Improvement of Molten Metal Fluidity in Casting Process by Ultrasonic-Assisted Vibration

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A Thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in Industrial and Production Engineering

Department of Mechanical and Production Engineering (MPE)

Islamic University of Technology (IUT)

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Candidate's Declaration

This is to certify that the work presented in this thesis, titled "**Improvement of Molten Metal Fluidity in Casting Process by Ultrasonic-Assisted Vibration**", is the outcome of the investigation and research carried out by me under the supervision of Prof Dr. Md. Anayet Ullah Patwari.

It is also declared that neither this thesis nor any part of it has been submitted elsewhere for the award of any degree or diploma.

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Recommendation of the Thesis Supervisors

The thesis titled "**Improvement of Molten Metal Fluidity in Casting Process by Ultrasonic-Assisted Vibration**" submitted by Rubaiyet Sharmin Nijhum, Student No: 200012138 and Ruckser Afrin Nipun, Student No: 200012140, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of BSc. in Industrial and Production Engineering **on 6th October 2025.**

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   Professor

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CO-PO Mapping of ME 4800 -Thesis and Project

<table>
<tr><td>COs</td><td>Course Outcomes (CO) Statement</td><td>(PO)</td><td colspan="2">Addressed by</td></tr>
<tr><td rowspan="3">CO1</td><td rowspan="3">Discover and Locate research problems and illustrate them via figures/tables or projections/ideas through field visit and literature review and determine/Setting aim and objectives of the project/work/research in specific, measurable, achievable, realistic and timeframe manner.</td><td rowspan="3">PO2
Problem analysis</td><td>Thesis Book</td><td>√</td></tr>
<tr><td>Performance by research</td><td>√</td></tr>
<tr><td>Presentation and soft skill</td><td>√</td></tr>
<tr><td rowspan="3">CO2</td><td rowspan="3">Design research solutions of the problems towards achieving the objectives and its application. Design systems, components or processes that meets related needs in the field of mechanical engineering</td><td rowspan="3">PO3
Design/development of solutions</td><td>Thesis Book</td><td>√</td></tr>
<tr><td>Performance by research</td><td>√</td></tr>
<tr><td>Presentation and soft skill</td><td>√</td></tr>
<tr><td rowspan="3">CO3</td><td rowspan="3">Review, debate, compare and contrast the relevant literature contents. Relevance of this research/study. Methods, tools, and techniques used by past researchers and justification of use of them in this work.</td><td rowspan="3">PO4
Investigation</td><td>Thesis Book</td><td>√</td></tr>
<tr><td>Performance by research</td><td>√</td></tr>
<tr><td>Presentation and soft skill</td><td>√</td></tr>
<tr><td rowspan="3">CO4</td><td rowspan="3">Analyse data and exhibit results using tables, diagrams, graphs with their interpretation.

Investigate the designed solutions to solve the problems through case study/survey study/experimentation/simulation using modern tools and techniques.</td><td rowspan="3">PO5
Modern tool usage</td><td>Thesis Book</td><td>√</td></tr>
<tr><td>Performance by research</td><td>√</td></tr>
<tr><td>Presentation and soft skill</td><td>√</td></tr>
<tr><td rowspan="3">CO5</td><td rowspan="3">Apply moral values and research/professional ethics throughout the work, and justify genuine referencing on sources, and demonstration of own contribution.</td><td rowspan="3">PO8
Ethics</td><td>Thesis Book</td><td>√</td></tr>
<tr><td>Performance by research</td><td>√</td></tr>
<tr><td>Presentation and soft skill</td><td>√</td></tr>
<tr><td rowspan="3">CO6</td><td rowspan="3">Perform own self and manage group activities from the beginning to the end of the research/work as a quality work.</td><td rowspan="3">PO9
Individual work and teamwork</td><td>Thesis Book</td><td>√</td></tr>
<tr><td>Performance by research</td><td>√</td></tr>
<tr><td>Presentation and soft skill</td><td>√</td></tr>
<tr><td>CO7</td><td></td><td>PO10</td><td>Thesis Book</td><td>√</td></tr>
</table>

	Compile and arrange the work outputs, write the report/thesis, a sample journal paper, and present the work to wider audience using modern communication tools and techniques.	**Communication**	Performance by research	√
			Presentation and soft skill	√
CO8	Recognize the necessity of life-long learning in career development in dynamic real-world situations from the experience of completing this project.	**PO12** **Life-long learning**	Thesis Book	√
			Performance by research	√
			Presentation and soft skill	√

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K-P-A Mapping of IPE 4800 -Thesis and Project

COs	POs	Related Ks								Related Ps							Related As				
		K1	K2	K3	K4	K5	K6	K7	K8	P1	P2	P3	P4	P5	P6	P7	A1	A2	A3	A4	A5
CO1	PO2	√	√	√	√					√											
CO2	PO3					√				√	√	√				√	√	√	√		
CO3	PO4								√	√	√	√					√	√			
CO4	PO5						√			√				√							
CO5	PO8							√													
CO6	PO9																				
CO7	PO10																				
CO8	PO12																				

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Prof Dr. Md. Anayet Ullah Patwari
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List of Sustainable Development Goals (SDGs) Addressed in this Project

G No.	Goals	Targets		Relevance to the Thesis	Remarks
1	No Poverty	1.1 Eradicate extreme poverty (people living on less than $1.25/day).			
		1.2 Reduce poverty in all its forms by at least half.			
		1.3 Implement nationally appropriate social protection systems.			
		1.4 Ensure equal rights to economic resources, services, property, inheritance, technology, and financial services.			
		1.5 Build resilience of the poor and reduce exposure to climate-related and other shocks.			
		1.a Mobilize resources to end poverty.			
		1.b Create pro-poor policy frameworks.			
2	Zero Hunger	2.1 End hunger and ensure access to safe, nutritious food year-round.			
		2.2 End all forms of malnutrition.			
		2.3 Double agricultural productivity and incomes of small-scale producers.			
		2.4 Ensure sustainable food production systems and resilient agricultural practices.			
		2.5 Maintain genetic diversity of seeds, plants, and animals.			
		2.a Increase investment in rural infrastructure, research, and technology.			
		2.b Correct and prevent trade restrictions/distortions in global food markets.			
		2.c Adopt measures to ensure proper functioning of food commodity markets.			
3	Good Healt h and	3.1 Reduce global maternal mortality ratio.			

		3.2 End preventable deaths of newborns and under-5 children.			
		3.3 End epidemics of AIDS, tuberculosis, malaria, and neglected tropical diseases.			
		3.4 Reduce premature mortality from NCDs and promote mental health.			
		3.5 Strengthen prevention and treatment of substance abuse.			
		3.6 Halve global deaths/injuries from road traffic accidents.			
		3.7 Ensure universal access to sexual and reproductive healthcare.			
		3.8 Achieve universal health coverage.			
		3.9 Reduce deaths from hazardous chemicals, pollution, and contamination.		√	Reducing casting defects lowers exposure to hazardous emissions.
		3.a Strengthen tobacco control (WHO FCTC).			
		3.b Support R&D of vaccines and medicines.			
		3.c Increase health financing and workforce.			
		3.d Strengthen capacity for early warning and risk management.			
4	Quality Education	4.1 Ensure all complete free, equitable, quality primary and secondary education.			
		4.2 Ensure access to quality early childhood development and pre-primary education.			
		4.3 Ensure equal access to affordable technical, vocational, and higher education.		√	Supports advanced technical learning in casting and simulation for higher education.
		4.4 Increase skills for employment and entrepreneurship.		√	Enhances manufacturing skills, and innovation

		4.5 Eliminate gender disparities in education.			
		4.6 Ensure literacy and numeracy for youth and adults.			
		4.7 Ensure learners acquire knowledge/skills for sustainable development.		√	Encourages sustainable and efficient casting practices
		4.a Build and upgrade education facilities that are inclusive and safe.			
		4.b Expand scholarships for developing countries.			
		4.c Increase supply of qualified teachers.			
5	Gender Equality	5.1 End all forms of discrimination against women and girls.			
		5.2 Eliminate violence against women and girls.			
		5.3 Eliminate harmful practices (child, early, forced marriage, FGM).			
		5.4 Recognize and value unpaid care and domestic work.			
		5.5 Ensure women's participation in leadership and decision-making.			
		5.6 Ensure universal access to reproductive health and rights.			
		5.a Undertake reforms to give women equal rights to resources.			
		5.b Enhance use of enabling technology to empower women.			
		5.c Adopt and strengthen policies and laws for gender equality.			
6	Clean Water and Sanitation	6.1 Achieve universal and equitable access to safe drinking water.			
		6.2 Achieve access to adequate sanitation and hygiene.			
		6.3 Improve water quality by reducing pollution.		√	Promotes cleaner casting to cut water pollution.
		6.4 Increase water-use efficiency and sustainable withdrawals.			

		6.5 Implement integrated water resources management.			
		6.6 Protect and restore water-related ecosystems.			
		6.a Expand international cooperation in water and sanitation.			
		6.b Support participation of local communities.			
7	Affordable and Clean Energy	7.1 Ensure universal access to affordable, reliable, modern energy services.			
		7.2 Increase substantially the share of renewable energy.			
		7.3 Double global rate of improvement in energy efficiency.		√	Promotes energy-efficient casting and simulation
		7.a Enhance international cooperation on clean energy research/technology.			
		7.b Expand infrastructure and upgrade technology for sustainable energy.			
8	Decent Work and Economic Growth	8.1 Sustain per capita economic growth.			
		8.2 Achieve higher levels of productivity through diversification, tech, and innovation.		√	Drives innovation via optimized casting techniques
		8.3 Promote policies for decent job creation and entrepreneurship.			
		8.4 Improve resource efficiency in production and consumption.		√	Encourages efficient use of resources in casting.
		8.5 Achieve full and productive employment for all.			
		8.6 Substantially reduce youth not in employment/education/training.			
		8.7 Eradicate forced labour, modern slavery, and child labour.			
		8.8 Protect labour rights and safe working environments.			
		8.9 Promote sustainable tourism.			

		8.a Increase aid for trade support.			
		8.b Develop a global youth employment strategy.			
9	Industry, Innovation, and Infrastructure	9.1 Develop quality, reliable, sustainable infrastructure.			
		9.2 Promote inclusive and sustainable industrialization.		√	Supports sustainable manufacturing in metal casting
		9.3 Increase access of SMEs to financial services and integration into value chains.			
		9.4 Upgrade infrastructure for sustainability and resource efficiency.		√	Encourages energy-efficient, optimized production.
		9.5 Enhance scientific research and technology development.		√	Promotes research and innovation in manufacturing.
		9.a Facilitate sustainable infrastructure in developing countries.			
		9.b Support domestic tech development and value addition.			
		9.c Increase access to ICT and internet.			
10	Reduced Inequalities	10.1 Achieve income growth of bottom 40%.			
		10.2 Empower and promote inclusion regardless of status.			
		10.3 Ensure equal opportunity and reduce inequalities of outcome.			
		10.4 Adopt policies for fiscal, wage, and social protection equality.			
		10.5 Improve regulation of global financial markets.			
		10.6 Ensure enhanced representation in global institutions.			
		10.7 Facilitate safe, regular, and responsible migration.			
		10.a Implement special treatment for developing countries.			

		10.b Encourage development assistance and investment in least developed areas.			
		10.c Reduce remittance costs.			
11	Sustainable Cities and Communities	11.1 Ensure access to adequate, safe, and affordable housing.			
		11.2 Provide sustainable transport systems.			
		11.3 Enhance inclusive urbanization and capacity for planning.			
		11.4 Protect cultural and natural heritage.			
		11.5 Reduce disaster impact and losses.			
		11.6 Reduce environmental impact of cities (air quality, waste).		√	Supports eco-friendly manufacturing practices.
		11.7 Provide access to safe, inclusive green/public spaces.			
		11.a Support positive links between urban, peri-urban, rural.			
		11.b Increase disaster risk reduction strategies.			
		11.c Support least developed countries in sustainable building.			
12	Responsible Consumption and Production	12.1 Implement 10-Year Framework on sustainable consumption/production.			
		12.2 Achieve sustainable management and use of resources.		√	Encourages resource-efficient casting
		12.3 Halve per capita global food waste.			
		12.4 Manage chemicals and waste sustainably.		√	Ensures proper handling of molten metal, alloys, and by-products to minimize environmental impact.
		12.5 Substantially reduce waste generation.		√	Promotes efficient use of materials in casting to

					minimize scrap and production waste.
		12.6 Encourage companies to adopt sustainable practices.		√	Supports industries in implementing eco-friendly and energy-efficient casting processes.
		12.7 Promote sustainable public procurement.			
		12.8 Ensure people have relevant information for sustainable development.			
		12.a Support developing countries' scientific and technological capacity.			
		12.b Develop tools to monitor sustainable tourism impacts.			
		12.c Rationalize inefficient fossil-fuel subsidies.			
13	Climate Action	13.1 Strengthen resilience and adaptive capacity to climate-related hazards.			
		13.2 Integrate climate measures into national policies.		√	Supports adoption of low-emission, energy-efficient practices.
		13.3 Improve education and awareness on climate change.		√	Raises awareness on sustainable casting methods
		13.a Implement UNFCCC commitments (mobilize $100 billion annually).			
		13.b Promote mechanisms for capacity-building in least developed countries.			
14	Life Below Water	14.1 Reduce marine pollution.		√	Encourages cleaner production to protect water bodies.
		14.2 Sustainably manage and protect marine ecosystems.			
		14.3 Minimize and address ocean acidification.			

