SPECIAL ISSUE ARTICLE
INNOVATION AND EMERGING TECHNOLOGIES

Effect of vibration casting on the properties and microstructure of aluminium alloy castings

Vyomesh Buch [1], Ankit D. Oza [2,*], Sandeep [3], Manoj Kumar [4], Manish Gupta [5] & Shuchi Midha [6]

This research focuses on investigating the impact of mechanical vibration on the solidification process. Previous studies have indicated that solidification plays a crucial role in enhancing the mechanical properties of materials. By incorporating mechanical vibration technology into the solidification process, the quality of castings can be improved by achieving a more uniform microstructure and reducing grain size. In today's industrial landscape, striving for excellence involves minimising casting defects to zero and enhancing mechanical characteristics. To comprehend the enhancement in microstructure and mechanical properties of castings, this experimental study examines the influence of mechanical mould vibration on the solidification of A356 alloy. The casting process involves a frequency of 50 Hz. To evaluate the effect of vibration during casting, a comparison is made between a casting without mould vibration and its corresponding mechanical properties. The experimental results clearly demonstrate that employing a vibrating mould during casting leads to grain refinement and a significant improvement in hardness when compared to castings produced without the utilisation of a vibrating mould.

***Keywords*: Vibration Casting; Aluminium Alloy; Casting Quality; Mechanical Properties; Microstructure.**

INTRODUCTION

Vibration treatment is a widely recognised method for enhancing the casting quality of aluminium alloys by reducing grain size and achieving a more uniform and stable microstructure[1]. Normal mechanical vibrations can generate amplitudes ranging from 4 to 5 cm and frequencies up to 9–10 kHz. Ultrasonic vibration of melts can also be performed at higher frequencies, typically above 20 kHz. Metal casting is a popular and cost-effective method for producing complex shapes due to its improved mechanical properties and straightforward manufacturing process[2]. Various microstructural refinement processes, such as stir casting, centrifugal casting, mechanical mould vibration, ultrasonic vibration, electromagnetic stirring vibration, electromagnetic processes, rheocasting process, and friction stir processing, have been developed to achieve higher mechanical strength with reduced defects. Among these techniques, mechanical mould vibration stands out as a simple, economical, and effective approach[3]. In summary, mechanical mould vibration is often considered cost-effective compared to some other refinement processes due to its simplicity, ease of implementation, and relatively low equipment and energy requirements. However, the choice of refinement method should consider the specific alloy, casting requirements, and available resources, as different methods may be more suitable for particular applications.

Applying vibration only at the beginning and end of the solidification process in casting, as mentioned in the manuscript, holds significance for several reasons:

1. Minimising Gas Capture: Vibration above the liquid's temperature has no practical value and may even act as a catalyst for undesirable gas capture. By applying vibration only at the beginning and end of solidification, the risk of trapping gases within the casting is reduced. This is crucial for achieving sound and defect-free casting.
2. Grain Refinement: Vibration during the initial stages of solidification helps promote grain refinement. It encourages the formation of finer and more uniform grains, which can enhance the mechanical properties of the final casting.
3. Reducing Defects: Vibrating the molten metal at the beginning of solidification helps to break up any potential dendritic structures and reduces the likelihood of shrinkage cavities and porosity. This contributes to improved casting quality by minimising defects.
4. Optimising Microstructure: Applying vibration at the end of solidification further refines the microstructure of the casting. It allows for the final stages of solidification to occur in a controlled and uniform manner, resulting in a more desirable microstructure.

