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RESEARCH ARTICLE

INVESTIGATION OF MECHANICAL PROPERTIES OF AL 7075 ALLOY SOLIDIFIED UNDER VIBRATION

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ABSTRACT

Al 7075 alloy is a material with high mechanical properties and limited plastic formability at room temperature. In some special applications, it may need to be obtained by casting. In this study, it is aimed to increase the strength of the Al 7075 alloy by solidification which has a wide range of applications in sectors such as automotive, aircraft and space defense industry, under mechanical vibration applied at different frequencies after casting. Microstructure examination, compression test and hardness measurement tests are conducted to determine the changes in the mechanical properties of Al 7075 alloy in different frequencies by after solidification under mechanical vibration. Maximum hardness value is obtained at 30 Hz frequency in mechanical vibrations applied at frequencies between 10-50 Hz. This hardness value is lower than the hardness values that can be obtained by precipitation hardening, but considerably higher than the material without heat treatment.

Keywords: *Al 7075, Mechanical Vibration, Solidification.*

1. INTRODUCTION

Vibration treatment is a common additional approach to materials during metal solidification, aimed at improving their macrostructure and microstructure, consequently enhancing their mechanical properties. Most studies on this subject explain the effects of the vibration process and its relation to the cavitation phenomenon. [1, 2].

Among aluminium alloys, Al 7075 is the most preferred material due to its high strength value. If an even higher strength value is desired, precipitation hardening can be employed. However, the application of this process is limited due to several factors: the high cost associated with precipitation hardening, the requirement for large furnaces when dealing with sizable components, and the formation of different thermal gradients at different cross-section thicknesses in complex shaped parts. For Al 7075 work pieces to be produced with casting process, if a slight strength increase from the current strength is desired, grain size reduction, which is another strength increasing method, can be applied. Strength value increase can be achieved in the material by applying the solidification method under vibration (mechanical or ultrasonic vibrations), which can be applied for grain reduction, at different frequencies.

The technique of solidifying metallic materials under mechanical vibration is discovered by Sokoloff. Compared to other techniques, this technique is used more because of its convenience and cheapness. Campbell [3], stated that grain refinement occurs in castings due to the application of vibration during casting, thus improving the mechanical properties, so that the production of high-strength structural materials is mainly based on the development of a product in which the grain size is as small as possible. He also observed that, the corrosion resistance of the alloys improved along with their mechanical properties. Guo et al. [4] observed that during solidification, the energy resulting from the excess heat and latent heat of the molten alloy is mainly absorbed by the die and that the mechanical vibration is indirectly given back to the molten alloy by vibrating the die. On the other hand, Southgate concluded in their study that eutectic formations are promoted, resulting in a 10% increase in tensile stress. Freedman and Wallace have found in their study that small grains with coarse eutectic components are formed. Also, as reported by Pillai, the same components have reduced in grain size under vibration treatment and become coarser only when modified with 0.05 wt% Na to the alloy [5]. Jiang et al. [6] used vibration in A356 aluminium alloy. They determined that, the mechanical properties of A356 aluminium alloy obtained from conventional casting decreased continuously with the increase of the wall thickness, and the mechanical properties and density of A356 aluminium alloy obtained by mechanical vibration are greatly increased. They also observed that, the tensile strength, yield strength, elongation and hardness of the sample with a wall thickness of 40 mm are 35%, 42%, 63% and 29% higher, respectively, than the sample obtained from conventional casting under T6 condition. Fisher used the vibration process on LM6 alloy (Al- 12.3%Si) and as a result, he reported the reduction of secondary dendrites and grain size on LM6 alloy. Along with this study, Burbure also reported a reduction in grain size for thick and short needle-shaped Al 12% Si as the vibration amplitude is increased. According to the report, the tensile stress decreased due to the coarsening of the silicon. However, no effect on ductility is observed [5]. Al-Ethari et al. [7] investigated the effect of mechanical and thermo mechanical treatment on the microstructure, grain size, porosity and hardness of Al-Zn-Mg alloy. As a result, they observed a 45% decrease in the grain size of the samples cast using mold vibration and hot forming. Additionally, the heat-treated and hot-shaped samples exhibited a 57% reduction in grain size. Along with these, they found that the porosity of these samples is decreased by 58% and 98%, respectively, while their hardness is increased by 11% and 81%, respectively.