		14.4 Regulate harvesting and end overfishing.			
		14.5 Conserve at least 10% of coastal and marine areas.			
		14.6 Prohibit harmful fisheries subsidies.			
		14.7 Increase economic benefits from sustainable marine resources.			
		14.a Increase scientific knowledge and marine technology transfer.			
		14.b Provide access for small-scale artisanal fishers.			
		14.c Implement international law for oceans.			
15	Life on Land	15.1 Conserve terrestrial and freshwater ecosystems.			
		15.2 Promote sustainable management of forests.			
		15.3 Combat desertification and restore degraded land.			
		15.4 Ensure conservation of mountain ecosystems.			
		15.5 Take urgent action to reduce biodiversity loss.		√	Reduces habitat loss via sustainable practices
		15.6 Promote fair benefit-sharing from genetic resources.			
		15.7 End poaching and trafficking of protected species.			
		15.8 Prevent introduction of invasive alien species.			
		15.9 Integrate ecosystem values into policies/planning.			
		15.a Mobilize resources for biodiversity.			
		15.b Finance sustainable forest management.			
		15.c Support local communities for forest and wildlife.			
16	Peace, Justice and Strong	16.1 Reduce violence and related death rates.			
		16.2 End abuse, trafficking, and violence against children.			

		16.3 Promote rules of law and equal access to justice.			
		16.4 Reduce illicit financial/arms flows, organized crime.			
		16.5 Reduce corruption and bribery.			
		16.6 Develop effective, accountable institutions.		√	Promotes ethical research and project management.
		16.7 Ensure inclusive, participatory decision-making.		√	Promotes collaborative, inclusive research
		16.8 Broaden participation of developing countries in global governance.		√	Supports global cooperation in sustainable practices
		16.9 Provide legal identity for all (including birth registration).		√	Not directly related to research or casting
		16.10 Ensure access to information and protect freedoms.		√	No direct relevance to casting or fluidity study
		16.a Strengthen national institutions for prevention of violence.		√	No link to casting or fluidity study
		16.b Promote/enforce non-discriminatory laws and policies.		√	Not directly related to thesis focus..
17	Partnerships for the Goals	17.1 Strengthen domestic resource mobilization.			
		17.2 Developed countries to implement ODA commitments.			
		17.3 Mobilize additional financial resources.			
		17.4 Assist developing countries with debt sustainability.			
		17.5 Invest in least developed countries.			
		17.6 Enhance access to science, technology, innovation.		√	Encourages innovation in casting and fluidity research.

		17.7 Promote environmentally sound technologies.		√	Encourages sustainable casting practices.
		17.8 Fully operationalize technology bank for LDCs.			
		17.9 Enhance international support for capacity-building.			
		17.10 Promote a universal, rules-based trading system (WTO).			
		17.11 Increase exports of developing countries.			
		17.12 Timely implementation of duty-free, quota-free market access.			
		17.13 Enhance global macroeconomic stability.			
		17.14 Enhance policy coherence for sustainable development.			
		17.15 Respect national policy space.			
		17.16 Enhance global partnerships.		√	Supports collaborative sustainable innovation.
		17.17 Encourage multi-stakeholder partnerships.			
		17.18 Enhance data capacity of developing countries.			
		17.19 Support capacity-building for sustainable development indicators.			

Acknowledgment

First and foremost, the authors express their deepest gratitude to the Almighty Allah (SWT), whose infinite blessings, mercy, and guidance have enabled us to complete this thesis successfully.

The authors would like to convey their sincere appreciation and heartfelt thanks to **Prof. Dr. Md. Anayet Ullah Patwari**, Department of Mechanical and Production Engineering (MPE), Islamic University of Technology (IUT), for his continuous guidance, encouragement, and valuable supervision throughout all stages of this research work. His insightful suggestions and constant support have been instrumental in shaping the direction of this study and bringing it to completion.

Summary

In some cases, when molten metal is poured into molds to create different things, it does not flow smoothly. This erratic flow might cause the mold to fill partially, which would result in flaws in the finished product. The phenomenon is comparable to trying to pour honey through a thin straw, where full passage is impossible due to limited flow.

The current study investigated the use of ultrasonic vibration as a solution to this problem. By applying high-frequency, inaudible sound waves to the molten metal, ultrasonic vibration improves its fluidity and allows it to move more freely through small mold channels. To explore this strategy, computer simulations were used in place of actual trials. A computer model of the mold and molten metal was created using design tools and specialist software (ANSYS Fluent). The flow behavior was examined under both standard and ultrasonic vibration settings. The findings showed that by extending the molten metal's flow length and lowering the possibility of premature solidification, ultrasonic vibration greatly enhanced mold filling. The disturbance actually served as a booster, encouraging more efficient and smoother metal flow.

With the potential for reducing manufacturing time and material waste while facilitating the development of stronger, better-quality metal components with fewer flaws, this discovery has significant industrial significance.

Nomenclatures and Symbols

Abbreviation	Meaning
VOF	Volume of Fluid
Re	Reynolds' number
PISO	Pressure-Implicit with Splitting of Operators.
kHz	Kilohertz
TUVC	Transverse ultrasonic vibration-assisted
FSW	Friction Stir Welding

List of symbols:

V = velocity
f = Frequency
A = Amplitude
t = Time
ρ = Density
v = Velocity of the fluid
d = Characteristic length
μ = Dynamic Viscosity of the fluid
T = Vibration Period

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Abstract

The fluidity of the molten metal during the casting process greatly affects the final cast components' overall quality, surface smoothness, and structural integrity. In addition to speeding up production, increased fluidity also smooths surfaces and lowers the likelihood of casting flaws, including cold shuts, misruns, and shrinkage voids. Due to its capacity to lower flow resistance and encourage smooth metal flow, ultrasonic vibration has become one of the most successful and energy-efficient methods for increasing fluidity. By reducing surface tension in the molten metal, ultrasonic waves minimize flow disruptions and enable smooth and complete mold filling. This work explores the impact of ultrasonic vibration on fluidity and the decrease in defects using the numerical simulation of molten metal movement in casting molds. ANSYS Fluent was used to create a solid computational fluid dynamics (CFD) model that included solidification, heat transport, and molten metal flow characteristics. The impact of various ultrasonic frequencies on flow length, defect development, and mold filling in various mold channel designs was investigated in the simulation. The study aimed to determine ideal circumstances that maximize fluidity while reducing turbulence and uneven flow patterns by methodically altering the frequency. The findings show that proper ultrasonic stimulation greatly increases the fluidity of molten metal, decreases flow resistance, and guarantees more consistent mold filling. Excessive ultrasonic frequencies, however, have the potential to cause turbulence, which might impair casting quality and negatively impact uniform metal flow. The results offer insightful information on the workings of vibration-assisted casting and offer useful suggestions for using ultrasonic vibration in industrial casting operations. All things considered, this study advances our knowledge of ultrasonic-assisted casting methods and provides a basis for enhancing the quality of goods, cutting down on material wastage, and increasing production efficiency in metal casting processes.

Chapter 1: Introduction

1.1: Background of the study

1.1.1: Metal casting and its industrial importance

Metal casting is one of the earliest and simplest techniques in manufacturing. It has been around for thousands of years and is still essential to contemporary industries. It involves pouring hot metal into a mold cavity of the appropriate shape, letting it cool, and then allowing it to harden. The solid metal portion, known as a casting, is achieved by removing the mold after the metal has solidified. Because of its inexpensive capacity to create intricate geometries of various sizes, casting is a vital technique in many different industries. Casting makes it feasible to create complex interior cavities, thin sections, and forms that would have been impractical or prohibitively expensive to fabricate, in contrast to machining or additive procedures.

Figure 1: Metal Casting Process (*Http://Www.Tms.Org/Pubs/Journals/JOM/9802/Vives/*, n.d.)

Casting is often used in industry to produce bulky machinery items, pipelines, valves, turbine blades, and aerospace and automotive components including engine pistons, cylinder heads, and transmission housings. The method's adaptability enables it to be used with a variety of metals and alloys, including as magnesium, steel, cast iron, aluminum, and copper alloys, all of which are chosen according to specifications for durability, resistance to corrosion, and weight.

Casting is significant because of its universality as well as its adaptability. It may be utilized for specialized one-off components in industries like electricity production, aviation, and military, or for mass manufacturing, producing thousands of similar parts with the same level of quality. There are numerous important factors, due to which the industries are using it massively.

- Complex Forms and Patterns: Casting makes it feasible to create intricate interior chambers, lightweight frameworks, and complicated shapes that would otherwise be impossible.
- Numerous Materials: Since nearly all metals and alloys, both ferrous and non-ferrous, may be cast, enterprises are able to choose materials according to the rigidity, toughness, and other properties they want.
- Affordable for Massive Production: Casting makes it possible to produce huge quantities of the same parts with great dimensional precision at a reasonable cost.
- Flexibility in Dimensions: Casting can handle a wide variety of sizes, from small precise items (such as jewelry or surgical implants) to large industrial elements (such as engine segments, turbine housings, ship propellers).
- Enhanced Mechanical characteristics: Advanced techniques including vibration-assisted casting, regulated solidification, and computational optimization can improve the rigidity, resilience, and microstructure refinements of cast parts.
- The Basis for Modern production: Casting is a key component among global production, supporting nearly every industrial sector, including military, power generation, automobiles, railroads, and aircraft.

All things considered; metal casting is still a fundamental aspect of production that connects conventional methods with contemporary technological advancements. Its ongoing advancement is essential to satisfy the rising need for components that are lightweight, dependable, and high performing.

1.1.2: Fluidity and challenges in molten metal casting

Fluidity in molten metal casting denotes the capacity of liquid metal to flow and entirely occupy a mold cavity prior to solidification. The effective production of defect-free castings is based upon its crucial role in facilitating the flow of molten metal into complex mold geometries, thin sections, and corners.

- **Complete mold filling:**
  Molten metal may enter all areas of the mold, including those with thin walls, sharp corners, and complex geometries, when there is sufficient fluidity. Inadequate fluidity might cause the molten metal to solidify too quickly, producing gaps that could lead to castings that are either unfinished or flawed. According to one research study, ultrasonic-assisted vibration improves the efficiency of filling complicated molds by reducing the fluid thickness of the resin (Xie et al., 2016)
- **Defect Prevention:**
  Enhanced fluidity reduces typical casting flaws including smaller cavities, cold shuts, and misruns. These flaws impair the casting's precision and form while also compromising its rigidity. Numerous casting flaws, including as blowholes, slag inclusions, shrinkage, cold shuts, and other connected flaws, are linked to the filling process (Yuwen et al., 2012)
- **Improved Surface Finish:**
  The molten metal more precisely replicates the small features and texture of the mold surface when it flows smoothly and fills the mold evenly. As a result, the end product has a smoother surface quality, requires less further processing and looks better overall.
- **Enhanced Mechanical Properties:**
  A regulated solidification process and consistent filling are ensured by proper fluidity, which lowers internal porosity, segregation, and residual strains. As a result, cast components become stronger, more dependable, and have enhanced mechanical efficiency and a longer lifespan.

Challenges Affecting Fluidity and Casting Quality:

Premature Solidification:

Misruns and cold-shut result from the metal solidifying too soon while it is flowing. This frequently occurs in thin portions, at low pouring temperatures, or when the metal has a low degree of intrinsic fluidity.

Turbulence During Flow:

Porosity and gas bubbles are created when air or gas bubbles are trapped in the molten metal by excessive turbulence. Additionally, oxide defects may become trapped inside the casting due to turbulent flow, which would reduce mechanical performance and quality.

Poor Mold Filling:

Incomplete filling occurs when the molten metal does not reach every area of the cavity (either because of low pouring velocity, a poorly designed gating system, or insufficient venting). This results in defects, dimension errors, or damage to the surface.

The right fluidity is essential for casting that is devoid of flaws. Defects and diminished quality are caused by problems such as fast solidifying, swirling, or improper filling. Fluidity can be enhanced and these issues avoided by adjusting the pouring temperature, designing the mold, or employing techniques like ultrasonic vibration.

1.1.3: Heat Transfer and Solidification in Casting

Heat Transfer and solidification are the key elements of the casting process. They have an immediate effect on the end product's integrity and mold-filling performance. Melted metal cools quickly after being placed in a mold because of heat extraction from the mold walls and the surroundings. If a hot metal can sufficiently occupy the space prior solidifying depends on how heat is transported and solidification develops.

The heat gradient created among the liquid metal and the cavity's material is a crucial element affecting this phenomenon. High temperature differences can provide a strong connection by accelerating solidification at the mold-metal interface, but they can also cause early formation at the fluid material's moving edge. This frequently results in casting flaws such as misruns, cold shuts, and insufficient fills. Conversely, reduced heat gradients make it possible for the hot metal to stay liquid for a greater length of time, improving the filling capacity of complicated and thin mold parts. The pace of cooling is equally significant.

