Journal of Materials & Manufacturing Technology

www.jmmt.reapress.com

**J. Mater. Manuf. Technol. Vol. 1, No. 1 (2024) 59–65.**

Paper Type: Original Article

# Evaluation of the Effect of Low-Frequency Vibration on the Mechanical Properties of Aluminium 6061 Alloy Under Varying Mould Sizes

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**Citation:**

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| *Received: 18 June 2024*<br>*Revised: 29 August 2024*<br>*Accepted: 09 September 2024* | Dokyoung, M. M. & Akor, T. (2024). Evaluation of the effect of low-frequency vibration on the mechanical properties of aluminium 6061 alloy under varying mould sizes. *Journal of Materials & Manufacturing Technology, 1* (1), 59-65. |

## Abstract

This study examined the effects of mechanical vibration and mould size on the mechanical properties of cast aluminium 6061 alloys. Aluminium rods were cast into moulds of varying sizes (12mm to 21mm) with and without vibration at 44 Hz. Tensile and impact tests were conducted to evaluate the samples. Results showed that vibrated samples had improved tensile strength and toughness compared to non-vibrated (control) samples. The 19mm vibrated mould yielded the highest tensile strength (138.25 N/mm$^2$), while the smallest mould (12mm) produced the toughest samples in impact tests. The application of vibration led to an average 12.8% improvement in tensile strength and 20.1% in impact toughness. Larger mould sizes were associated with decreased toughness, highlighting the positive impact of vibration and mould size optimization on material properties.

**Keywords:** Grain refining, Low-frequency vibration, Mould size, Tensile strength, Impact strength.

## 1 | Introduction

Grain refining is an important part of the metal casting process that aims to reduce the size of grains during the solidification phase. The main purpose of grain refinement is to achieve fine grain size and improve the mechanical properties of the metal. Optimizing the industrial application of grain refinement of materials is very important [1].

There are three major methods for carrying out grain refinement in metals. They include the thermal method, Chemical method, and Mechanical method.

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The thermal refinement method involves controlling the cooling rate of the melt by promoting a rapid cooling rate during the solidification process, which allows for the desired fine microstructure. Examples of the methods used to carry out this process are twin-roll casting and spray deposition. The twin-roll casting method combines casting and hot rolling to make a metal strip from liquid metal, while the spray deposition method uses an inert gas to atomize the liquid metal stream into droplets, which are then driven out from the atomization region by airflow [1].

In the chemical method, master alloys as grain-size refiners are employed. Master alloys help to promote nucleation, as inoculation is a common type of chemical grain refinement method. The most common master alloys added into aluminum are a mixture of titanium and boron, or titanium may be added alone. All types of aluminum alloys respond well to chemical grain-size refiners. When using the chemical method to obtain the desired results, the amount, form, size, and quantity of master alloys must be controlled [2].

In the mechanical method, the metal is agitated during the solidification phase. The three most common methods used are electromagnetic stirring, ultrasonic vibration, and mechanical vibration. The electromagnetic stirring method uses an electromagnetic field to refine the microstructure by removing inclusions/gas bubbles, homogenizing the melt composition and temperature, and finally, a refined microstructure. The ultrasonic vibration method uses either mechanically and electrically generated ultrasonic vibrations to produce fine, uniform grains during the nucleation stage. Mechanical vibration is the most cost-effective grain refining process of the three methods. The generated vibrations cause significant agitation of the melt, resulting in uniform crystallization across the volume [1].

This study aims to investigate the relationship between the application of mechanical vibration at a single frequency and mould size variation on the mechanical properties of a casted metal by using an aluminium alloy as the specimen.

Grain refinement helps to improve the mechanical properties of a metal by ensuring uniform mechanical properties; it decreases the size of porosities and thus improves the surface finish and machinability of the metal. Grain refinement also helps to reduce hot tears, increase the resistance of the metal to fatigue, and reduce ingot cracking. Grain refinement helps to improve feeding to eliminate shrinkage porosity and also helps disperse micro-shrinkage. It also helps to reduce the thermal treatment cycles. Another advantage of grain refinement is that it reduces the number and size of pores in casting alloys. Because created voids can fill between the aluminum dendrites and the solidified eutectic during the solidification process, the development and expansion of the grains can induce gas porosity. Reduced grain size reduces the amount of area available for pores to develop.