In Al-Si alloys, when low-frequency vibration is applied depending on the effect of frequency, modification is observed in the alloy, and it has been determined that the porosities are more involved in low vibration than in high vibration. Kocatepe and Burdett applied vibration to two types of LM6 alloys. In the results, they found that the grain size of the unmodified alloy was reduced by 52% due to vibration (while the modified alloy exhibited 76% grain purification/refinement). As a consequence of the vibration treatment, the eutectic silicon in each alloy became coarser. Additionally, they observed that the coarsening of silicon increases as both the vibration amplitude and frequency increase [5, 8].

By examining the studies given above, it can be said that, the application of vibration has led to both the eutectic composition of aluminium and the microstructural change of its dendritic structure.

Vibration can improve ordered structures when the amplitude is wide enough. As a result, severe radial segregation is lost, as is the case with samples that solidify under microgravity conditions [9]. Deshpande's study also concluded that the grains in Al-Si alloy are tighter, denser and more uniform throughout the casting as a result of mechanical mold vibration [10]. Mehda et al. [11] studied the effect of mechanical vibration on Al4.5Cu (LM11) alloy during permanent die casting. They found that increasing mold vibration amplitude raises casting density due to improved fluidity from α-Al dendrite fragmentation and spherical structure formation. They also investigated the formation of α-Al dendrites during solidification prevents the molten metal from flowing easily into the mold, consequently causing shrinkage porosity. Additionally, their findings revealed that while gas porosity is observed in castings produced in fixed molds, there is no evidence of gas porosity in castings produced by mold vibration. This suggests that mechanical vibration is effective in degassing the melt. Vorozhtsov et al. [12] suggested that vibration has no effect when applied above the liquidus temperature, which is related to the duration of mechanical vibration. It may even be the source of unwanted gas retention events, so vibration should be initiated at the very beginning of solidification and terminated by full metal solidification.

In this work, apart from the studies in the literature, the microstructure variation and its effect on mechanical properties of the Al 7075 alloy solidified under mechanical vibration applied at different frequencies are investigated.

2. EXPERIMENTS AND EVALUATION

At the first stage of the study, samples are placed in a specially designed vibrating mold (Figure 1) with an average weight of 20 g (± 2 g). Then, based on the relation $T_m = T + 0.2T$ [13], the samples are melted in the furnace at 735 °C for about an hour, and after that, they are taken to the mechanical vibration mechanism (Figure 2) together with the mold. The dimensions of the molds containing the samples solidified by vibration are Ø15x50 mm.

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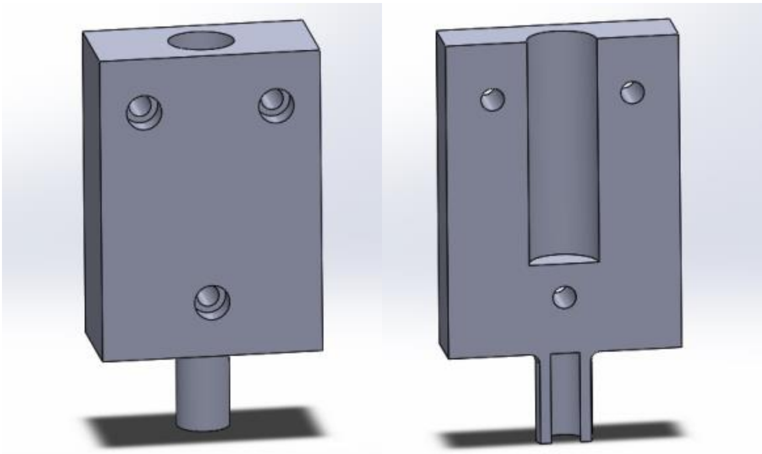


Figure 1. Mechanical vibration molds.