[1]Department of Mechanical Engineering, Parul Institute of Technology, Parul University, Waghodia, Vadodara, Gujarat 391760, India (vyomesh.buch165001@paruluniversity.ac.in), [2]Department of Mechanical Engineering, Parul University, Vadodara, Gujarat, India (ankitoza6060@yahoo.in), [3]Division of Research and Innovation, Uttaranchal University, Dehradun, Uttarakhand, India (Sandeep.uietmdu@gmail.com), [4]Department of Mechanical Engineering, ABES Engineering College, Ghaziabad, Uttar Pradesh, India (mky2011@gmail.com), [5]Division of Research and Development, Lovely Professional University, Phagwara, Punjab, India (gupta.manishlpu@gmail.com), [6]SIES School of Business Studies, Navi Mumbai, Maharashtra 400706, India (shuchim@sies.edu.in). *Correspondence should be addressed to: A.D.O. (ankitoza6060@yahoo.in).

Received 12 July 2023; accepted 11 October 2023; published online; doi:10.1142/S2737599423400108

This article is part of the "Special Issue on Innovative and Emerging Advanced Manufacturing Technologies", edited by Chander Prakash (Lovely Professional University, India), Alokesh Pramanik (Curtin University, Australia), Mohammad Khalid (Sunway University, Malaysia) & Shankar Sehgal (Panjab University, India).

5. Controlled Timing: By applying vibration only at specific times, casting professionals have greater control over the solidification process. This controlled timing ensures that the benefits of vibration are realised without causing any unintended consequences.
6. Efficiency: Applying vibration throughout the entire solidification process can be energy-intensive and may not provide additional benefits. Limiting vibration to the critical phases of solidification optimises its effectiveness without unnecessary energy consumption.

The significance of applying vibration only at the beginning and end of solidification lies in its ability to enhance casting quality by promoting grain refinement, reducing defects, and optimising the microstructure while minimising the risk of gas entrapment and ensuring efficient use of resources. This approach balances the advantages of vibration with the practical considerations of the casting process.

Aluminium alloy precision components are commonly produced using die casting, permanent mould casting, sand casting, and lost foam casting (LFC) methods[4]. The objective of this study is to optimise the solidification process by utilising mechanical vibration to improve casting quality, reduce residual stress, and enhance wear resistance.

Kudryashova *et al.*[5] conducted an experimental study investigating vibrations with an intensity of approximately 60 Hz and an amplitude of approximately 0.5 mm. In such conditions, significant reductions in ingot grain size were observed, accompanied by improved soundness (density) of the cast metal. It should be noted that vibration above the liquid's temperature has no practical value and may even act as a catalyst for undesirable gas capture. Vibrations should only be applied at the beginning and end of the metal's solidification process.

Varun *et al.*[6] examined the mechanical vibration of LM25 aluminium alloy solidified in a graphite mould. Their experiments revealed an optimal hardness value of 52.1 Brinell hardness number (BHN) at a frequency of 100 Hz. The effect of vibration on microstructural behaviour was observed through grain refinement, and mechanical properties such as hardness demonstrated an increase with higher vibration frequencies. While the ultimate tensile strength (UTS) initially decreased in the lowest frequency range (20–30 Hz), it exhibited an upward trend after 30 Hz, reaching an optimal UTS of 142.01 MPa at 50 Hz compared to the unvibrated sample. However, due to the alloy's high brittleness relative to the unvibrated sample, the elongation (ductility) and 0.2% proof stress (yield stress) values decreased significantly. While the study identified the optimal frequency for achieving the highest hardness value, it also highlighted that the choice of vibration frequency could have complex effects on other mechanical properties, such as ultimate strength and brittleness. Therefore, the optimal frequency may depend on the specific mechanical property or characteristic of interest and must be carefully considered in the context of the desired alloy properties.

Siddharth Yadav *et al.*[7] investigated the effects of horizontal mechanical vibration on the microstructure, mechanical characteristics, and fracture behaviour of the A308 aluminium alloy. Compared to casting without vibration, mechanical parameters such as UTS, yield strength (YS), elongation (percent El), and hardness were enhanced by 13%, 8%, 17%, and 16%, respectively, at a frequency of 30 Hz. Metallurgical characteristics such as the average values of primary α-Al particle size, average area of eutectic silicon, aspect ratio, and percent porosity were significantly reduced by 34%, 59%, 56%, 22%, and 62%, respectively. However, the average percentage of roundness increased by 25% and 66% at 30 Hz frequency, compared to casting without vibration. Vibration also substantially improved the mechanical properties and wall thickness of the A356 aluminium alloy. These observations indicate that horizontal mechanical vibration had a positive impact on the mechanical characteristics and microstructure of the A308 aluminium alloy. It led to improvements in strength, ductility, hardness, and a reduction in microstructural defects such as porosity and irregularities. These findings highlight the potential benefits of applying vibration to enhance the properties of aluminium alloys in casting processes.

