Zr % | Hf % | Ta % | |
| | 0.92 | 8.04 | 1.56 | 86.48 | 0.65 | 0.10 | 0.75 | 1.51 | |
| ± | 0.229 | 0.114 | 0.052 | 0.337 | 0.036 | 0.026 | 0.090 | 0.103 | |

Grades: No Match
Reference:

Fig.2: PMI Result for Zinc

| Name | | Class | | | Date | | Time | | Duration |
|---|---|---|---|---|---|---|---|---|---|
| CALEB | | Alloy_LE_FP | | | 07/02/2023 | | 10:48:03 | | 15.5 s |
| **Element** | Si % | Fe % | Co % | Cu % | Zn % | Zr % | Nb % | Sb % | |
| | 1.66 | 1.27 | 0.14 | 90.94 | 1.38 | 2.59 | 1.08 | 0.94 | |
| ± | 0.383 | 0.048 | 0.024 | 0.352 | 0.043 | 0.063 | 0.049 | 0.216 | |

Grades: C197 (2.07), C655 (2.17)
Reference:

Fig. 3: PMI Result for Copper

From the figures above, it can be observed that figure 1 which gives the PMI result for Aluminum, have the Aluminum element to have a composition of 99.03% while the remaining were other impurities. This is an indication that the material is almost in its pure state. Same applies for the zinc in figure 2, the zinc element has a composition of 86.48% while the remaining are the impurities in the material. This also is an indicator that the zinc metal is almost pure. Lastly, copper from figure 3 show that copper element account for 90.94% of the composition, which makes is also almost pure.

### 3.2 Effect of Heat Treatment on the Mechanical Properties of the samples.

The hardness and the tensile strength of the metals were considered before and after the two different heat treatments.

Table 1: Hardness Test Results of Heat Treated and Untreated Aluminum

| HEAT TREATMENT | 1st SHOT (HL) | 2nd SHOT (HL) | 3rd SHOT (HL) | AVERAGE (HL) |
|---|---|---|---|---|
| **Untreated** | 340 | 362 | 361 | 354 |
| **Normalized** | 241 | 268 | 217 | 242 |
| **Quenched** | 273 | 242 | 234 | 250 |

Table 1 above describes the effect of the heat treatments on the hardness of Aluminum. It is observed that before heat treatment, Aluminum has a hardness of 354HL. The result of the heat treatment shows that for the normalized method, the hardness was an average of 242MPa while for the Quenched method the hardness was an average of 250HL. Comparing the result with the untreated sample, normalized sample showed lower hardness of 242 HL while the quenched has 250 HL. This shows that the hardness was higher before the heat treatment and lower after the heat treatment. This implies that the two heat treatments carried out are not effective methods to be implored when trying to improve the hardness of Aluminum.

Table 2: Tensile Strength Test Results of Heat Treated and Untreated Aluminum

| HEAT TREATMENT | 1st SHOT (MPa) | 2nd SHOT (MPa) | 3rd SHOT (MPa) | AVERAGE (MPa) |
|---|---|---|---|---|
| **Untreated** | 406 | 446 | 444 | 432 |
| **Normalized** | 223 | 273 | 198 | 225 |
| **Quenched** | 282 | 224 | 209 | 238 |

Table 2 describes the effect of the heat treatments on the tensile strength of Aluminum. It is observed that before heat treatment, it has an average tensile strength of 432MPa. The result of the heat treatment shows that for the normalized method, its tensile strength is an average of 225MPa while for the Quenched method, the average tensile strength is 238MPa. Comparing the tensile strength of the normalized aluminum sample with the untreated sample, normalized sample showed lower tensile strength (225 MPa) while comparing the tensile strength of the quenched aluminum with the untreated sample, the quenched sample showed a lower tensile strength (238MPa). The result of the tensile strength for aluminum shows that the tensile strength was higher before the heat treatments and lower after the heat treatments. This implies that the two heat treatments carried out are not effective methods to improve the tensile strength of Aluminum.

Table 3: Hardness Test Results of Heat Treated and Untreated Copper

| HEAT TREATMENT | 1st SHOT (HL) | 2nd SHOT (HL) | 3rd SHOT (HL) | AVERAGE (HL) |
|---|---|---|---|---|
| **Untreated** | 286 | 260 | 285 | 277 |
| **Normalized** | 202 | 321 | 228 | 250 |
| **Quenched** | 346 | 293 | 334 | 324 |

Table 3 describes the effect of the heat treatments on the hardness of Copper. It is observed that before heat treatment, the copper sample has a hardness of 277HL. The result of the heat treatments shows that for the normalized method, the average hardness was 250HL while for the Quenched method, the average hardness is 324HL. Comparing the hardness of copper after the Normalized heat treatment method and that after the Quenched methods, it shows that the hardness is higher with the quenched heat treatment method than the normalized method. This implies that the quenched heat treatment method should be implored when trying to improve the hardness of Copper.