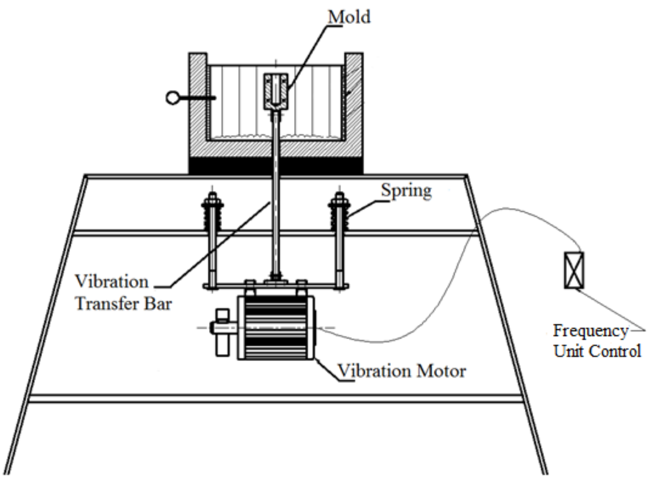


Figure 2. Solidification test setup under mechanical vibration.

A total of 27 samples are manufactured at frequencies between 10 and 50 Hz (10, 15, 20, 25, 30, 35, 40, 45, 50 Hz), adjusted in the mechanical vibration mechanism, with the same cooling criteria at each frequency. The vibration applied to the samples taken from the furnace continued until the solidification of the material is achieved.

Among the samples examined after the process, especially those that are solidified between 30 – 50 Hz, macro-sized porosities and slag are formed on the upper parts of the samples. For this reason, the samples are cut by using cooling liquid in an abrasive cutting machine by taking very few areas from

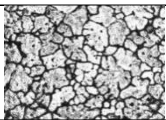
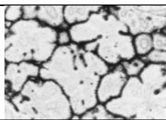
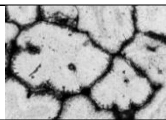
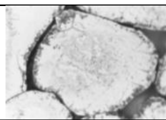
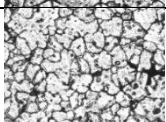
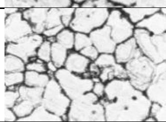
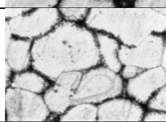
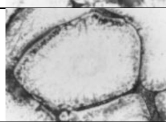
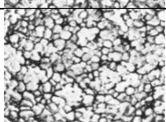
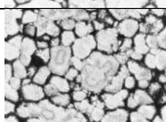
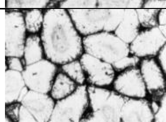
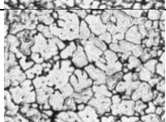
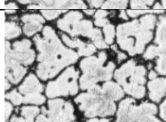
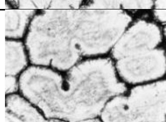
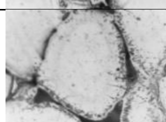
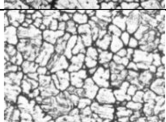
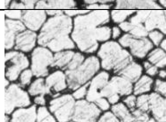
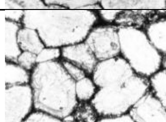
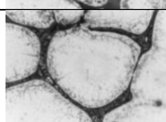
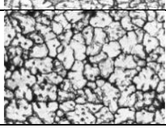
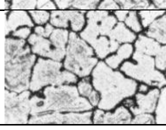
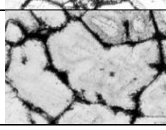
the lower part and the upper part. As a result, samples with a diameter of Ø15 and a height of approximately 30 mm are obtained.
Samples are etched with Keller's reagent for metallographic examination. After etching, microstructure photos of the samples are taken at 5X, 10X, 20X, 50X magnifications, and grain sizes are measured.