Sahadeva *et al.*[8] found that high-intensity ultrasonic vibrations facilitated the removal of coarse grains and the formation of globular grains, resulting in improved mechanical properties, such as increased hardness and ultimate tensile strength. The experimental findings indicated that ultrasonic treatment increased the average hardness and final tensile strength by approximately 13% and 16%, respectively, compared to pure aluminium AA-356 without ultrasonic treatment. These improvements in hardness and tensile strength suggest that high-intensity ultrasonic vibrations had a positive impact on the mechanical properties of the A356 aluminium alloy, making it stronger and harder.

Aramide Fatai Olufemi *et al.*[9] demonstrated that higher mould vibration frequencies lead to finer grain size during solidification, enhancing the strength and stiffness of the alloy specimens due to grain refinement. The maximum values of these mechanical properties increased with higher vibration rates, with the mechanical characteristics peaking at a frequency of 12 Hz. These findings indicate that higher mould vibration frequencies were effective in promoting grain refinement and enhancing the mechanical properties of the aluminium alloy. This suggests that mould vibration can be used to optimise the solidification process and achieve desired mechanical characteristics in the castings.

Rahul Kumar *et al.*[10] emphasised the significant influence of mechanical mould vibration on the composition and characteristics of castings. Compared to normal casting without mould vibration, precise and improved mechanical characteristics can be achieved. Grain refinement continues to improve as the vibration frequency rises from 40 to 150 Hz. Additionally, casting toughness increases within the frequency range of 40–150 Hz. These observations indicate that mechanical mould vibration had a significant effect on the microstructure and mechanical characteristics of the castings. It led to grain refinement and increased casting toughness, which are desirable attributes in many casting applications.

Chirita *et al.*[11] investigated the effects of vibration on mechanical properties, as well as the rates and characteristics of solidification. Vibration was found to have a connection with heat transfer. These observations suggest that the application of vibration in casting can influence the heat transfer dynamics, leading to more controlled and optimised solidification, which, in turn, affects the mechanical properties and characteristics of the final casting. The interaction between vibration and heat transfer is an important aspect of understanding how vibration can be used to enhance the quality of castings in the context of aluminium alloy manufacturing. It enhanced heat transmission in liquids, while it could dramatically reduce heat transfer at the metal–wall interface due to contact loss, primarily through two speculative mechanisms: high surface tension and the wall roughness effect.

In a specific case involving a sample with a 40 mm wall thickness, the tensile strength, YS, elongation, and hardness were found to be 35%, 42%, 63%, and 29% higher, respectively, compared to the sample produced through stationary casting under the T6 condition.

Overall, the application of vibration treatment in aluminium alloy casting has shown promising results in improving casting quality, reducing defects, enhancing mechanical properties, and refining the microstructure. These overall benefits suggest that applying vibration treatment to aluminium alloy casting can result in superior castings with improved mechanical properties, microstructure, and reduced defects. This technique is considered both effective and cost-efficient, making it a valuable method for enhancing the quality of aluminium alloy castings. These findings highlight the potential of mechanical mould vibration and ultrasonic vibration as effective techniques for achieving desired mechanical characteristics and optimising the solidification process in aluminium alloy castings.