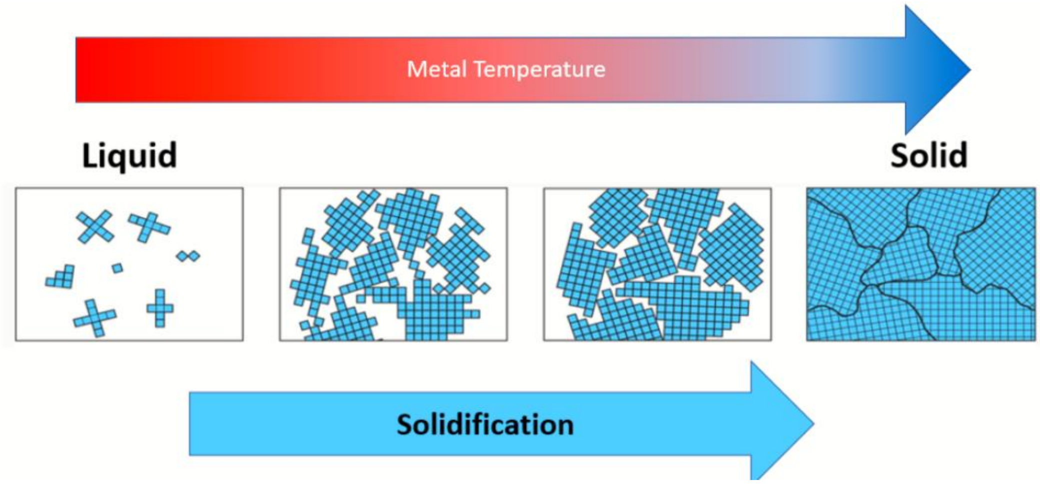


Figure 2: Metal Solidification Process

Since solidification happens swiftly and the liquid's length within the die is limited, faster cooling rates often result in less fluidity of liquid metals. Nevertheless, by fine-tuning the grain arrangement, quickly cooling can also enhance mechanical characteristics. Therefore, regulated cooling needs to balance attaining the required microstructural properties with permitting enough fluid flow.

Heat loss, which happens via radiation, convection to the outside environment, and conduction into the mold, is another crucial factor to take into account. The molding substance's thermal characteristics, the mold coatings, the preheated circumstance, and the cavity's design all have a significant impact on how much heat is lost. For instance, without outside help, metallic molds quickly remove heat, which causes solidification to occur more quickly and fluidity to decrease. Sand molds, on the other hand, allow for more travel but frequently result in coarser finishes on surfaces because they delay the cooling process. Additionally, thermal strains and contraction problems brought on by excessive heat loss might jeopardize the integrity of the casting.

In summary, the overall effectiveness of mold filling and solidification behavior is determined by the combined impact of temperature gradients, cooldown speeds, and energy loss processes. To guarantee casting free of flaws, these factors must be properly controlled and optimized.

Additionally, by decreasing viscosity and postponing solidification, sophisticated methods can improve the fluidity of molten metal and lessen the negative impacts of fast cooling.

1.1.4: Conventional methods to improve fluidity

To improve the fluidity of molten metals during the casting process, a number of traditional techniques have been used. Among these, alloying, applying outside pressure, and preparing the mold are particularly popular.

Preheating of Molds:

Preheating the mold raises its starting temperature, which slows down the molten metal's rate of cooling during filling. The molten metal may more easily reach complex areas of the mold cavity due to this delay in solidification. Continuous mold preheating, on the other hand, is less feasible for modern massive operations due to its considerable rise in consumption of energy, cycle time, and potential to accelerate mold deterioration or thermal fatigue.

Alloying Addition:

Another popular technique to increase fluidity is the use of elemental alloys. Phosphorus in copper alloys and silicon in aluminum alloys are examples of elements that improve flow properties and lower the melting temperature. However, alloying can adversely affect other crucial material qualities like mechanical strength, toughness, or corrosion resistance and frequently results in higher manufacturing costs. In crucial applications, over-alloying might lower the final casting's overall quality.

Application of Pressure:

By pushing molten metal into intricate geometries and thin sections, pressurized casting techniques—like pressure die casting—improve fluidity and lower the possibility of partial filling. This approach necessitates costly equipment, accurate control systems, and regular maintenance despite its efficacy. Furthermore, pressure casting may increase expenses for tools and may not be suitable for larger castings.

Limitations in modern industries:

These different techniques have historically increased flexibility, but they have drawbacks in terms of expense, energy consumption, and sustainability. Efficiency, environmental concerns, and process flexibility are becoming more and more important in today's industry. Consequently, other methods are being investigated as more effective and environmentally friendly ways to improve fluidity in casting procedures, such as the use of electrical stirring or ultrasonic vibration.

1.1.5: Vibration-assisted casting technology

An inventive and successful method for enhancing mold filling, improving hot metal flow, and fine-tuning the internal structure of cast materials is vibration-aided casting. Because of high metallic viscosity or early solidification, conventional methods of casting frequently encounter issues such as porosity, cold shuts, partial filling, and coarse microstructures. By altering a hot metal's dynamics at the microscopic level, the introduction of outside vibrations throughout the casting process might lessen these issues. There are several ways to use vibration in casting, including mechanical, electromagnetic, and ultrasonic vibrations.

- **Mechanical Vibration:** Mechanical vibration is the low-frequency oscillation of the casting system or mold to enhance consistent mold filling and lessen the trapping of air.
- **Electromagnetic Vibration:** During the process of solidification, opposing magnetic forces cause conductive molten metals to stir or oscillate, increasing fluidity and lowering dendritic development.
- **Ultrasonic vibration:** It is a high-frequency vibration that improves flow, reduces viscosity, refines microstructure, and creates cavitation and acoustic movement.

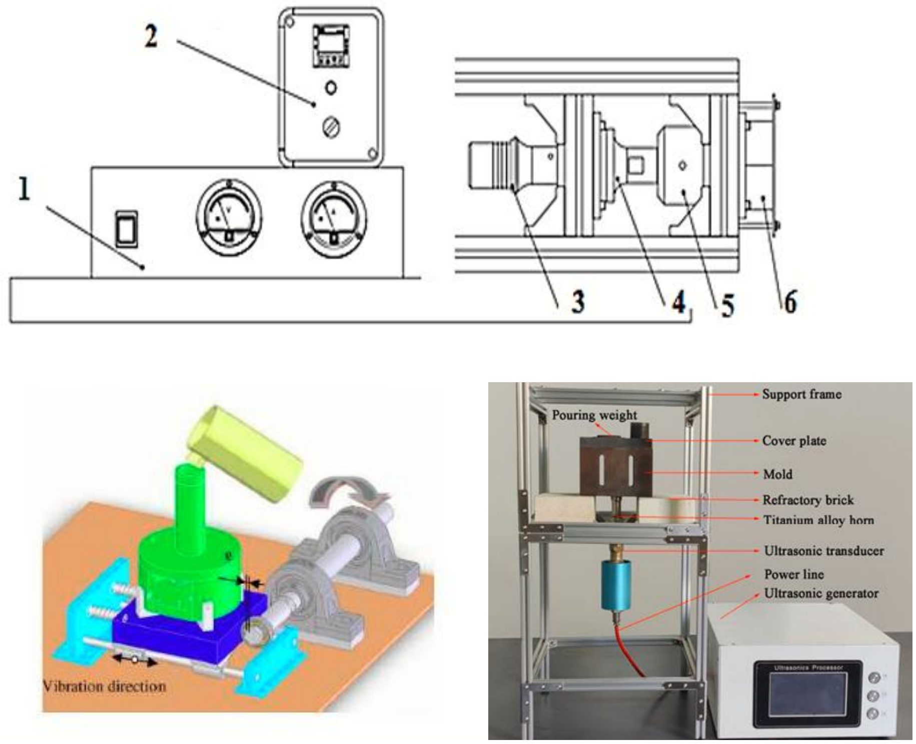


Figure 3: Different Techniques to apply vibration during metal casting (Li et al., 2023) (Campbell, 1995) (Qui et al., 2022)

Because of its high frequency range (usually 20–100 kHz) and special capacity to create phenomena like noise and bubbles within the molten metal, ultrasonic vibration has drawn a lot of interest recently. During solidification, these processes cause dendritic formations to be disrupted, mixing to be improved, and visible viscosity to decrease. Consequently, ultrasonic-assisted casting can eliminate casting flaws such as porosity, shrinkage, and cold laps, create finer and more consistent microstructures, and greatly increase the flow duration of molten metal in molds.

Numerous factors, including vibration frequency, amplitude, time frame, and starting point, affect how successful vibration-assisted casting is. While high-frequency ultrasonic waves are more suited for improving fluidity at the microstructural level, low-frequency mechanical vibrations are often more successful for mass mold filling and air extraction. Manufacturers may produce castings with better surface smoothness, increased mechanical effectiveness, and better mold filling by carefully adjusting these variables.

Vibration-assisted casting enhances fluidity while simultaneously reducing material use and energy consumption. Improved mold filling enables more accurate casting of complicated shapes, while decreased solidification flaws reduce debris and repair. The use of vibration technologies, especially ultrasonic vibration, in contemporary casting processes has drawn more attention from researchers as a result of these advantages.

To sum up, vibration-assisted casting is a viable way to get around the drawbacks of traditional casting techniques. It is very significant for companies looking for complicated geometries in superior cast parts because of its capacity to improve hot metal movement, improve microstructure, and minimize flaws. The current study on ultrasonic-assisted vibration in casting processes is based on the fact that ultrasonic vibration, in particular, is a potent instrument for increasing the movement of molten metals.

1.1.6: Ultrasonic vibration over other methods

Although traditional techniques like alloying, mold preheating, and applying external pressure have been widely used to increase the fluidity of molten metals, they have a number of disadvantages, including high energy costs, restricted applicability, and more. On the other hand, a more successful and efficient method for improving the flow of molten metal during casting is ultrasonic vibration.

Ultrasonic vibration is preferable because it may act at the microstructural level. The introduction of high-frequency ultrasonic pulses into molten metal produces acoustic streaming and cavitation. Cavitation breaks down the metal's boundary layer and facilitates improved flow via complex and small mold passageways. It is typified by the creation and burst of minute bubbles. In the mold cavity, acoustic streaming helps maintain homogeneous metal transfer and decrease stagnant zones.

The decrease of the molten metal's effective viscosity is a significant benefit of ultrasonic excitation. Fluidity is greatly improved by a decreased viscosity, which allows the molten metal to move farther before solidifying. This increase in flow time lowers the possibility of flaws like misruns, cold shuts, and unfinished sections and guarantees more thorough mold filling.

Additionally, improving fluidity without requiring extensive alloying changes or continuous heating from outside is a benefit of ultrasonic vibration, which reduces material prices and energy usage. Ultrasonic vibration is more adaptable than pressure-assisted methods and may be used in a variety of casting processes without the need for highly specialized equipment.

In conclusion, ultrasonic vibration provides a more technologically sophisticated and environmentally friendly substitute for conventional fluidity-enhancement techniques. Because of its high frequency action, micro-level cavitation effects, viscosity reduction, and flow length improvement, it is the best option for producing castings free of defects in contemporary industrial applications.

1.1.7: Simulation-Based Approach in Analyzing Fluidity

Studying the flow and solidification of liquid metals requires the use of computational methods, particularly when sophisticated methods like vibration-aided casting are used. Researchers may simulate complicated processes involving the movement of fluids, heat transport, solidification, and the impact of mechanical or ultrasonic vibrations on molten metal using computational tools like ANSYS Fluent, ANSYS Mechanical, COMSOL Multiphysics, and other CFD/thermal analysis software. These simulations offer significant insights into the effects of process variables on molten metal fluidity and mold filling, including vibration frequency, amplitude, mold shape, and pouring temperature.

Compared to conventional experimental techniques, simulation has a number of benefits. Because several process parameters can be digitally examined without the need to create molds or carry out repeated casting tests, it drastically cuts down on both time and expense. Additionally, it enables the thorough observation of solidification fronts, fluid percentage, flow velocity, and temperature contours—all of which are sometimes challenging to quantify experimentally.

For instance, COMSOL Multiphysics works well for coupled thermal-structural simulations, ANSYS Fluent is frequently used for in-depth fluid flow evaluation, and specialist casting simulation software (such as ProCAST or MAGMASOFT) may offer specific mold filling and solidifying forecasts. A multi-tool strategy improves the analysis's precision, dependability, and thoroughness.

In conclusion, simulation-based techniques offer a strong, economical, and accurate way to assess and maximize the fluidity of molten metal during vibration-assisted casting. They provide in-depth insights that are essential for enhancing casting both quality and effectiveness, supplement practical research, and lessen failing attempts.

1.2 Objectives of the study

The purpose of this study is to create a numerical simulation model for analyzing the flow characteristics of molten metal in casting molds and to look at how ultrasonic vibration might improve fluidity. Understanding how various vibration frequencies affect mold filling and coming up with ways to improve casting quality are the main goals of the study. The study's particular goals include–

- To create a thorough numerical simulation model in ANSYS Fluent for examining the solidification, heat transport, and flow characteristics of molten metal in casting molds
- To investigate improvements in fluidity and mold filling at different vibration frequencies by including the impacts of ultrasonic vibration into the simulation model.
- To examine the molten metal's flow length and behavior in three different mold channels, both with and without ultrasonic vibration.
- To identify the most efficient range for improving metal fluidity by comparing the simulation results under various vibration frequencies.
- To determine how well ultrasonic vibration reduces typical casting flaws such gap formation, cold shuts, and misruns in intricate or small mold parts.
- To determine areas vulnerable to partial filling and examine how mold shape and channel design affect the flow of molten metal.
- To evaluate how the frequency and amplitude of vibrations affect the mold's solidification patterns, temperature gradients, and velocity distribution.
- To offer feasible recommendations for applying ultrasonic vibration in industrial casting procedures in order to maximize mold filling, reduce flaws, and enhance the general quality of the final product.

- To improve knowledge of vibration-assisted casting methods in order to provide the groundwork for next studies and practical uses.

The study thoroughly assesses molten metal flow in casting molds by combining advanced numerical modeling techniques with the recently developed technology of ultrasonic vibration.To better our understanding of fluidity improvement mechanisms in casting processes, the project will construct a robust CFD model, incorporate ultrasonic vibration effects, analyze diverse mold shapes, and systematically compare findings across different vibration frequencies. The results of this study might help guide actual casting operations, cut down on material waste, enhance product quality, and further our understanding of vibration-assisted metal casting techniques.