The hardness of the samples prepared for Brinell Hardness method is measured using a ball diameter of Ø2.5 mm and a load of 67.5 kgf. Compression test is carried out to determine the mechanical properties of AL 7075 materials such as compressive yield strength, compressive strength, compressive elasticity modulus and strain under static loading conditions. Compression test is carried out by applying 10 mm compression distance to the samples.

3. RESULTS

3.1. Microstructure Observations

The microstructure photos at different magnification ratios taken from the surfaces of each etched sample after metallographic preparations are shown in Figure 3.

SAMPLE (Hz)	X50	X100	X200	X500
10 Hz				
15 Hz				
20 Hz				
25 Hz				
30 Hz				
35 Hz				

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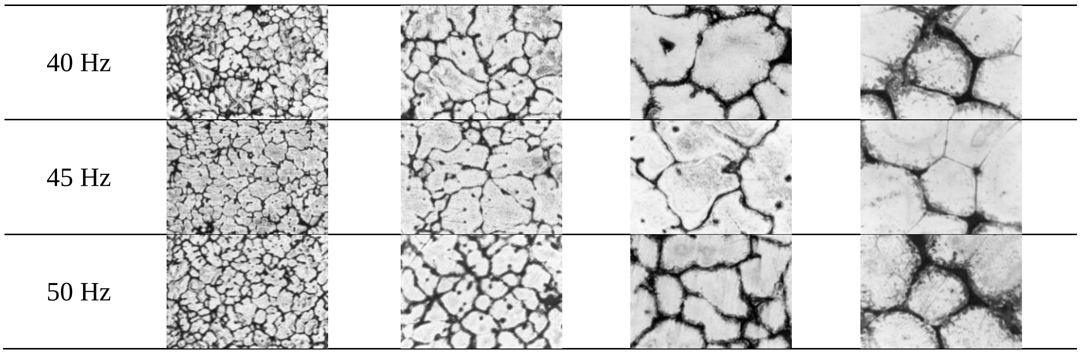

Figure 3. Microstructure photos of samples at different magnification ratios.

Upon optical microscope examinations following the application of mechanical vibrations, it is determined that grain shrinkage did not occur uniformly across all grains forming the structure. Instead, small-sized grains are observed to form in random locations.

As seen in Figure 4, obtained through optical microscope measurements, the grain size decreases with increasing vibration frequency, consistent with findings in the literature. With these results, it can be said that it is possible to obtain fine grained structures in solidification with high frequency ultrasonic vibration.

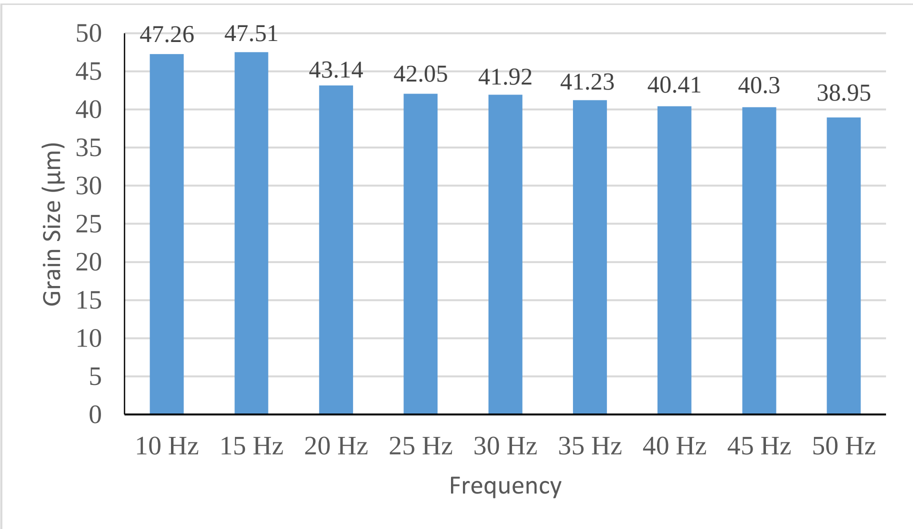

Figure 4. Grain size measurements.