EXPERIMENTAL SETUP

The experimental setup developed for the investigation consists of various components that facilitate the implementation of mechanical vibration during the casting process. Among the different available heat-treatable aluminium alloys, A356 aluminium is widely utilised and commercially accessible. This alloy composition includes 7% Si, 0.3% Mg, with a maximum content of 0.2% Fe and 0.10% Zn. A356 aluminium casting alloy exhibits excellent machining characteristics and casting ability, making it a preferred choice in many applications.

To conduct the experiments, an experimental setup was designed and constructed, as depicted in **Fig. 1**. The setup comprises several key elements, including an unbalanced vibratory motor, a spring system, a shell mould, and a crucible. The primary objective of this setup is to provide controlled mechanical vibration during the solidification process of the molten metal.

Figure 1 illustrates the arrangement of the experimental setup. The table, constructed from mild steel, forms the base of the setup. At each of the four corners of the table, stainless steel springs are mounted, which serve to absorb and transmit the vibrational energy. On top of the springs, a 5-mm-wide plate made of mild steel is welded, creating a stable platform for the subsequent components.

Underneath the table, an unbalanced vibratory motor with a power rating of 0.25 hp and a rotational speed of 3,000 rpm is securely mounted. This motor is responsible for generating the mechanical vibration required for the experiment. The motor's unbalanced design creates an oscillating motion that is transmitted to the mild steel plate above, initiating the desired vibration. A normal stainless-steel spring is used for damping purposes, so the vibration could not go below the vibrating plate. A shell mould made up of resin cover sand to form a pattern in which the molten metal is poured. Rubber foot is used to help create voids in the surface and provide excellent shock absorption and energy rebound.

Positioned above the vibrating plate is a mould box, firmly clamped in place. Within this mould box, a shell mould is carefully positioned, ready to receive the molten metal during the casting process. The shell mould provides the necessary cavity for the molten metal to solidify into the desired shape.

Figure 1 Actual setup.

Figure 2 Specimen without vibration casting.

During the experiment, the mechanical vibration is initiated at the beginning of the solidification process, coinciding with the pouring of the molten metal into the shell mould. The vibration continues throughout the solidification phase until the metal has completely solidified, at which point the vibration ceases. This controlled application of vibration allows for the exploration of its effects on the casting process and subsequent material properties.

The experimental setup described above provides a reliable and controlled platform for investigating the impact of mechanical vibration on the solidification behaviour and quality of A356 aluminium alloy castings. By precisely controlling the vibration parameters, such as frequency and amplitude, it becomes possible to study the influence of these factors on the resulting microstructure, mechanical properties, and casting characteristics of the alloy. A356 aluminium was chosen as the casting alloy for the experiments because it is a well-established and practical alloy that allows researchers to investigate the effects of mechanical vibration on a widely used aluminium alloy in a controlled and consistent manner, and most importantly, it is easily available.

Figures 2 and 3 present a comparison between specimens cast without vibration (**Fig. 2**) and specimens cast with the application of mechanical vibration (**Fig. 3**). These figures offer visual evidence of the impact of vibration on the casting process and the resulting microstructure of the A356 aluminium alloy. In **Fig. 2**, the specimen cast without vibration exhibits a relatively coarse microstructure, characterised by larger grains and possibly a lower density. On the other hand, **Fig. 3** showcases the specimen cast with the aid of mechanical vibration, demonstrating a refined microstructure with smaller and more uniformly distributed grains. This comparison highlights the significant effect of vibration on grain refinement and the potential improvement in casting quality achieved through its application.

Figure 4 illustrates the defects observed on a specimen that was cast without the use of mechanical vibration. The image provides a visual representation of the potential casting flaws and imperfections that can arise in the absence of vibration during the solidification process. Several defects can be identified, including porosity, shrinkage cavities, and an uneven distribution of material. The presence of porosity is noticeable as irregular voids or gas pockets within the structure of the casting. Shrinkage cavities appear as irregular depressions or voids resulting from the contraction of the material during solidification. Furthermore, the uneven distribution of material can be observed as localised variations

Figure 3 Specimen with vibration.