Kang et al. [2] investigated the ultrasonic vibration effects in several metal melts. Ultrasonic melting and cavitation are the principal effects of ultrasonic treatment of melts. It compared the ultrasonic streaming in water, aluminum, and steel melts. The results reveal that the effective streaming and cavitation region in steel melt was smaller than that of the aluminum melt and significantly smaller than water. Selivorstov et al. [3] studied the effect of vibration on the mechanical properties of an aluminium alloy; they discovered that the mechanical properties of A356 alloy, after vibration treatment with frequencies of 100 Hz and 150 Hz, improved by 20% and 10%, respectively, but the use of vibration frequencies of 200 Hz caused the formation of a high porosity microstructure and caused major defects.

Kudryashova et al. [4] carried out vibration treatment of solidifying metals and discovered that vibration improves the structure of castings by allowing for extensive heat transport in the melt. The vibration energy is expended on dendritic branch fragmentation, which results in grain multiplication. Kumar et al. [5] investigated the effect of mould vibration on the microstructure and mechanical properties of tofu aluminum-silicon eutectic castings during solidification. Castings with mechanical mould vibration during solidification demonstrated a definite refinement of grains and an increase in hardness. The results demonstrated the dendrite grain size of the cast samples was at frequencies (5,10,15,20, and 25) Hz; they were reduced by 15%, 26%, 32%, 42%, and 53%, respectively. The hardness of the samples also increased by 7%, 16%, 25%, 33%, and 40% receptively, and the porosity of the cast sample was reduced by 35%, 46%, 58%, 69%, and 77% receptively.

Haydar et al. [6] investigated the effects of mechanical mould vibration on the microstructure and mechanical characteristics of Al-Si eutectic and discovered that mechanical mould vibration reduced the dendritic grain size and porosity of the cast samples. The hardness, Ultimate Tensile Strength (UTS), elastic modulus (E), and elongation of the cast samples were also found to have increased.

## 2 | Materials and Methods

The material used for this experiment is an Aluminium 6061 alloy, and the chemical components are shown in *Table 1*.

**Table 1. Chemical components of the aluminium 6061 alloy.**

| S/N | Sample | | Al | Mg | Si | Cu | S | Cl | K |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Aluminium | wt (%) | 94.922 | 1.908 | 1.833 | 0.038 | 0.098 | 0.486 | 0.092 |
| | | | Ca | Ti | V | Cr | Mn | Fe | Ni |
| | | wt (%) | 0.145 | 0.011 | 0.008 | 0.009 | 0.0395 | 0.301 | 0.004 |

### 2.1 | Experimental Procedure

The Al-6061 alloy rod was cut into small lengths of 50mm and put into a metal crucible. The crucible was placed in the furnace and heated to the melting temperature of about 873$^{o}$C for the Al-6061 alloy. The molten Al-6061 alloy was poured into the moulds of varying diameters (12mm, 13.5mm, 16mm, 19mm & 21mm) which were already secured on the vibrator table. The vibrator was set at a vibrating frequency of 44 Hz during pouring. The molten Al-6061 alloy was allowed to cool while it was on the vibrator table for about 20 minutes, after which the samples were removed from the moulds. Control samples were also produced without induced vibration. The casted samples were left to air cool, after which they were machined into test specimens for tensile and impact energy tests.

**Fig. 1. Casting of the samples.**

### 2.1.1 | Tensile strength test

A monsato tensiometer, a type 'W' tensile testing machine, was used to carry out the tensile test of all the specimens. The initial diameter and initial gauge length of the given specimen were measured with the aid of a vernier calliper. The specimen was inserted into the anvil and secured with the aid of rings and pins. The mercury bubble in the glass veriola tube was removed by turning the knob to 0 KN. The specimen was subjected to slight tension by turning the hand of the wheel in every two divisions (in every 0.2mm extension); the hand wheel was turned until the specimen fractured. The pins and rings were removed to remove the fractured specimen. The two fractured pieces were joined, and the final diameter and final gauge length were measured with the aid of the Vernier calliper. The mechanical properties of the specimen were calculated using the obtained values. The process was repeated for all the samples.