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3.2. Hardness Measurement

In the examined studies in the literature, it is stated that the hardness values of the lower parts close to the vibration source are higher than the upper parts in the samples solidified under vibration. Hardness measurements (HB) are made on both the upper and lower parts of the 30 mm long samples obtained from this point of view. The obtained hardness values are given in Figure 5.

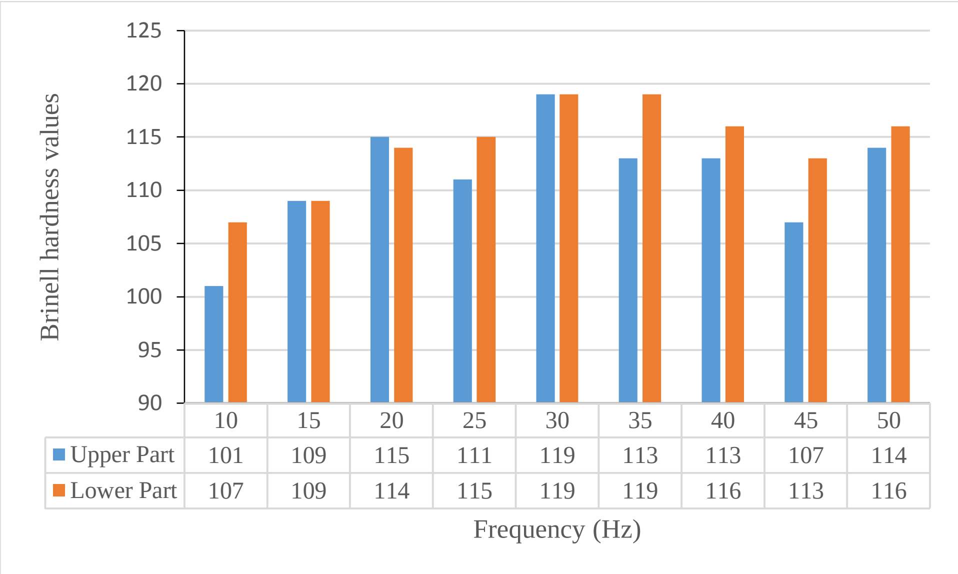

Figure 5. Brinell hardness values of upper and lower parts of samples between 10-50 Hz.

In the hardness measurements made, the hardness values taken from the lower part of the sample increases up to 30 Hz. After 30 Hz, a decrease is observed, and at 50 Hz, an increase is detected again. In general, the hardness values taken from the upper side of all samples are partially lower than the hardness values taken from the lower side. However, as can be seen in Figure 5, the mechanical vibration applied at a frequency of 30 Hz reached the maximum hardness value (119 HB) in both the upper and lower parts of the sample. This shows that 30 Hz frequency value can be determined as a critical value in solidification under mechanical vibration for Al 7075 alloy.

3.3. Compression Tests

Compression tests are applied to the samples, which are solidified by mechanical vibration at all frequencies and applied precipitation hardening, with a feed rate of 3 mm/min and a maximum compression distance of 10 mm. Stress - % Strain graphs obtained as a result of the tests are given in Figure 6, and Stress - % Strain values according to mechanical vibration frequencies are given in Table 1.