Figure 4 Defects on the specimen without vibration casting.

in thickness and irregular surface texture. The presence of these defects indicates the importance of employing mechanical vibration to enhance the casting quality and reduce the occurrence of such imperfections, ultimately improving the mechanical properties of the final product.

Figure 5 depicts the defects observed on a specimen that underwent the casting process with the application of mechanical vibration. The image provides visual evidence of the potential flaws and imperfections that can still occur despite the use of vibration during solidification. Several defects can be identified, including small voids, surface irregularities, and discontinuities in the casting. These defects may be attributed to factors such as improper mould filling, inadequate vibration parameters, or variations in the casting process. While the presence of defects in **Fig. 5** suggests that vibration alone may not eliminate all casting imperfections, it is important to note that the overall quality of the specimen appears to be improved compared to specimens cast without vibration. The defects observed in **Fig. 5** serve as valuable insights for further optimisation of the casting parameters and vibration techniques to minimise or eliminate such imperfections, ultimately enhancing the mechanical properties and overall quality of the castings. Due to mechanical vibration was conducive to mass feeding by refining the primary grains, to interdendritic feeding by reducing the threshold pressure gradient, and to burst feeding by collapsing the barrier.

Figure 5 Defects on the specimen with vibration casting.

RESULT AND DISCUSSION

The material chosen for the manufacturing of the test samples was Aluminium 356. The study involved conducting three tests on two sets of samples: one cast with mould vibration and the other cast without mould vibration. The tests performed included the Tensile test, Hardness test, and Microstructure analysis. The Tensile test was carried out using a Universal Testing Machine at the Advanced Metal Testing Laboratory, as shown in **Figs. 6 and 7**. The evaluation of Ultimate Tensile Strength and percentage elongation followed the ASTM E8 2016A standard. For the Hardness test, Brinell hardness tests were conducted at the Advanced Metal Testing Laboratory. A load of 187.5 kg was applied to a 2.5-mm-diameter hardened steel ball to create indentations on the samples, following the ASTM E10 2012 standard. The Microstructure test for both sets of samples was also performed at the Advanced Metal Testing Laboratory, following the procedures outlined in ASM Handbook Volume-9: 2004. The experimental results for both sets of samples, including BHN, yield load (N), YS (MPa), ultimate load (N), ultimate tensile strength (MPa), and percentage of elongation (%), are presented in the tables below. These

Figure 6 Specimen without vibration casting after testing.

Figure 7 Specimen with vibration casting after testing.

tests and analyses provide crucial insights into the mechanical properties and microstructural characteristics of the castings.

After conducting the tests on the specimen without vibration casting, several observations can be made:

1. Tensile Strength: The ultimate tensile strength of the specimen without vibration casting was found to be lower compared to the specimen with vibration casting. This indicates that the absence of mould vibration during the casting process may have resulted in reduced strength properties.
2. YS: The yield load and YS of the specimen without vibration casting were also lower compared to the specimen with vibration casting. This suggests that the material exhibited lower resistance to deformation and plastic flow when no vibration was applied during casting.
3. Hardness: The BHN of the specimen without vibration casting was measured to be lower compared to the specimen with vibration casting. This indicates that the absence of vibration during casting resulted in a softer material with reduced hardness.
4. Microstructure: The microstructure analysis of the specimen without vibration casting revealed certain microstructural features, such as larger grain sizes and potential porosity. These characteristics may be associated with the absence of mould vibration, which could have hindered the proper refinement and solidification process, leading to the formation of defects.

Overall, the test results on the specimen without vibration casting indicate inferior mechanical properties, including lower tensile strength, YS, and hardness, along with potential microstructural defects. This highlights the significance of mould vibration in improving the casting quality and achieving desirable material characteristics in the aluminium alloy specimens.