1.3 Problem Statement

Among the earliest and most used manufacturing techniques, metal casting is essential to the production of parts for the end-user, automobile, aviation, and infrastructure sectors. The restricted fluidity of molten metal, particularly if it has to flow down lengthy, small, or intricately carved mold channels, remains one of the most persistent problems in traditional casting despite tremendous breakthroughs in casting technology. The dimensional accuracy, surface quality, and mechanical performance of the finished product are all directly impacted by inadequate fluidity, which commonly leads to partial mold filling, premature solidification, cold shuts, porosity, and other casting flaws. Because of increased failure rates, revisions, or the requirement for extra preparation, these problems not only lower the overall quality of the cast item but also raise costs related to production.

Historically, a number of techniques have been investigated to increase the molten metals' fluidity. In reality, methods including raising the pouring temperature, changing the alloy's composition, or changing the mold design have been used. All of these alternatives, though, have drawbacks. Boiling the molten metal, for example, boosts the expenditure of energy and the danger of corrosion, and alloy alteration sometimes entails the expensive inclusion of rare materials. In the same way, design specifications limit the geometric changes that may be made to molds. Innovative and effective ways to increase the fluidity of molten metal while placing a heavy financial or energy load on the production system are therefore becoming more and more necessary.

The use of ultrasonic energies throughout the casting process is one intriguing method that has gained interest recently. When applied to molten metals, ultrasonic energy has been shown to produce phenomena like dendritic disintegration, cavitation, and acoustic streaming that improve melt flow, encourage homogeneous solidification, and lessen the production of defects. Applying ultrasonic vibration has been shown across multiple studies to increase tensile characteristics, reduce permeability, and optimize microstructure. The precise effect of ultrasonic vibration on the fluidity of molten metals during mold filling has not been thoroughly investigated, despite these encouraging results. The majority of earlier research has focused on improving mechanical properties and microstructural refinement, with considerably less attention paid to the dynamic fluid flow behaviour under ultrasonic vibration, especially in complicated and narrow mold shapes.

The change in flow patterns during ultrasonic vibration is a further significant hurdle. At smaller vibration frequencies, the molten metal flow may exhibit laminar behavior; at higher vibration frequencies, it may exhibit turbulent behavior. Mold filling is significantly impacted by this change. Despite increasing flow length through greater momentum transfer, turbulent flow can result in non-uniform filling and the possibility of flaws, whereas laminar flow encourages smooth, uniform filling with less air trapping. The ideal vibration frequency for striking a balance between increased fluidity and fewer faults, as well as the circumstances under which this shift takes place, are yet unknown in the literature. Industries have trouble using ultrasonic vibration casting as a dependable solution if these flow characteristics are not well understood.

The absence of a thorough knowledge of how ultrasonic vibration affects the mobility and circulation patterns of molten metal while mold filling in confined channels is thus the main issue this thesis attempts to solve. In particular, nothing is known about how temperature distribution, flow length, vibration frequency, and the laminar-to-turbulent shift in molten metal flow are related. The efficient use of ultrasonic vibration in industrial casting processes is limited by this problem, especially for parts with complex mold geometries where fluidity is essential.

In order to solve this issue, the current work uses ANSYS Fluent for computational modeling to examine how molten aluminum flow is affected by ultrasonic vibration at various frequencies throughout mold filling. The present research aims to determine the circumstances in which ultrasonic vibration most efficiently enhances molten metal fluidity while lowering the risks of casting defects by examining variables like flow length, velocity distribution, temperature contour evolution, and flow regime transitions in three distinct mold geometries. The results of this study should help create more dependable, effective, and flawless production processes by offering fresh perspectives on the use of ultrasonic vibration in casting.

1.4 Possible Outcomes

A number of potential results are expected based on the goals and computational methodology of this study. The main anticipated result is that, in comparison to the no-vibration scenario, the use of ultrasonic vibration during mold filling would greatly increase the fluidity of molten aluminum. Increased flow lengths, more consistent temperature distribution, and more effective filling of intricate and small mold channels are probably indicative of this gain.

The impact of mold geometry is a further possible result. It is anticipated that cavity design will have a significant impact on how effective ultrasonic vibration is. systems with small passageways and abrupt curves, for instance, could gain more from the momentum transfer that ultrasonic waves give, but systems with broader channels or sinusoidal shapes might still experience diminished energy and obstacle to flow. This result will show that even though ultrasonic vibration improves the movement of liquid aluminum, mold geometry restrictions cannot be disregarded.

Furthermore, by keeping the fluid's kinetic energy greater and lowering temperature gradients throughout the cavity, ultrasonic vibration may assist postpone early solidification, according to an examination of temperature contour evolution. A more uniform filling mechanism and fewer cold closes might result from such behavior.

In general, the following are potential results of this study:

- Ultrasonic vibration's ability to increase the fluidity of molten metal while mold filling is demonstrated.

- Determining the ideal ultrasonic vibration frequency to achieve long fluid distance and consistent laminar flow.
- Mold shapes are compared in order to demonstrate how vibration and design work together to affect liquidity.
- Perspectives on the dynamics of solidification and spreading of temperatures during vibration-assisted casting.
- Suggestions for improving ultrasonic vibration casting methods in order to reduce flaws including air capture, permeability, and inadequate filling.

If these results are obtained, the study will prove ultrasonic vibration as a practical and effective method for increasing the fluidity of molten metal, which will add important knowledge toward better casting processes. The findings will also give companies useful recommendations for implementing this technique in actual casting operations.

1.5 Research Methodology

The investigative technique was thoughtfully created to accomplish the goals in an organized way. Establishing the issue and goals, literature study, shape design, mesh production, numerical simulation, comparison and analysis, and conclusion were the seven main steps of the procedure. Here is a detailed explanation of all of those phases.

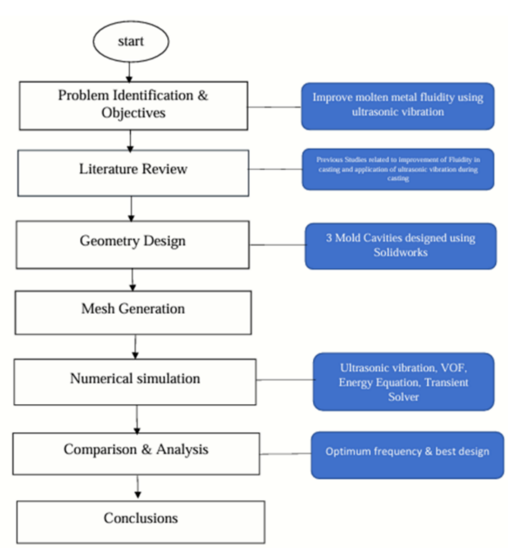


Figure 4: Research Methodology

1.5.1. Problem Identification and Objectives

Finding the primary issue affecting the casting procedure—the insufficient fluidity of molten metal, particularly in intricate mold geometries—was the first stage of this study. Molten metal frequently loses its kinetic and thermal energy too soon during the act of filling, which can result in cold shuts, porosity, inadequate mold filling, and other flaws that lower the quality of the casting. When the molten metal must flow via irregular or small passages with greater flow resistance, this problem becomes even more serious.

The alloy composition, pouring temperature, and mold design all have a significant impact on the metal flow in traditional casting. However, raising the pouring temperature by itself won't solve the problem because it will also cause additional issues including grain discoloration, contraction permeability, and increased energy expenditures. Therefore, a different strategy is required to increase the fluidity of molten metal while substantially changing the process parameters.
Thus, this study's goal was to find out how ultrasonic vibration may enhance the fluidity of the hot metal throughout mold filling. The study particularly sought to (i) model the flow pattern of molten aluminum over various vibration frequencies, (ii) assess the effects of mold geometry on filling regularity and flow length, and (iii) determine the ideal vibration circumstances that improve casting efficiency.

1.5.2. Literature Review

To lay the groundwork for the study, a thorough evaluation of pertinent literature was conducted in the second step. To comprehend the physical processes governing flow resistance and solidification behavior, prior research on metal casting fluidity was examined. To examine the possibilities for improving metal flow, studies into ultrasonic vibration was examined. Research in the experimental and computational sectors shed light on processes that are thought to enhance the fluidity of molten metal, including bubbling, acoustic streaming, and a decrease in solidification barrier.

In order to comprehend how computational approaches may reflect the intricate relationship among flow and solidification in casting, publications that used computational modeling tools—specifically, ANSYS Fluent—were also reviewed. The research gap was also identified at this stage: although ultrasonic vibration has been effectively used in other formation methods, nothing is known about how it affects mold filling, particularly when paired with various mold shapes.

1.5.3. Geometry Design

In the third step, several mold shapes were created in order to examine how shape and channel arrangement affected the flow of the hot aluminum. Three designs were taken under consideration:
Design 1 : This channel has broad turns and is comparatively broader, suggesting a different resistance mechanism because of the production of vortices at bends.
Design 2 : This medium-size channel is intended to depict modest flow resistance and has smooth curves.
Design 3: High resistivity to flow is anticipated in Design 3, an extended, thin passage with abrupt twists.

CAD software was used for modeling these shapes. In order to examine the way vibration affects flow under various resistance circumstances, diverse geometries were used. The investigation might ascertain if geometry dominates even when ultrasonic vibration is present through analyzing efficiency among designs.

1.5.4. Mesh Generation

Following the development of the geometry, mesh generation was used to divide the simulations into limited control elements. Since meshing has an immediate effect on precision and computing effectiveness, it is an essential stage in numerical simulation. A mesh independence investigation was conducted using both coarse and fine meshes. As the mesh was further developed, the study made sure that the solution stabilized and that the findings did not change much.
To represent velocity gradients and solidification fronts more accurately, finer meshing was added around corners and small passages, while a structured mesh was used in areas with simple

geometry. Accurate results were guaranteed without unduly high computational costs thanks to the final mesh balancing.

1.5.5. Numerical Simulation

At this point, the pouring of molten aluminum was modeled by numerical simulations in ANSYS Fluent. The liquid metal–air contact was tracked using the Volume of Fluid (VOF) framework, and the heat transmission and solidification effects were captured using the energy equation. To reflect the true mechanical properties of aluminum, temperature-dependent material parameters including density, viscosity, specific heat, and thermal conductivity were specified.

Heat dissipation via the mold was taken into consideration, the walls were created as no-slip limits, and an input velocity was specified at the pouring gate. The mold walls were thought to be at ambient temperature, and the starting temperature of the molten aluminum was selected at the pouring temperature.

In addition with vibration-free condition, ultrasonic vibration was used at frequencies of 20 kHz, 40 kHz, 60 kHz, and 80 kHz throughout the pouring phase. In order to simulate the real-world vibration-assisted pouring method, the oscillatory effect was added as a boundary condition that affected the liquid velocity.

1.5.6. Comparison and Analysis

Findings were retrieved and compared across all cases when the simulations were finished. Two primary criteria were taken into account:

- Flow Length: The path that molten metal travels within the mold cavity before fully solidifying is known as the "flow length."
- Temperature Distribution: The temperature curve as time passes is used to examine filling homogeneity, solidification, and loss of heat.

Tests were performed across various shapes and across both vibration-assisted and no-vibration instances. To give quantifiable proof of progress, measurements were noted. In order to assess filling homogeneity and thermal behavior, temperature contour plots were analyzed at various time intervals.

The study demonstrated how shape and vibration frequency interact. Although fluidity was enhanced by ultrasonic vibration in every situation, the degree of improvement varied greatly depending on the geometry.

1.5.7. Conclusion

The results of the analysis and simulations were compiled in the last step. It is shown that by lowering flow resistance, preserving forward momentum, and postponing solidification, ultrasonic vibration greatly increases the fluidity of molten metal. The results still show that mold shape is a significant factor in deciding how successful the vibration is.
The foundation for determining the ideal frequency range and parameters of design for enhanced casting performance was also established at this stage. Furthermore, suggestions for further research were delineated, encompassing both industrial implementation and experimental confirmation.

1.6 Thesis Organization

To give an easy and methodical representation of the study that was conducted, this thesis is divided into five chapters. Each chapter's synopsis is provided below:

Chapter 1: Introduction

In this chapter, the study's background is presented, emphasizing the significance of liquid metal fluidity in the casting process as well as the difficulties posed by insufficient mold filling and early solidification. This chapter also covers the issue description, research goals, study scope, and the importance of ultrasonic vibration as a possible remedy.

Chapter 2: Literature Review

The fluidity of liquid aluminum, ultrasonic vibration in manufacturing processes, and numerical simulation techniques used in casting analysis are all thoroughly reviewed in this chapter. The review lays out the justification for carrying out this investigation and identifies the research gaps in the existing body of knowledge.

Chapter 3: Numerical Simulation

The research approach used is described in this chapter. It describes the physics setup, boundary conditions, mesh creation, geometry design, and integration of ultrasonic vibration in ANSYS Fluent. Here, we also offer the specifics of simulation examples for various frequencies and mold shapes.

Chapter 4: Results and Analysis

The simulation findings are thoroughly discussed in this chapter. Various vibration frequencies and mold designs are used to display comparisons of flow length, temperature distribution, velocity-time analysis, and cavity filling performance. The impact of ultrasonic vibration on fluidity and solidification is ascertained by analyzing the data.

Chapter 5: Conclusion and Recommendation

The study's main outcomes are outlined in the last chapter, which also makes recommendations on how ultrasonic vibration could enhance the fluidity of molten metal. This chapter also offers proposals for future study areas and industrial application considerations.

Chapter 2: Literature Review

A thorough analysis of the literature on vibration-assisted procedures, casting fluidity, and molten metal casting is provided in this section. It starts with the fundamentals, uses, and constraints of conventional casting techniques. It then concentrates on variables that impact fluidity, such as metal structure, pouring temperature, and mold properties. Vibration-assisted and ultrasonic-assisted casting are next reviewed, with an emphasis on how they affect flow movement, internal structure, and defect elimination. The current work is motivated by the identification of research gaps concerning the impact of ultrasonic frequencies, amplitudes, and larger-scale circumstances on fluidity.