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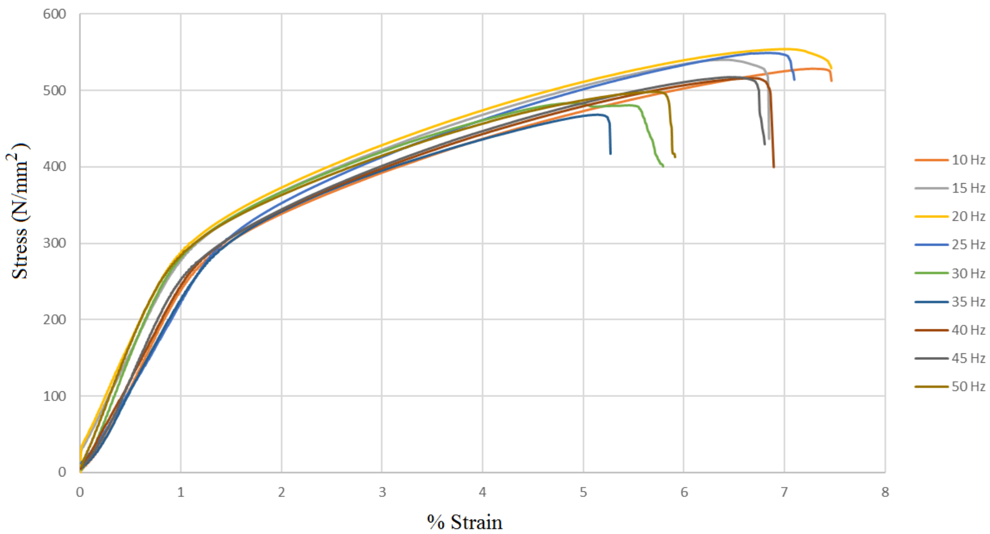

Figure 6. Stress - % Strain graph of samples according to mechanical vibration frequencies.

Table 1. Stress-% Strain values according to mechanical vibration frequencies.

Sample	σ_{max} (N/mm^2)	% ε_{max}
10 Hz	528,4	7,28
15 Hz	540,1	6,40
20 Hz	554,1	7,01
25 Hz	549,0	6,85
30 Hz	483,3	4,90
35 Hz	468,3	5,13
40 Hz	516,1	6,68
45 Hz	517,4	6,45
50 Hz	498,3	5,70

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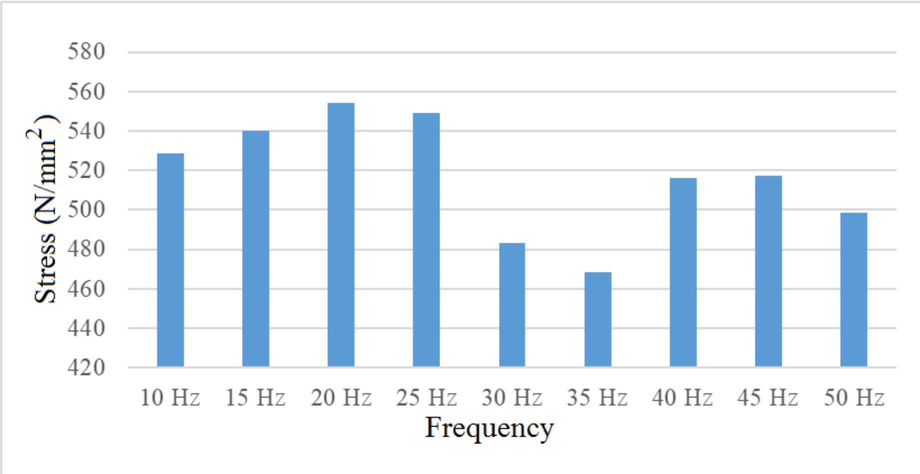

Figure 7. Stress - mechanical vibration graph.

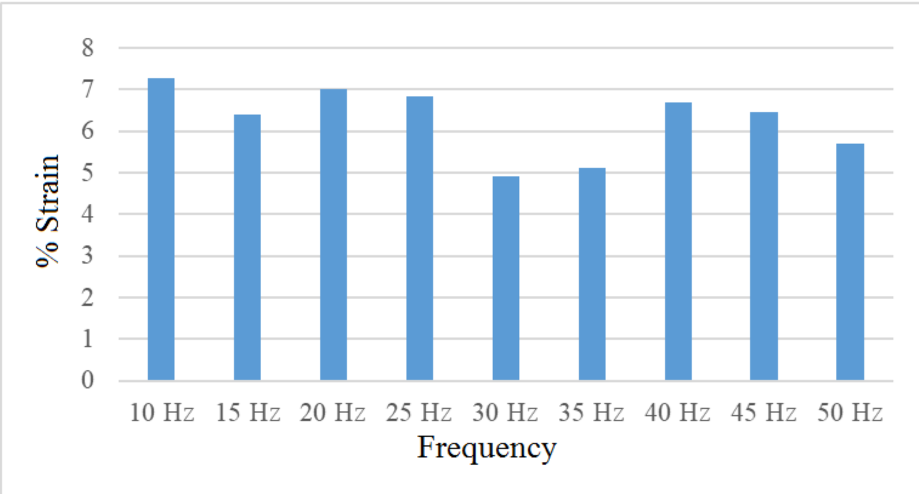

Figure 8. Mechanical vibration - % strain graph.