After performing the tests on the specimen with vibration casting, several observations can be made:

1. Tensile Strength: The specimen with vibration casting exhibited higher ultimate tensile strength compared to the specimen without vibration casting. This indicates that the application of mould vibration during the casting process has improved the overall strength properties of the material.
2. YS: The yield load and YS of the specimen with vibration casting were also higher compared to the specimen without vibration casting. This suggests that the material demonstrated increased resistance to deformation and plastic flow when vibration was applied during casting.
3. Hardness: The BHN of the specimen with vibration casting was measured to be higher compared to the specimen without vibration casting. This indicates that the application of vibration during casting resulted in a harder material with improved hardness characteristics.
4. Microstructure: The microstructure analysis of the specimen with vibration casting revealed finer grain sizes and a reduced presence of potential porosity. These microstructural features are attributed to the effects of mould vibration, which aided in the refinement and solidification processes, resulting in improved casting quality.

The test results on the specimen with vibration casting demonstrate enhanced mechanical properties, including higher tensile strength, YS, and hardness, along with improved microstructural characteristics. This highlights the effectiveness of mould vibration in optimising the casting process and achieving superior material properties in the tested aluminium alloy specimens.

The following **Table 1** presents the comparison of properties between the sample without vibration casting and the sample with vibration casting:

The comparison of properties between the sample without vibration casting and the sample with vibration casting reveals interesting findings. Firstly, the hardness observed in the sample with vibration casting is significantly higher at 68.67 BHN compared to 54.33 BHN in the sample without vibration. This suggests that the application of vibration during casting has a positive effect on the material's hardness, indicating improved strength and resistance to deformation. The hardness of the alloy is increased by 26.4% as compared to without vibration. The YS of the alloy is increased by 9.96% as compared to without vibration.

Furthermore, the yield load and YS values also show an increase in the sample with vibration casting. The sample with vibration exhibits a yield load of 10,020 N and a YS of 12.14 MPa, whereas the sample without vibration has a yield load of 9,080 N and a YS of 11.04 MPa. These results indicate that the application of vibration during casting leads to an enhancement in the material's ability to withstand stress and deformation before permanent deformation occurs.

Interestingly, the ultimate load in the sample with vibration casting is slightly lower at 10,680 N compared to 10,880 N in the sample without vibration casting. Similarly, the tensile strength of the sample with vibration casting is slightly lower at 12.95 MPa compared to 13.23 MPa in the sample without vibration. These slight decreases might be attributed to the specific characteristics of the casting process and the interaction between vibration and solidification. However, the differences in ultimate load and tensile strength between the two samples are relatively small.

Table 1 Comparison of the samples with and without vibration with respect to different properties.

Properties	Sample without vibration	Sample with vibration
Hardness Observed (BHN)	54.33	68.67
Yield Load (N)	9,080	10,020
Yield Strength (MPa)	11.04	12.14
Ultimate Load (N)	10,880	10,680
Tensile Strength (MPa)	13.23	12.95
Elongation (%)	4.70	2.08

Figure 8 Microstructure of the specimen without vibration.

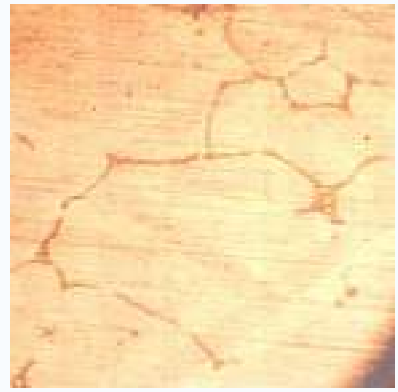

Figure 9 Microstructure of the specimen with vibration.

One notable difference is the elongation of the samples. The sample without vibration casting exhibits a higher elongation value of 4.70%, indicating better ductility and the ability to deform before fracture. In contrast, the sample with vibration casting shows a lower elongation value of 2.08%, suggesting reduced ductility. This could be attributed to the refining effect of vibration on the microstructure, which may lead to a more brittle material. It is important to consider this trade-off between improved mechanical properties and reduced ductility when employing vibration casting techniques. The results highlight the potential benefits of vibration casting in enhancing certain mechanical properties of the A356 aluminium alloy. The increased hardness, yield load, and YS in the sample with vibration casting indicate improved material performance, while the slight decreases in ultimate load and tensile strength suggest the need for further optimisation. The trade-off between improved properties and reduced ductility should be carefully considered based on the specific requirements of the application to determine the suitability of vibration casting as a manufacturing technique.