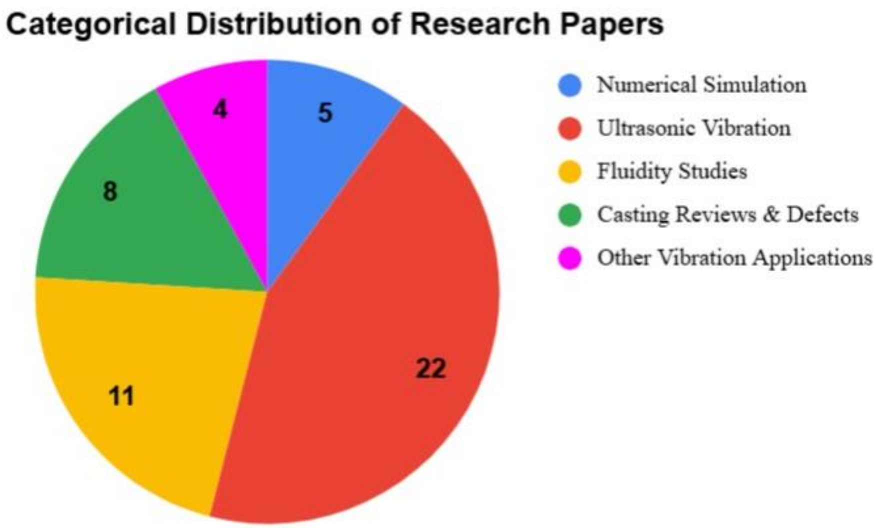


Figure 5: Distribution of Research Paper By topic

2.1 Review of Molten Metal Casting Process

One of the simplest and adaptable manufacturing techniques for a long time has been molten metal casting, which makes it possible to produce parts with intricate shapes, a range of dimensions, and specific material qualities. Casting, which is the act of depositing molten metal into molds and letting it solidify, has been essential in forming a variety of sectors, including aerospace, automotive, construction, and energy. With an emphasis on their working principles, industrial uses, and relative benefits, this paper seeks to provide a thorough understanding of the traditional molten metal casting technologies.

The technique of pouring or pressing molten metal into steel molds is known as die casting. One method of creating lasting molds is die casting. These steel forms—also known as tools or dies—are created especially for every job. This enables the precise and repeatable creation of every component. A frequently used method for casting Al, Zn, and Mg is pressure die casting. The pressure at which the molten metal is driven into the die cavity is between 0.7 MPa and 700 MPa. Once the molten metal has been poured into the mold, pressure is maintained till the casting solidifies. The use of low- and high-pressure die casting is the two varieties of die casting procedures. Although this approach provides minimal supervision of flaws, it enables large-scale manufacturing with efficient pressure distribution. Even though good-quality dies can endure for many cycles, die wearing is an issue because of high pressure and heat strains (Chadha et al., 2022). Significant investment costs are associated with the metal molds and foundry machinery, which tend to restrict the procedure to large-scale manufacturing. Die casting makes part manufacturing comparatively easy (Sai et al., n.d.).

Sahoo and Goswami (Eslamian & Zabihi, 2015) examined the origins and solutions of porosity and other casting flaws, emphasizing how design, material characteristics, and process variables affect the development of defects. They underlined that process modifications, suitable material selection, and improved design may all help to reduce porosity and shrinkage. The study offers information on defect control techniques meant to raise production, save expenses, and improve casting quality.

A design composed of waxes or an appropriate polymer is used in the production technique known as investment casting or lost foam casting (B. Ravi & Datta, n.d.). Another study explained that to create a sturdy mold, investment casting entails repeatedly submerging, curing, and fusing wax patterns with refractory material. To create extremely precise, seamless, and intricate castings, the wax is melted off, producing a hollow that is then filled with liquid metal. Although it may be used to cast complex forms and materials, its high tooling cost makes it more feasible for specialist uses or huge manufacturing quantities (Anglani & Pacella, 2018)

A vibration-induced fatigue damage technique was presented by Huang et al. (Huang et al., 2014) to isolate the casting components from the runner system in investment casting. Through the application of pneumatic hammer stimulation and a V-shaped notch at the ingate, fatigue fracture was triggered by resonance-induced stress concentration, allowing for the safe removal of the component. Simulation and experimental findings demonstrated the method's cost-effectiveness, speed, and safety.

Some of the most popular casting techniques are sand casting, in which hot material is poured into a mold made of sand that has been rammed around a design. Pattern creation, mold, and core setup, pouring, solidification, and casting removal are all steps in the whole procedure. Sand molds' primary benefit is their affordability, which makes them ideal for intricate forms and small-batch manufacturing. Its drawbacks include low-dimensional precision and diminished mechanical qualities brought on by the delayed cooling's porous microstructure (Goenka et al., 2020). This method is favored due to its low cost and near-free nature. Yet, sand cast parts frequently include defects that alter the castings' characteristics (Sai et al., n.d.).

This review emphasizes how traditional casting methods serve as the foundation for the production and casting sectors. Every procedure has its own advantages and disadvantages. It is crucial to comprehend these conventional techniques since they not only emphasize the significance of casting in manufacturing processes.

2.2: Review of Defects in Casting

Table 1: Defects in casting

Casting Defects	**Causes**	**Effects**	**References**
Porosity	It happens when voids or air pockets develop inside the casting throughout the solidifying phase	This flaw may lead to diminished structural integrity and poor mechanical qualities.	(Ammar et al., 2008)

Shrinkage	Happens when the casting cools and hardens. Making it shrink and create holes or voids	Can lead to warping and dimensional errors.	(Goswami et al., 2022)
Surface Irregularities	Several factors, such as gas porosity, mold permeability, or inadequate mold coating, can result in surface irregularities	This flaw may have an impact on the final product's functionality and look.	(Ha et al., 2008)
Inclusion	Occurs due to oxidation of hot metal, degradation of mold or core components, turbulence while pouring, and contaminated raw materials.	increasing corrosion, surface imperfection, and crack formation, which eventually reduces casting quality	(Akhyar et al., 2020)
Sand Inclusion	Due to poor mold strength, turbulence during pouring, or loose sand grains or fractured mold/core pieces entering the molten metal	produce uneven surfaces, impair dimensional accuracy, and increase stress, all of which diminish mechanical strength	(Chandra Kandpal et al., 2021)
Cold Flow	Occur when molten metal does not flow uniformly during die filling; caused by turbulence, delayed filling.	Poor surface quality, splashes, vent obstructions, gas porosity, uneven surface finish	(Armillotta et al., 2016)
Misruns	Misruns occur when the molten metal does not completely fill the mold's cavity, producing incomplete castings.	Results in components that are cast either wholly or partially in an unfinished state	(J. C. Chen & Buddaram Brahma, 2014)
Warpage	Deformation in cast component due to uneven cooling, internal	Dimensional inaccuracies, part rejection, reduced quality and productivity	(Tawele & Raut, 2015)

	stress, process parameter variation		

2.3: Review of Fluidity in Casting

The length that a metal can go in a conventional fluidity test mold is the definition of fluidity in casting language. In simple terms, fluidity is a dimension expressed, for example, in millimeters (Campbell, 1995). Hua et al. (Hua et al., 2007)examined the impact of alloy structure and pouring temperature on fluidity in their investigation on Mg–Al–Zn–Mn–Ce alloy combinations. The findings demonstrated that fluidity declines when alloying components are added, with susceptibility in the Ce > Al > Zn > Mn sequence. While changes in melting temperature and solidifying range had a major impact on solidification and flow pattern, the connection between flow length and pouring heat followed an exponential damping curve. Additionally, it was shown that the development of intermetallic phases rich in Ce and Al decreased casting fluidity.

Another study used a controlled atmosphere fluidity test to examine the effects of pouring temperature and alloy composition on fluidity in the research they conducted on elevated-pressure die-cast Al–Si alloys. The findings showed that various alloys had distinct temperature sensitivity, both silicon and magnesium having a major impact on the pattern of flow. Furthermore, compared to clean melts, impurities with 50% scrap decreased fluidity and increased oxide inclusions. Among 580 and 680 °C, fluidity was shown to rise linearly with temperature, plateauing at greater poured temperatures (Timelli & Bonollo, 2007)

The impact of foam pattern characteristics on fluidity in Lost Foam Casting was investigated by a study (Siavashi, n.d.). Using either γ- or E-beam irradiation to reduce the molecular weight of PMMA-PS copolymer patterns decreased permeability and enhanced fluidity, with E-beam proving a better option. Adjusting the qualities of the foam pattern can improve fluidity and casting performance, as demonstrated by the fact that PMMA reduced more than PS-PMMA, while EPS stayed the same.

One of the investigation of fluidity under high-pressure die casting (HPDC) situations, Han and Zang, (Q. Han & Zhang, 2020) found that flow pattern cannot be explained by traditional solidification-based concepts. According to their research, the primary cause of flow choking is already solidified dendrites (PSDs), which are created in the shot sleeve and moved towards the runners. PSDs raise the pressure loss in the mushy zone, decrease porosity, and create dendritic structures. Liquid metal flow stops once the pressure drop reaches or surpasses the injection pressure, which restricts fluidity in HPDC operations.

An artificial neural network (ANN) model was created to forecast the molten metal flow length in ductile iron (DI) sand casting across various circumstances. The model was trained using 108 tests and FlowCast simulations, taking into account variables including filling duration, metallurgical quality, casting temperature, and cross-sectional width. With a significant accuracy in forecasting (R2 = 0.986), their findings demonstrated that the ANN with six hidden neurons performed most effectively, demonstrating its efficacy in calculating flow length in casting operations (Teke, 2022).

The parameters influencing the fluidity of Al–Si series alloys for lightweight automotive applications were reviewed by Niu et al.(Niu et al., 2022).Grain size, DCP, reinforced particles, alloying components, and solidification mode all affect fluidity, with the second being the most important factor, they observed. Because their solidification intervals were less extended, Al–Si–Mg alloys exhibited more fluidity than Al–Si–Cu alloys.

Han and Zhang (Armillotta et al., 2016) looked at how alloys flow-choked when they were subjected to high-pressure die casting (HPDC). For HPDC, where mold filling happens in a matter of a second and temperature fluctuations at the flow front are minimal, they discovered that traditional fluidity theories based on the solidification mode are insufficient. The molten metal stops flowing when this pressure drop equals or surpasses the injection pressure, proving that PSDs control flow stoppage under HPDC.

In order to determine casting reliability, Hanumanth et al. (Hanumanth et al., 1989) stressed the significance of pouring time. They recommended minimizing the duration of contact among the molten metal and the mold in iron castings at elevated pouring temperatures in order to produce a higher surface quality and prevent penetration flaws. Their research suggests that the hardened surface layer that forms before the mold filling process should not be melted again since doing so would improve its exterior quality while preserving enough fluidity to allow for full mold filling.

This review emphasizes how casting fluidity is greatly impacted by alloy structure, pouring temperature, contaminants, and other circumstances. Additional research demonstrates that method improvement and predictive models may increase flow control, which raises the quality and dependability of castings.

2.4: Review of Vibration-Assisted Casting Techniques

The mold or workpiece is securely positioned on a vibrating table that is attached to a vibration exciter in vibrating casting. The vibrations produced by the stimulation device at different frequencies are transferred to the table and then to the molds, that shake in response to the respective frequencies. Such vibrating circumstances cause the hot metal to solidify. The shaking of the molding improves the castings' qualities throughout the solidification phase (Suresh & Chandrasekar, 2014)

Chirita et al. (Chirita et al., 2009) examined how vibration affected the solidification and mechanical characteristics of Al–Si hypereutectic alloys. The study studied how vibration frequency affected microstructural uniformity, permeability decrease, and refinement of grains. Heat transfer methods were found to be the primary element impacting findings, which indicated that low-frequency vibration increased tensile strength while higher frequencies lowered it. This review emphasizes how important vibration conditions are for maximizing mechanical performance and casting quality. Another study found A356 aluminum alloy is greatly impacted by mechanical vibration; frequencies as high as 50 Hz and durations of 15 minutes result in optimum particle refinement (53%) and a reduction in α-Al phase size to 173 µm. Due to better mass supply and melt degassing, these circumstances also increased density from 2.40 g/cm^3 to 2.66 g/cm^3, emphasizing the significance of vibration factors in casting quality (Taghavi et al., 2009)

Kumar et al. (Kumar et al., 2023) used a new sound-wave-assisted vibrational casting technique to create Al-B_4C functionally graded materials. According to SEM, EDS, and XRD, vibration frequencies (45–75 Hz) allowed B_4C particles to gradually diffuse from the inner to outside areas. From 37 HV in the inner area to 347 HV in the outside region, the micro-hardness gradually increased. Defect-free FGMs with regulated reinforcement distribution and enhanced mechanical qualities were made possible by the technique.

Chen et al. (W. Chen et al., 2022) investigated how mechanical vibration affected the mechanical characteristics and shrinkage flaws of Al–Cu–Mn–Ti alloy during low-pressure sand casting (LPSC). Applying resonant vibration along with increased pressure proved to be the most successful method, eradicating shrinkage flaws and increasing density by 2.7% when they tested various solidification pressures (20 and 40 kPa) with and without vibration. Tensile testing demonstrated a 21.7% increase in ultimate strength and a 7.8% improvement in elongation, while microstructural studies revealed a 29.5% reduction in primary-Al particle size. According to the study's findings, vibration improved solidification feeding by collapsing interdimeric barriers, reducing the threshold pressure gradient, and purifying grains.