Table 4: Tensile Strength Test Results of Heat Treated and Untreated Copper

| HEAT TREATMENT | 1st SHOT (MPa) | 2nd SHOT (MPa) | 3rd SHOT (MPa) | AVERAGE (MPa) |
|---|---|---|---|---|
| **Untreated** | 306 | 258 | 304 | 289 |
| **Normalized** | 150 | 371 | 198 | 240 |
| **Quenched** | 417 | 319 | 395 | 377 |

Table 4 describes the effect of the heat treatments on the tensile strength of Copper. It is observed that before heat treatment, the copper sample has an average tensile strength of 289MPa. The result of the heat treatments shows that for the normalized method, the average tensile strength was 240MPa while for the Quenched method, the average tensile strength is 377MPa. Comparing the tensile strength of copper after the Normalized heat treatment method and that after the Quenched methods, it shows that the tensile strength is higher with the quenched heat treatment method than the normalized method. This implies that the quenched heat treatment method would produce Copper with higher tensile strength.

Table 5: Hardness Test Results of Heat Treated and Untreated Zinc

| HEAT TREATMENT | 1st SHOT (HL) | 2nd SHOT (HL) | 3rd SHOT (HL) | AVERAGE (HL) |
|---|---|---|---|---|
| **Untreated** | 417 | 379 | 438 | 411 |
| **Normalized** | 558 | 531 | 446 | 512 |
| **Quenched** | 461 | 386 | 419 | 422 |

Table 5 describes the effect of the heat treatments on the hardness of Zinc. It is observed that before heat treatment, the Zinc sample has an average hardness of 411HL. The result of the heat treatments shows that for the normalized method, the average hardness was 512HL while for the Quenched method, the average hardness is 422HL. Comparing the hardness of Zinc after the Normalized heat treatment method and that after the Quenched methods, it shows that the hardness is higher with the normalized heat treatment method than the quenched method. This implies that the normalized heat treatment method should be implored when trying to improve the hardness of Zinc.

Table 6: Tensile Strength Test Results of Heat Treated and Untreated Zinc

| HEAT TREATMENT | 1st SHOT (MPa) | 2nd SHOT (MPa) | 3rd SHOT (MPa) | AVERAGE (MPa) |
|---|---|---|---|---|
| **Untreated** | 547 | 478 | 586 | 537 |
| **Normalized** | 803 | 754 | 600 | 719 |
| **Quenched** | 628 | 490 | 551 | 556 |

Table 6 describes the effect of the heat treatments on the tensile strength of Zinc. It is observed that before heat treatment, the Zinc sample has an average tensile strength of 537MPa. The result of the heat treatments shows that for the normalized method, the average tensile strength was 719MPa while for the Quenched method, the average tensile strength is 556MPa. Comparing the tensile strength of Zinc after the Normalized heat treatment method and that after the Quenched methods, it shows that the tensile strength is higher with the normalized heat treatment method than the quenched method. This implies that the normalized heat treatment method would produce Zinc metals with higher tensile strength.

## 4. Discussions

From the results it is clear that different heat treatment is used to improve the properties of different metals. This was seen as the two heat treatment methods was employed in this study i.e. normalizing and quenching were not effective in improving the mechanical properties of Aluminum. This is seen also from the test results where the value of the hardness and tensile strength of the untreated Aluminum sample was far higher than the treated sample. Several works stated that ageing is the best heat treatment method for improving the mechanical properties of aluminum. This corroborated in the works of [13] who carried out a study on the effect of ARB and ageing processes on mechanical properties and microstructure of 6061 aluminum alloy.

The results also revealed that the quenching heat treatment method would produce a better output in terms of hardness and tensile strength for copper while the normalizing heat treatment method would be better to produce a better hardness and tensile strength for zinc than the other methods.

## 5. Conclusions

Heat treatment of metals is a very crucial aspect of metal working and metal fabrications. Its impact is such that it affects the mechanical, physical and chemical properties of metals which is done by subjecting the metal to controlled heating and cooling. Heat treatment offers engineers, material scientists and metallurgists a means of adjusting the material characteristics to suit its applications for different purposes. Amongst the several heat treatment methods, the normalizing method seem to be more effective in improving the mechanical properties of Zinc, while quenching method improves that of copper. But both methods have very little effect on aluminum.

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