Figure 8 presents the microstructure of the specimen without vibration casting. The microstructure provides valuable insights into the material's internal characteristics and can reveal information about its mechanical properties. In this case, the microstructure of the specimen without vibration casting exhibits certain features and attributes.

Upon close examination of the microstructure, it is observed that the grain structure appears relatively coarse and uneven. The grains are larger in size and exhibit irregular shapes, indicating a less refined and less controlled solidification process. This coarser grain structure can have implications for the material's mechanical properties, such as reduced strength and increased susceptibility to cracking or failure under applied loads.

Additionally, the microstructure reveals the presence of certain defects and imperfections. These defects can include porosity, inclusions, or discontinuities within the material. The presence of such defects can have detrimental effects on the material's structural integrity and overall performance, as they can act as stress concentration points and decrease the material's resistance to deformation and fracture.

The microstructure of the specimen without vibration casting suggests a less optimised casting process, resulting in a coarser grain structure and the presence of defects. These characteristics can negatively impact the material's mechanical properties, leading to reduced strength and the potential for failure. This highlights the importance of employing techniques such as vibration casting to refine the microstructure and improve the overall quality and performance of the cast aluminium alloy.

Figure 9 displays the microstructure of the specimen with vibration casting, which provides valuable insights into the internal structure and characteristics of the material. The microstructure of the specimen with vibration casting exhibits distinct features and attributes that differentiate it from the specimen without vibration.

Upon closer examination, it is evident that the microstructure of the specimen with vibration casting displays a finer and more uniform grain structure compared to the specimen without vibration. The grains appear smaller in size and exhibit a more regular and compact arrangement. This refined grain structure indicates a more controlled and optimised solidification process achieved through the application of vibration during casting.

Furthermore, the microstructure reveals a significant reduction in the presence of defects and imperfections compared to the specimen without vibration. The occurrence of defects such as porosity, inclusions, or discontinuities within the material is noticeably diminished, leading to improved overall structural integrity and mechanical performance. The refined microstructure achieved through vibration casting helps minimise stress concentration points and enhances the material's resistance to deformation and fracture. The microstructure of the specimen with vibration casting demonstrates the effectiveness of the vibration casting technique in achieving a finer and more uniform grain structure while reducing the occurrence of defects. These improvements in microstructure contribute to enhanced mechanical properties, including increased strength and improved resistance to failure. The results highlight the benefits of utilising vibration casting to optimise the casting process and enhance the quality and performance of cast aluminium alloys.

CONCLUSION

In conclusion, the experimental study on the effect of vibration casting on the properties and microstructure of aluminium alloy specimens provides valuable insights into the benefits of this technique. The results indicate that the application of vibration during casting has a significant impact on the mechanical properties and microstructure of the cast specimens.

Comparing the samples with and without vibration casting, it is evident that vibration casting leads to improved properties. The specimens subjected to vibration casting exhibited higher hardness values, indicating increased material strength. Additionally, the yield load and YS were higher in the specimens with vibration casting, indicating improved material performance under load.

The microstructural analysis further supports the positive influence of vibration casting. The specimens with vibration casting displayed finer and more uniform grain structures compared to those without vibration. This refinement in grain structure contributes to enhanced mechanical properties, such as increased strength and improved resistance to deformation and fracture. Moreover, the microstructural analysis revealed a reduction in defects, such as porosity and inclusions, in the specimens with vibration casting, indicating improved structural integrity.

These findings highlight the effectiveness of vibration casting as a technique for optimising the casting process and improving the quality and performance of aluminium alloy castings. By applying vibration during solidification, the grain size can be reduced, resulting in improved mechanical properties and a more uniform microstructure. Furthermore, the reduction in defects enhances the overall integrity of the castings.