Abdul-Karem et al. (Abdul-Karem et al., 2013) looked at how low-frequency vibration affected the Al–7Si–Mg thin-wall investment castings' mechanical dependability. The Weibull modulus of tensile strength was used to assess reliability, while porosity, oxide films, and fault distribution were used to assess casting quality. The findings indicated that while vibration at 1.2 g considerably increased reliability with a Weibull modulus of 38, vibration accelerations below 1 g generated poor reliability (Weibull modulus 12–12.7). According to the study's findings, vibration increases the driving power of molten metal flow, improving mechanical reliability and flaw dispersion.

Omura et al. (Omura et al., 2009) investigated how mechanical vibration (0–120 Hz) affected the cooling rate and dendritic arm spacing (DAS) of gravity die castings made of AC4C aluminum alloy. They found that the cooling rate and mold temperature were raised by vibration, and that the impact was amplified at higher frequencies. As the vibration frequency increased, DAS in the specimens' outer area dropped, suggesting grain refinement. On the other hand, specimens that were cast with vibration showed surface roughness, but those that were produced without vibration had smooth surfaces.

The impact of electromagnetic vibration on the internal structure of magnesium alloy ingots made of AZ80 was examined by Shi-jie et al. (Shi-jie et al., 2007). The research examined the particle size dispersion at the alloys' middle, mid-length, and surface by contrasting vibration-assisted casting with traditional direct-chill casting. In order to improve the total homogeneity and consistency of the cast ingots, the findings showed that electromagnetic vibration greatly improved the microstructure, mainly by dendritic fragmentation and enhanced initiation inside the melting liquid.

Jiang et al.(Jiang et al., 2016) investigated the impact of vibration frequency on A356 aluminum alloy during disposable pattern shell casting. With the best results at 100 Hz, mechanical vibration enhanced particle shape, decreased SDAS, and purified α-Al grains and eutectic silicon. When compared to samples that were not vibrated, the tensile strength, yield strength, elongation, and hardness rose by 35%, 42%, 57%, and 28% respectively, at this frequency. Better ductility and dependability were shown by the fracture mode changing from brittle to ductile with deep, evenly spaced dimples.

Kund (Kund, 2018) looked into how slanted plate vibration affected the microstructural characteristics and solidification of semisolid-cast A356 aluminum alloy. The finest globular microstructure was produced at 30 Hz out of five vibration frequencies (0–50 Hz).Grain coarsening was driven by increased vibration, but dendritic fragmentation was restricted by lower vibration. Heat treatment also increased chemical uniformity, decreased porosity, and improved surface quality.

Yu et al. (Yu et al., 2009) investigated, a 10 T, 10 A electromagnetic field was used to apply electromagnetic vibration straight to the Al-6%Si alloys melting throughout directed solidification. The hot metal was affected by the vibration procedure, which changed the shape of eutectic silicon from flake to filamentous and broke up rough dendritic networks into more spherical granules. This improved mold filling and intake, improved the molten alloy's fluidity, and corrected the microstructure—all of which led to a significant gain in tensile strength and ductility.

Lin et al. (Lin et al., 2013) used a titanium detector, ultrasonic vibration (USV) is delivered directly to molten Al-Si alloys at regulated temperatures, frequencies (20 kHz), and power (1.6 kW). Better mold filling and improved mechanical qualities, including tension, rigidity, and stretch, are the results of the produced bubbles and auditory circulation, which also purify Fe-containing intermetallic and increase fluidity.

2.5: Review of Ultrasonic Vibration in Molten Metal

It is crucial to use ultrasonic vibration to investigate the performance and movement of molten metal flow while casting. It is essential for figuring out the macroscopic and small-scale effects on metal movement, solidifying patterns, and defect formation. The purpose of this review of the literature is to examine the status of development and research in the area of ultrasonic vibration used to molten metal processing, emphasizing significant discoveries, processes, and developments that lead to better casting performance and quality.

Zi-heng Han (Z. Han et al., 2022) applied ultrasonic vibration to improve the fluidity and quality of non ferrous alloy.The mold receives vibrations from a system that consists of an ultrasonic generator, transducer, and horn. As the molten metal solidifies, vibrations are sent to it by the horn, which is fastened to the bottom part of the mold.Uniform vibration can limit flow and create swirling motion, whereas controlled vibration increases fluidity by encouraging cavitation.The consistency of vibration dispersion is affected by many vibration modes, namely AUOS and AUBS, which in turn affect the whole performance of the casting.Fluidity was enhanced by the AUBS mode with uniform vibration and decreased by the AUOS mode. Although turbulence from uneven vibration might counteract the impact of cavitation, it did enhance fluidity. According to Liang et al. (Liang et al., 2016), using ultrasonic waves to refine the microstructure into desired equal grains during the casting of 35CrMo steel improved its durability and tensile strength.In addition to preventing high-temperature corrosion, the silicon nitride ceramic radiator improved mold filling and decreased flaws, making the T-shaped ultrasonic wave guide more effective than the L-shaped design. Both experimental studies and numerical simulations supported these results, demonstrating that ultrasonic treatment significantly enhances mechanical characteristics and casting performance in general. According to Han et al. (Z. Han et al., 2023), research on ultrasonic vibration in casting, resonance-based vibration produced cavitation pressures beyond the threshold, refined dendrites and eutectic silicon, and decreased grain size. Additionally, they observed that refining was affected by cooling rate and that supply effectiveness was enhanced by vibration close to the feeding channel, which removed shrinkage voids. Murakami et al.(Murakami et al., 2016) prepared semi-solid AC4CH aluminum alloy slurries using mechanical vibration (MV) and assessed its fluidity under various shear situations. A spiral mold cavity was used to test the slurry, which was created at 50 Hz with an acceleration amplitude of 166.6 m/s^2. According to their findings, MV slurry only displayed 25–40% of liquid aluminum's fluidity; meanwhile, fluidity was increased by around 30% when shear force was applied at the mold gate. Additionally, at greater shear rates and pressures, the MV slurry attained fluidity equivalent to electromagnetically stirred (EMS) slurry, demonstrating its promise for semi-solid forming applications. Greater shear rates also polished and rounded the solid particles. The influence of mechanical vibration on the fluidity of Al-12%Si alloy during thin-section casting was examined by Al-Mallak et al. (Al-Mallak & Doos, 2021). Within the frequency range of 0–60 Hz, vibrations were used in both vertical and horizontal motions at two intensities. According to their findings, fluidity was greatly enhanced by vertical vibration, with a maximum improvement of 30.61% at 60 Hz. Fluidity improvement peaked at 33.35% at 12 Hz in a horizontal manner, but at higher frequencies, it declined because of circular flow patterns brought on by intense vibrations. It was discovered that horizontal vibration worked best at lower frequencies, whereas vertical vibration was often more effective. Chan Cho-Yee (*6006*, n.d.) investigated the use of ultrasonic treatment (UST) on a large scale to enhance the mechanical characteristics and quality of aluminum castings. In contrast to earlier small-scale crucible experiments, UST was dynamically applied during mold filling, focusing on the mushy zone of solidification. The findings showed that regulated UST improved tensile strength as well as ductility by up to 30% and dramatically decreased porosity, with some castings attaining total absence of internal voids. Furthermore, the results of programmed UST along the mushy zone were superior to those of continuous treatment during solidification. These results suggest that UST can provide the aluminum sector with an economical and ecologically friendly substitute by creating porosity-free castings with forging-like integrity, therefore bridging the gap between casting and forging.

Wu et al. (Wu et al., 2018) used ultrasonic vibration casting to create A356–CNF nanocomposites in order to investigate their wear and mechanical characteristics. CNFs reduced the friction coefficient and greatly increased strength, hardness, and wear resistance. At 1.2 weight percent CNFs, the hardness increased to 106–109 HV, the wear rate decreased to less than one-third of the basic alloy, and the friction coefficient was less than 0.35. Superior wear behavior was facilitated by the creation of a carbon coating that functioned as a solid lubricant, as demonstrated by SEM examination.

Gomes et al. (Gomes et al., 2023) investigated how the aging behavior of AlSi7Mg alloy under T6 heat treatment was affected by ultrasonic-assisted casting. The most effective refinement was seen when the ultrasonic treatment was administered completely above liquidus. It refined grains, changed Fe-rich phases, and transformed eutectic Si. This environment accelerated aging kinetics, lowering peak aging time by 25% and underaging time by 50% without sacrificing strength because of solute enrichment and greater vacancy density that encourage the development of GP zones.

During permanent mold casting, Dao et al. (Qui et al., 2022) examined how ultrasonic vibration affected the mechanical characteristics, microstructure, and mold filling capacity of ADC12 aluminum alloy. In comparison to traditional casting, they found that ultrasonic vibration increased mold filling in narrow cross-sections, decreased porosity, and refined grains when applied to SKD11 steel molds at a frequency of 20 kHz. While hardness only little changed, tensile strength rose by 20% at 660 °C and 9% at 700 °C. Results have shown that fluidity and mechanical performance are improved by ultrasonic-assisted casting, and that the ideal temperature for better casting quality is 660 °C.

When treating molten metal, ultrasonic vibration is a very efficient method that improves fluidity, refines microstructure, and lowers porosity and flaws. Its effectiveness is dependent on the vibration mode, frequency, and application technique; the optimum effects are produced by carefully regulated and positioned vibrations. All things considered, casting with ultrasonic assistance greatly enhances mechanical qualities and casting quality, providing a dependable and effective process for high-performance metal part.

2.6: Research Gaps in Fluidity Improvement Studies

Ultrasonic vibration improved mold filling, decreased porosity, and increased the tensile strength of ADC12 alloy castings, as demonstrated by Dao et al. (Qui et al., 2022). However, the study was constrained to a single frequency and a short temperature range, and the results of mechanical testing were limited to hardness and tensile strength. Xian and Lin (Xian & Lin, 2008) created a compound multifrequency ultrasonic transducer and used tests and simulations to show its many resonance frequencies. However, the study only looked at controlled tests and theoretical analysis; it didn't look at how well it worked in real-world applications like metal processing or ultrasonic-assisted casting. According to Li et al.(Li et al., 2023), Ultrasonic vibration can increase the fluidity of aluminum alloys by lowering flow resistance and breaking dendrites. Nevertheless, it is still unknown how turbulence at high intensities affects fluidity, and the impacts of various ultrasonic frequencies, amplitudes, and industrial-scale circumstances were not investigated. Prukkanon et al. (Prukkanon et al., 2009) investigated the effect of Scandium (Sc) modification on the fluidity of A356 aluminum alloy, showing that Sc can refine grains and enhance fluidity, particularly at higher temperatures. However, the impacts of other modifying combos or concentration were not investigated because the study only looked at certain Sc and Sc+Zr compositions. Furthermore, the fundamental processes that restrict fluidity at extremely small grain sizes, such in 0.4 weight percent Sc, were not well understood, suggesting that more research is necessary to maximize the usage of modifiers for improved castability. The variables affecting aluminum alloys and composites were examined by Ravi et al.(K. R. Ravi et al., 2008).In order to maximize aluminum alloy castability in sophisticated applications, further experimental and modeling research is required to fully understand the interactions between processing factors and fluidity in thin-wall or complicated casting geometries.

Chapter 3: Computational Methodology

In order to investigate the flow of hot liquid aluminum and the spread of heat throughout casting, the simulation technique integrates geometry design, mesh creation, boundary condition setting, and ultrasonic vibration implementation. Making use of ANSYS the filling performance of three distinct mold designs at various vibration frequencies (0, 20, 40, 60, and 80 kHz) was captured using fluid, transient CFD models. By incorporating the impacts of ultrasonic vibration into an equation, the approach makes it possible to analyze temperature contours, fluid stability, and flow length. Insight into the ideal vibration settings and mold design for improved fluidity and decreased casting errors may be gained by post-processing the findings to compare various frequencies and designs.

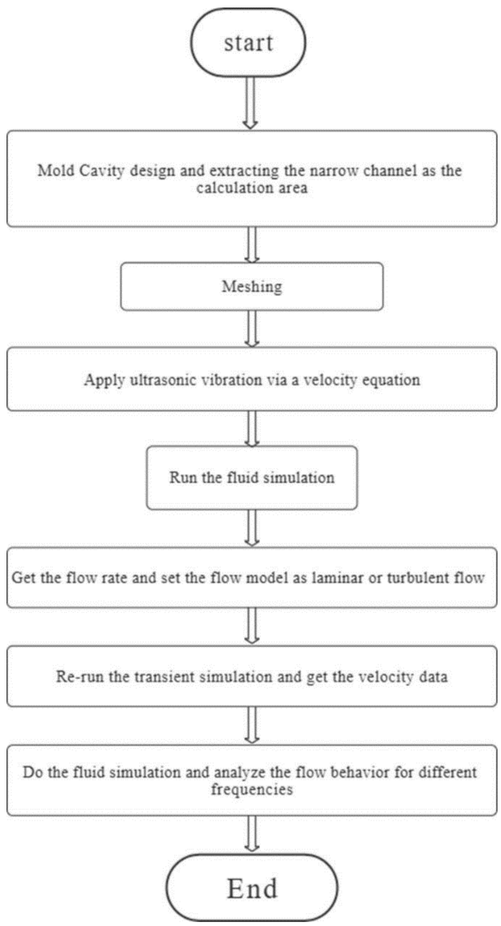


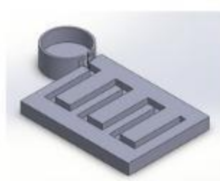
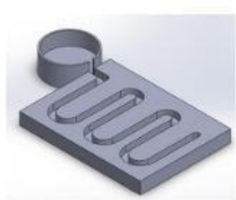
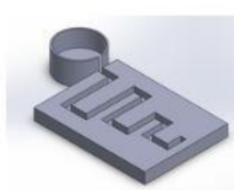
Figure 6: Computational Process for Simulation

3.1: Geometry Preparation

A geometric model of the casting setup was created using CAD software in order to precisely depict the mold and the molten metal flow domain for numerical simulation. The model was created using ANSYS software, incorporating all the critical features that influence metal flow, solidification. To guarantee integrity with the physical casting process, key dimensions were based on experimental standards. In order to minimize computing complexity without compromising the overall flow behavior, simplifications were used, such as ignoring tiny fillets and surface defects. This geometric model offers a solid foundation for meshing and further simulations under different ultrasonic vibration settings, allowing for a thorough examination of mold filling and molten metal fluidity.