### 2.1.2 | Impact test

The impact test was carried out with the lostech JB-300B impact tester. The specimen was mounted one after the other on the machine. The test was carried out by releasing the elevated hammer to strike the specimen, and the energy at fracture was recorded on the machine's scale. The process was repeated for all the samples.

# 3 | Results and Discussion

## 3.1 | Tensile Strength Test

The tensile test samples were tested for fractures on a tensile testing machine. From the data generated, the Yield Stress (YS), UTS, percentage elongation (%), and Reduction in area were calculated, and the results were presented in *Table 2*. *Fig. 2* shows the graphical relationship between UTS and the different mould sizes for both the control and vibrated samples.

**Table 2. Average of the tensile test results of the aluminium 6061 Alloy samples.**

| Specimen | Vibration (Hz) | UTS (N/mm$^2$) | YS (N/mm$^2$) | Elongation (%) | Reduction in Area (%) |
|---|---|---|---|---|---|
| 12B | 0 | 97.235 | 74.255 | 7.4 | 50.15 |
| 13.5B | 0 | 74.255 | 53.04 | 7.85 | 44 |
| 16B | 0 | 88.4 | 70.72 | 5.8 | 44 |
| 19B | 0 | 93.745 | 70.72 | 7.4 | 44 |
| 21B | 0 | 58.355 | 38.9 | 5.8 | 44 |
| 12A | 44 | 129.835 | 101.83 | 7.4 | 56.3 |
| 13.5A | 44 | 83.145 | 63.645 | 7.1 | 44 |
| 16A | 44 | 117.105 | 101.83 | 3.7 | 56.3 |
| 19A | 44 | 138.25 | 102.755 | 14.95 | 50.15 |
| 21A | 44 | 72.485 | 44.2 | 9.25 | 44 |

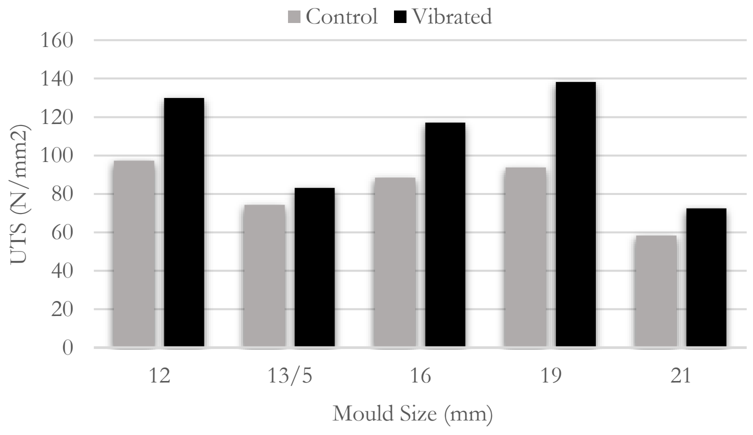

**Fig. 2. Variation of UTS against mould size.**

The samples were cast in five different moulds with sizes: 12mm, 13.5mm, 16mm, 19mm, and 21mm. A vibration of about 44Hz was applied to the (A) samples, while no vibration was applied to the control (B) samples. The highest UTS of 138.25 N/mm$^2$ and YS of 102.755 N/mm$^2$ were obtained from the samples vibrated in the 19mm mould, while the lowest value of tensile strength of 72.485 N/mm$^2$ and YS of 44.2 N/mm$^2$ were obtained from the samples vibrated in the 21mm mould.