The results of this study provide valuable insights for researchers and practitioners in the field of casting and aluminium alloy manufacturing. They demonstrate the potential of vibration casting as a simple, cost-effective, and efficient method for enhancing the properties and microstructure of aluminium alloy castings. Future research can further explore the optimal vibration parameters, such as frequency and amplitude, to maximise the benefits of this technique.

Overall, the study contributes to advancing the understanding of vibration casting and its potential applications in the production of high-quality aluminium alloy castings with improved mechanical properties and enhanced structural integrity.

CONFLICT OF INTEREST STATEMENT

The authors declare that; they have not received any financial or non-financial interest that is directly or indirectly related to the work submitted for publication.

ORCID

Vyomesh Buch https://orcid.org/0000-0002-1101-9597
Ankit D. Oza https://orcid.org/0000-0001-8104-1266
Sandeep https://orcid.org/0000-0002-2085-7998
Manoj Kumar https://orcid.org/0000-0003-2815-8443
Manish Gupta https://orcid.org/0000-0002-5232-378X
Shuchi Midha https://orcid.org/0000-0002-1768-2736

REFERENCES

1. Jian, X., Meek, T.T. & Han, Q. Refinement of eutectic silicon phase of aluminium A356 alloy using high-intensity ultrasonic vibration. *Scripta Mater.* **54**, 893–896 (2006).
2. Swallowe, G.M., Field, J.E., Rees, C.S. & Duckworth, A. A photographic study of the effect of ultrasound on solidification. *Acta Metall.* **37**(3), 961–967 (1989).
3. Ferguson, J.B., Schultz, B.F., Cho, K. & Rohatgi, P.K. Correlation vs. causation: The effects of ultrasonic melt treatment on cast metal grain size. *Metals* **4**, 477–489 (2014).
4. Atamanenko, T.V., Eskin, D.G., Zhang, L. & Katgerman, L. Criteria of grain refinement induced by ultrasonic melt treatment of aluminium alloys containing Zr and Ti. *Metall. Mater. Trans. A* **41**, 2056–2066 (2010).
5. Kudryashova, O. & Vorozhtsov, S. On the mechanism of ultrasound-driven deagglomeration of nanoparticle agglomerates in aluminium melt. *JOM* **68**, 1307–1311 (2016).
6. Varun, S. & Chavan, T.K. Influence of mould vibration on microstructural behaviour and mechanical properties of LM25 aluminium alloy using gravity die casting process. *Mater. Today: Proc.* **46**, 4412–4418 (2021).
7. Yadav, S., Tewari, S.P., Singh, J.K. & Ram, S.C. Effects of mechanical vibration on the physical, metallurgical and mechanical properties of cast A308 (LM21) aluminium alloy. *Int. J. Miner. Metall. Mater.* **29**, 1206–1215 (2022). https://doi.org/10.1007/s12613-020-2209-7
8. Sahadeva, G.N., Ravindran, A.S., Chandrashaker, T. & Vitala, H.R. Influence of ultrasonic vibrations on grain size and mechanical properties of A-356 by adding Al-5Ti-1B master alloy during solidification. *Int. J. Sci. Res. Publ.* (2015).
9. Olufemi, A.F. & Ademola, I.S. Effects of melt vibration during solidification on the mechanical property of Mg-Al-Zn alloy. *Int. J. Metall. Eng.* **1**, 40–43 (2012).
10. Kumar, R., Mishra, S.S. & Kumar, A. Effect of mould vibration on microstructure and mechanical properties of casting during solidification. *Int. J. Eng. Res.* **3**, 90–92 (2014).
11. Chirita, G., Stefanescu, I., Soares, D. & Silva, F.S. Influence of vibration on the solidification behaviour and tensile properties of an Al–18 wt% Si alloy. *Mater. Des.* **30**, 1575–1580 (2009).