Initially, CAD software was used to construct the three distinct mold cavities in this study. By combining three different channel configurations, these designs allow for an organized investigation of how changes in channel geometry affect the molten metal's overall fluidity and flow length during the casting process

Table 2: Three mold cavities

Design	CAD Model
Design-1	
Design-2	
Design-3	

3.2: Numerical Simulation

ANSYS Fluent was selected for the numerical simulation of the casting process because of its sophisticated solidification, heat transfer, and fluid flow modeling features. In order to evaluate fluidity and mold filling, it precisely forecasts the behavior of molten metals, including temperature-dependent viscosity, turbulence, and velocity distribution. Additionally, Fluent offers extensive post-processing capabilities to examine flow patterns and solidifying behavior, and it facilitates the use of user-defined functions (UDFs) to add certain process characteristics, including ultrasonic vibration. It is the perfect option for reproducing intricate casting processes because of its accuracy, flexibility, and validation in both academic and industry investigations.

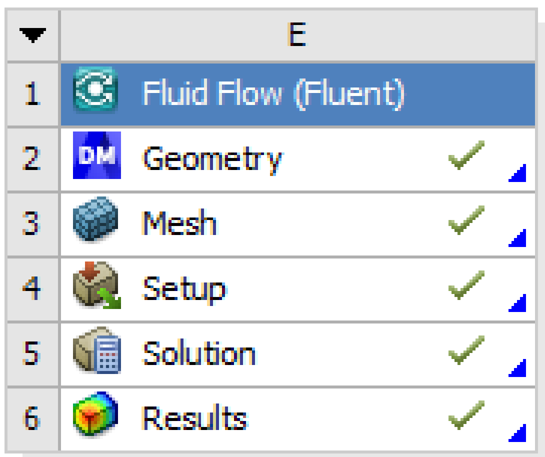


Figure 7: Ansys Fluent module

The simulation procedure was started by first importing the created model into ANSYS Workbench's Geometry module. The casting system's geometrical elements were meticulously developed and improved in this setting to ensure an exact replica of the real domain. Since the narrow channel section is crucial in controlling the flow behavior of molten metal during the casting process, special attention was paid to it. This part was created especially to support a thorough computational fluid dynamics (CFD) analysis, allowing for accurate modeling and analysis of molten-metal flow properties including filling layouts, swirling, and velocity distribution inside the mold cavity.

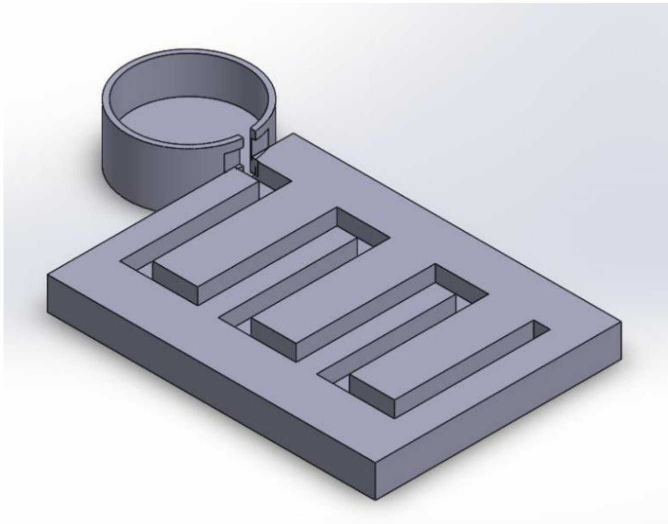


Figure 8: Mold cavity for design 1

3.2.1: Mesh Generation

A form of linear mesh was implemented during the meshing step. The selection of linear meshes over higher-order or more sophisticated meshes was based on their computational efficiency, simplicity, and speed of production, which made them ideal for large-scale simulations. Even though linear meshes are simple, they can produce precise and dependable results, especially in areas with less complex geometries or mild curvature. With over 59,000 nodes and over 57,000 elements, the mesh produced for this investigation has enough detail to capture the flow behavior of molten metal inside the casting domain. Additionally, mesh quality criteria, such as element quality and skewness, were kept within reasonable bounds. This reduced separation errors, guaranteed numerical stability, and offered a strong basis for obtaining accurate and reliable simulation results.

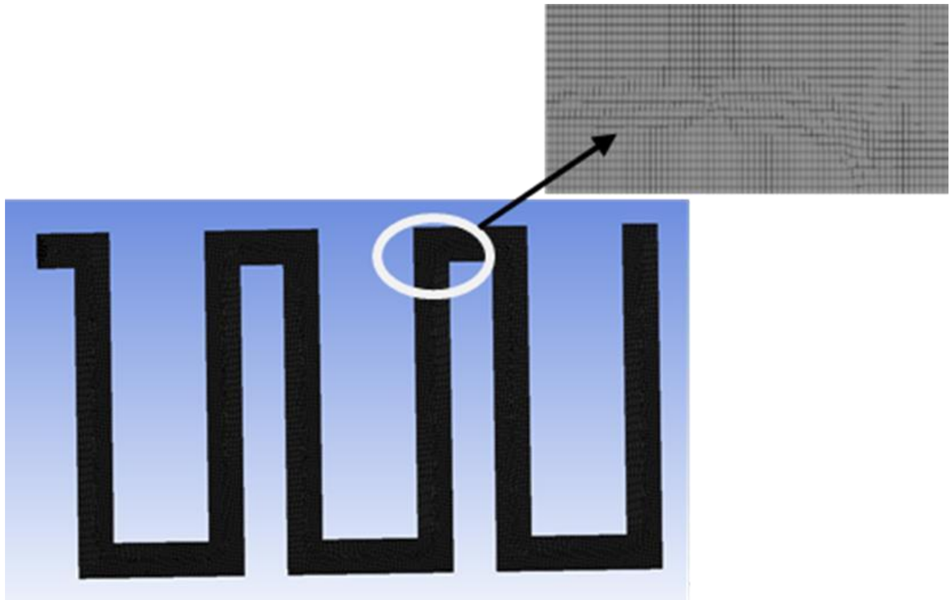


Figure 9: Generated Mesh in the fluid channel

3.2.2: Fluent Setup

To build up the solution, the narrow channel geometry was loaded into ANSYS Fluent. The multiphase flow model was enabled in the model section to take into consideration the molten metal and ambient air that were present in the mold cavity at the same time. This stage was crucial because, in real-world casting processes, the molten metal interacts with two phases that are indistinguishable by dissolving air as it passes through the mold. The Volume of Fluid (VOF) method was used to record this phenomenon. The application can trace the progress of the molten metal front while keeping an eye on air displacement and possible trapping because of the VOF model's exceptional ability to track and resolve the interface between liquid and gaseous phases. The simulation environment was able to accurately mimic actual casting circumstances by enabling this multiphase representation, guaranteeing that the anticipated flow patterns, mold filling properties, and possible fault forms matched actual observations.

The VOF model was chosen due to its ability to precisely follow the molten metal's free surface during mold filling. Other models, such the Mixture or Eulerian techniques, are less useful in this case and better suited for other kinds of multiple phase flows. The VOF model offers a more accurate and realistic forecast of flow behavior and possible defect generation since cavitation filling and liquid metal flow must be accurately represented in casting operations.

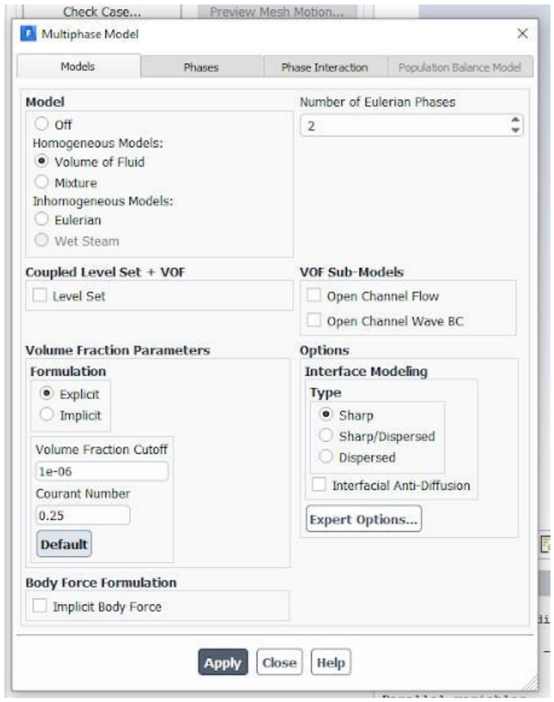


Figure 10: Multiphase Model Selection

Since the pressure-based solver is well suited for incompressible and moderately compressible flows, like those seen in casting operations, it was chosen for the numerical solution. For the pressure–velocity coupling, the Pressure-Implicit with Splitting of Operators (PISO) method was used. This technique was selected because it offers improved computing efficiency and accuracy for transient flow issues, which makes it especially useful for capturing the molten metal's erratic mold-filling behavior. In order to take into consideration the crucial part that heat transmission plays in the casting process, the energy equation was also enabled. ANSYS Fluent was able to solve for the temperature distribution throughout the computational domain by enabling the energy equation, which is crucial for comprehending the system's thermal behavior. The model took into account the effects of convection inside the molten metal and the surrounding air, conduction through the mold walls, and latent heat during the molten metal's phase shift. The simulation may successfully simulate the thermal conditions of real casting processes by including these heat transfer mechanisms, offering a realistic forecast of solidification patterns, cooling rates, and overall casting quality.

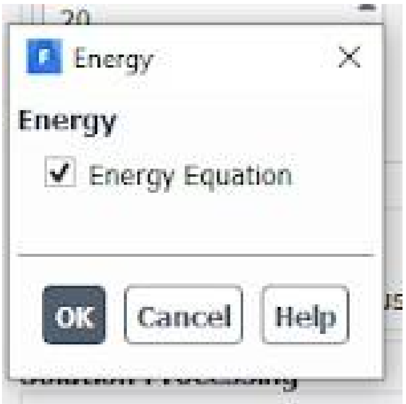


Figure 11: Energy Equation Enabled for Thermal Analysis

The flow regime was considered laminar as the molten metal flows within the mold and small channel in a generally smooth and organized way, represented by low Reynolds numbers. Thus, in ANSYS Fluent, the viscosity model was adjusted to laminar. For casting operations involving molten metals, where viscous forces often predominate over turbulent variations, this assumption is valid. Laminar flow modeling allows the simulation to better represent the pressure gradients, flow front advancement, and velocity distribution inside the mold without adding needless computing complexity that comes with turbulence modeling. This method indicates that the fluid behavior and anticipated mold-filling patterns remain to be aligned with the physical properties of low Reynolds number metal flow in constrained geometries.

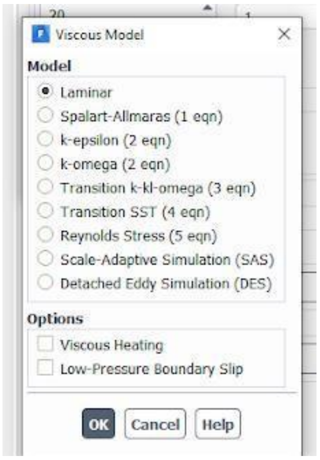


Figure 12: Viscous Model Setup

To take into consideration the phase shift of the molten metal inside the mold, the simulation's solidification/melting model was turned on. The final characteristics of the cast component, such as its microstructure, dimensional correctness, and defect susceptibility, are greatly influenced by the phase transition that occurs when the molten metal gradually cools and solidifies throughout the casting process. The simulation would merely monitor the distribution of temperatures and fluid flow without the solidification/melting model, ignoring the crucial impacts of latent heat release and the development of the solid-liquid interface. This model allows ANSYS Fluent to accurately forecast solidification patterns, cooling rates, and possible trouble spots like incomplete filling, cold shuts, or porosity formation by capturing the associated thermal and phase-change events. This guarantees that the simulation offers a thorough depiction of the casting procedure, faithfully capturing the fluid dynamics and temperature development that control casting quality.

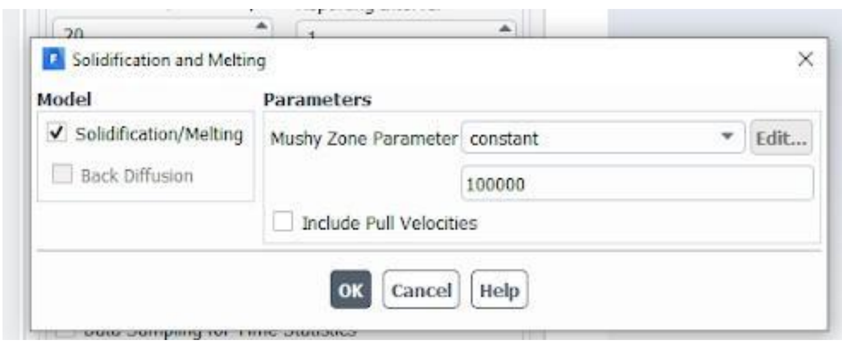


Figure 13: Solidification and Melting Model Enabled

The material details of the molten metal were accurately described within ANSYS Fluent in order to precisely measure its temperature and flow behavior during the casting process. Density, specific heat capacity, thermal conductivity, and dynamic viscosity were among these characteristics; each is crucial for resolving the simulation's fluid and thermal dynamics. In order to ensure that the expected mold-filling dynamics and thermal development closely resemble actual casting circumstances, the simulation was able to accurately represent the heat transfer, solidification behavior, and flow patterns of the molten metal by giving exact material properties.