For the control samples, the highest UTS of 97.235 N/mm$^2$ and YS of 74.255 N/mm$^2$ were obtained from the samples produced in the 12mm mould, while the lowest value for tensile strength of 58.355 N/mm$^2$ and YS of 38.9 N/mm$^2$ were obtained from the samples produced in the 21mm mould. When the results of the test are compared, it can be seen that the samples produced in the mould that was vibrated have higher values; thus, the mechanical vibration applied improved the tensile strength of the Aluminium 6061 alloy, which is in agreement with similar research carried out by Haydar et al. [7].

## 3.2| Impact Test

The results obtained from the V-notch Charpy test are shown in *Table 3*, and *Fig. 3* shows the graphical relationship between the Charpy Impact values and the different mould sizes for both the control and vibrated samples.

**Table 3. Impact test results of the aluminium 6061 Alloy sample.**

| Sample | Charpy Impact Values (J) | Charpy Impact Values (J) | Average (J) |
|---|---|---|---|
| 12B | 5 | 7 | 6 |
| 13.5B | 7 | 8.45 | 7.725 |
| 16B | 11.8 | 8.2 | 10 |
| 19B | 9.95 | 10.3 | 10.125 |
| 21B | 9.8 | 7.8 | 8.8 |
| 12A | 17.99 | 13.6 | 15.795 |
| 13.5A | 11.8 | 15 | 13.4 |
| 16A | 9.9 | 15.9 | 12.9 |
| 19A | 11.7 | 14 | 12.85 |
| 21A | 10.9 | 8.2 | 9.55 |

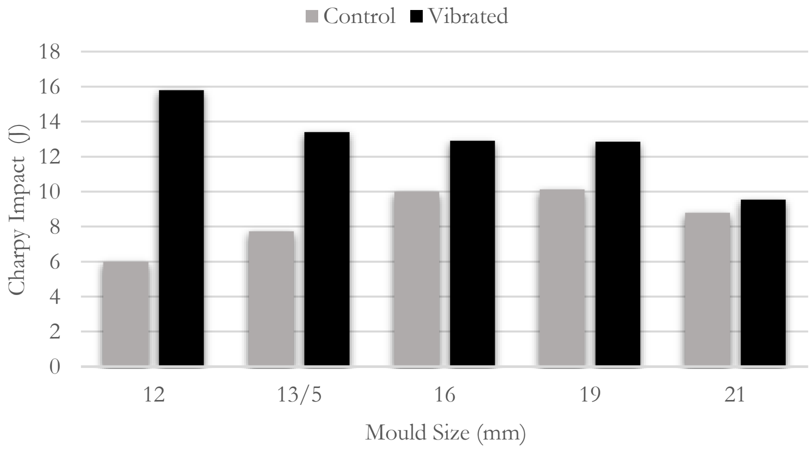

**Fig. 3. Variation of charpy impact against mould size.**

From the results, the vibrated samples showed an increase in the toughness of the Aluminium 6061 alloy samples when compared to the values obtained for the control samples. The results are in agreement with similar research carried out by Haydar et al. [7]. From the results of the impact test, it can be seen that the mould size affected the toughness of the samples produced because the samples produced in the smallest mould had a higher toughness than the samples produced in the larger moulds.

## 4 | Conclusion

The study on the effect of mechanical vibration on the mechanical properties and microstructure of an Aluminium 6061 alloy was conducted, and attempts were made to relate the mechanical properties. After the investigation, the following conclusions were drawn regarding the effect of mechanical vibration on the aluminium alloy:

I. The mechanical properties investigated (tensile and impact) were improved when mechanical vibration at 44 Hz was applied regardless of the mould size.

II. The mould size variation had more effect on the toughness of the samples produced with applied vibration; the samples produced with the smaller moulds had higher impact test values than those produced with larger moulds. The mould size variation did not have much effect on the tensile test of the samples produced with applied vibration.

## Author Contributions

Maranatha Menduas Dokyoung conceptualized and supervised the experimental design, conducted the tensile and impact tests, and analyzed the data. Terngu Akor contributed to the alloy preparation, vibration setup, and machining of specimens. Both authors collaboratively drafted and revised the manuscript.

## Funding

This research was conducted without external funding.

## Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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