When the graphs obtained as a result of the compression tests and the maximum compressive strength and maximum strain amounts obtained from the graphs are examined (Figure 7), a homogeneous stress increase is detected in the samples applied with 10 – 15 – 20 Hz vibration. However, a relationship could not be determined between the stress values obtained at higher frequencies (25-50 Hz). Although the lowest compressive stress values are obtained in the samples manufactured at 30 Hz and 35 Hz, where the highest hardness value is measured, it is noteworthy that their strain values

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are also the lowest (Figure 8). As it is known, the strength of the materials increases as the deformation capacity decreases. To investigate this difference at 30 Hz and 35 Hz, the samples are cut vertically and examined for any cracks or porosities in the internal structure. As a result of visual inspection and penatrant fluid application, no capillary cracks are detected, but it is determined that there are significant number of porosities in the sample as seen in Figure 9.

These determined porosities explain the inconsistency of the data obtained in the compression test plots.

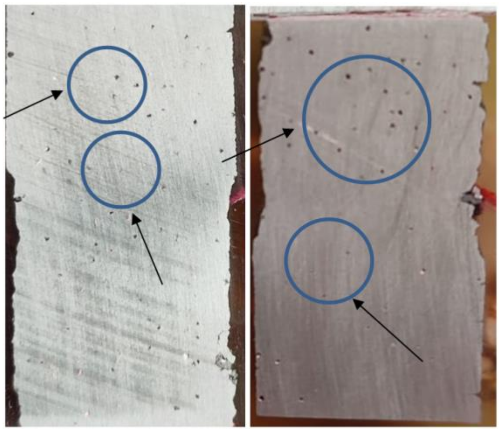

Figure 9. The porosities in the samples.

4. CONCLUSION

At the results of the experiments, we observed that, by applying mechanical vibration to Al 7075 alloy at different frequencies during the solidification, partially smaller sized grains are obtained in the microstructure, and it is determined that the hardness values of the samples increased. It has also been determined that the frequency of 30 Hz among the different frequencies applied in the current experimental setup provides the best hardness value for the Al 7075 material. It has been proven by many studies in the literature that solidification under vibration has a grain size reducing effect on the material microstructure. As it is commonly known, reducing the grain size of a material leads to an enhancement in both its strength and hardness. However, findings of this study reveal an interesting insight. While the grain size is observed to decrease with an increase in vibration frequency, it is noted that the change in hardness isn't directly proportional to the grain size change. Considering this, the solidification of Al 7075 alloy under vibration might trigger various material changes beyond grain size, such as precipitate and phase formation. These anomalies will be subjects of investigation in forthcoming studies by authors.

The increase in the hardness values of the samples obtained as a result of the mechanical vibration applied during solidification is lower than the hardness values obtained by the precipitation hardening process. However, if a product made from Al 7075 material is intended to be obtained through casting and will be used in an application area where an increase in strength value isn't necessary, solidification under mechanical vibration will be more advantageous in terms of both cost and time compared to precipitation hardening.

On another side of view, the compression test results of the samples are not as favorable as anticipated due to the porosities formed in the casting materials as a consequence of the applied mechanical vibrations. In this study, there is a potential to eliminate material porosities by implementing appropriate conditions for applying mechanical vibrations in an open atmosphere. These conditions include applying mechanical vibrations to the material under vacuum or pressure and designing mechanisms capable of vibrating within the furnace before material solidification is achieved. Furthermore, with the implementation of these conditions, a rise in compressive strength equivalent to the increase in hardness values can be attained.

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