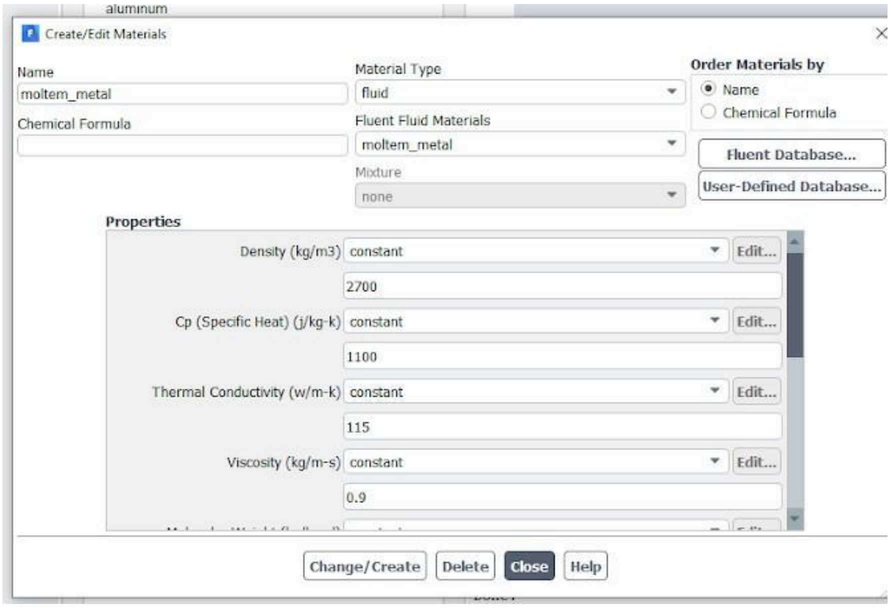


Figure 14: Material Properties Setup in Ansys Fluent

Table 3: Material Properties

Properties	**Value**
Density	2700 kg/m3
Viscosity	0.9 kg/m-s
Specific Heat	1100 j/kg-k
Thermal Conductivity	115 w/m-k
Solidus Temperature	873 k
Liquidus Temperature	973 k
Pure Solvent melting heat	397000

Appropriate boundary conditions were carefully incorporated in the simulation to produce a realistic representation of the physical environment throughout the casting process. The flow inside the computational domain was driven by providing a certain velocity value to the molten metal at the mold or channel's input. Mold-filling behavior, flow front advancement, and possible air entrapment are all strongly impacted by the initial flow rate and velocity of the molten metal as it enters the mold, which is precisely replicated by this boundary condition. Apart from the intake specification, additional boundary conditions were established to closely resemble the thermal and fluidic interactions that take place in the real casting environment. These included temperature or heat flux at the mold walls and, whenever necessary, pressure outlets.

A custom expression was made in ANSYS Fluent to incorporate the influence of ultrasonic vibration in the simulation. This expression was created to capture the dynamic behavior brought forth by ultrasonic stimulation and to represent the oscillatory motion of the mold. The formula contained important variables that together characterized the properties of the applied vibration, including velocity, time, frequency, amplitude, and the mathematical constant π. By setting these parameters, the simulation accurately depicted how ultrasonic vibration affected the flow of molten metal, including its impact on fluidity, filling patterns, and the potential for defect removal. A more thorough examination of the casting process was made possible by the inclusion of this vibration model, which made it possible to investigate how ultrasonic energy alters the flow dynamics, heat transfer, and solidification behavior inside the mold.

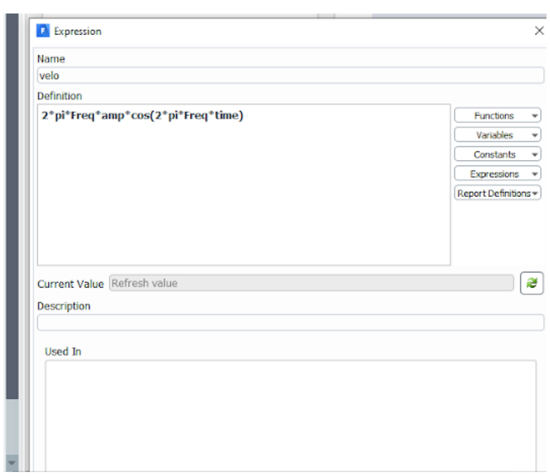


Figure 15: Velocity Defined as an Expression in Fluent

For applying ultrasonic vibration, a mathematical equation (1) was used as an expression, and other parameters were given.

$$v = 2\pi f A\cos(2\pi f t) \quad \text{(Li et al., 2023)} \tag{1}$$

Where f is frequency, t is time, and A is amplitude.

To investigate its impact on flow behavior and mold filling, several frequencies of ultrasonic vibration were directly applied to the molten metal. The molten metal gained more kinetic energy from the forced vibration, which increased its rate of motion and caused the mold cavity to move faster. The simulation time step was carefully chosen based on the vibration period in order to correctly reflect the oscillatory motion and its effect on the metal flow. The simulation accurately replicated the dynamic interplay between ultrasonic vibration and molten metal flow by using a time step that matched the vibration frequency. This assured that the transitory impacts of the oscillatory motion were resolved with enough timing detail.

$$(T) = 1/f \quad \text{(Li et al., 2023)} \tag{2}$$

In the flow model, at first, the laminar flow model was used to simulate, and then the flow rate was obtained from the simulation result. That flow rate was used to determine the Reynolds number. The Reynolds number was calculated using the formula

$$Re = \rho\, v\, d / \mu \quad \text{(Li et al., 2023)} \tag{3}$$

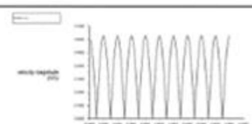
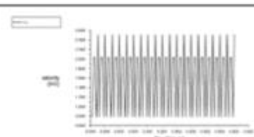
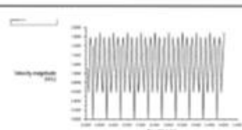
The simulation was run in a laminar flow model, and then the flow rate was calculated from the simulation result. according to the flow rate laminar and k-ϵ turbulence model was used. If the Reynolds number of the fluid exceeded 2300, the k-ϵ turbulence model was used for the simulation. The simulation was performed for 400 time steps and time step size 0.00125 seconds, for a total duration of 0.5 seconds.

Chapter 4: Results and Analysis

The examination of molten metal flow, temperature change, and fluidity under various ultrasonic vibration frequencies across three mold designs is presented in the Results and Discussion section. To comprehend how vibration affects mold filling behavior and solidification patterns, temperature contours, volume fraction plots, and flow length data are analyzed. To find patterns in fluidity augmentation, turbulence generation, and defect avoidance, comparisons are made between no vibration and different vibration frequencies (20, 40, 60, and 80 kHz). Additionally, the part assesses how mold design affects flow length and filling efficiency, emphasizing the ideal vibration frequency and mold configuration combination for better casting quality.

4.1: Application of Ultrasonic Vibration to energize the molten

Table 4: Velocity–Time Analysis at Varying Ultrasonic Frequencies

Frequency	Velocity Profile
20KHz	
40KHz	
60KHz	
80KHz	

Compared to a foundation situation without vibration, ultrasonic vibration was given at four distinct frequencies: 20 kHz, 40 kHz, 60 kHz, and 80 kHz. In order to guarantee that the provided excitation had an immediate impact on the entering flow of molten metal, the ultrasonic wave was aimed at the mold intake during the pouring stage. The speed reaction of the molten metal was monitored and captured for a brief inspection time in order to estimate the impact. Patterns that show how frequency affects flow dynamics have been created using these velocity–time values.

There are obvious differences among vibrated and non-vibrated circumstances in the velocity–time plots. The total amount of oscillation cycles per unit of time grows proportionately with an increase in ultrasonic frequency. For instance, the molten metal exhibits comparatively sluggish cycles at 20 kHz, with a peak velocity of around 0.65 m/s and roughly 6–7 waveform cycles in the measured time span. On the other hand, the oscillation cycles rise to around 18–20 at 60 kHz, and the highest speed approaches 1.9 m/s.

The velocity waveform exhibits weaker and greater oscillations at 20 kHz, indicating that the hot metal absorbs comparatively less energy from its surroundings. In this instance, the simultaneous impacts of surface tension and thickness cannot be completely counteracted by the transmission of energy, which leads to short flow lengths within the mold cavity. In contrast, the waveform gets significantly thicker and straighter at 60 kHz, with notably greater maximum values. This suggests that energy transmission to the liquid metal is more consistent and regular, therefore enhancing fluidity.

The impact is greatly enhanced around 80 kHz. With stronger cycles and less time across subsequent peaks, the velocity–time graph displays the highest peak velocities. As a result, the molten metal receives a far greater energy input in a much shorter amount of time, greatly increasing its capacity for surpassing flow resistance. In comparison with reduced frequency circumstances, this leads to improved fluidity, larger flow pathways, and further thorough mold filling.

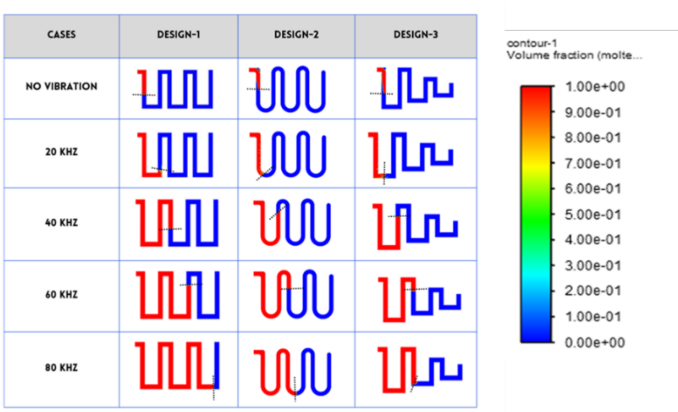
The examination of several frequencies reveals a robust, favorable correlation among inlet velocity and ultrasonic vibration frequency. Increased power transmission via an ultrasonic source to the molten metal occurs at increasing frequencies. The two main obstacles to flow while casting—surface tension and viscous resistance—are both lessened by this extra energy. The increased filling ability of hot metal during higher-frequency ultrasound circumstances is thus evident in both peak velocity and total flow length.

There are two main reasons for the increased fluidity seen between 60 kHz and 80 kHz. First, specific shock waves are produced by ultrasonic cavitation, which is brought on by the creation and dissolution of small air bubbles. The resulting waves provide the liquid metal with further energy for motion. Second, a more uniform velocity distribution is produced by sound streaming brought on by high-frequency vibrations, which lessens stagnation zones and facilitates the melt's seamless transit. By preventing early solidification and enhancing mold filling efficiency, each of these actions guarantees that the molten metal retains speed across greater lengths.

According to these results, ultrasonic vibration, especially at high frequencies, may be a useful technique for enhancing the casting of metals like aluminum alloys when fluidity is a constraint. The enhancement is only slight at 20 kHz vibration because the waves are too gradual to impart much momentum. The advantages increase significantly at 60 kHz and higher, as improved fluidity results in larger paths of flow and more dependable filling of complex structures. Although efficiency continued to increase throughout the measured range up to 80 kHz, findings also suggest that there might be an ideal limit to frequencies, as too high frequencies run the risk of causing energy losses through heat or severe cavitation.

4.2: Simulation Contour Plots of Three Different Designs:

Table 5: Fluid length across different channels and ultrasonic frequencies



The flow lengths attained by every design during ultrasonic vibration with frequency from 20 kHz to 80 kHz and without vibration were contrasted in the table.

Out of the three designs, Design 1 has the longest fluid length due to the angular zigzag pattern and comparatively lengthy channel length. With the impact of ultrasonic vibration, the hot metal managed to move substantially longer in this shape during its lengthy journey. Because of the abrupt twists in the design, the fluid length for the no-vibration scenario measured just 130 mm, indicating severe obstacle to flow and restricted filling ability. Yet, the flow length is much enhanced with the use of ultrasonic vibration and a rise in frequency. The fluid length of the molten metal at 80 kHz was 1215 mm, which is almost an order of magnitude longer than the no-vibration condition. The energy shift that ultrasonic treatment provides explains this remarkable development. The warm metal penetrates the chamber with increased kinetic energy when vibration is added during the pouring step. Even when there are several steep twists, the pace of travel is maintained by the regular energetic bursts that ultrasonic waves transmit. This enables the metal to fill lengthier portions of the mold by reducing early solidification and delaying energy loss.

Although the path length of Design 2 was less than that of Design 1, the fluid flow pattern was less advantageous. The molten metal barely moved around 120 mm without losing momentum in the no-vibration scenario. The fluid length did increase with higher vibration frequencies, reaching 666 mm at 80 kHz, but it was still far less than the figures seen in Design 1. The sinusoidal shape's turning barrier is the primary cause of this restriction. Because of the numerous variations in the flow path caused by the constant smooth twists, the molten metal rapidly loses kinetic energy. The breakdown of energy is too great to maintain flow throughout the whole channel, even with ultrasound aid, which improves momentum transmission. Therefore, even in the presence of ideal vibrating circumstances, geometry limits fluidity.

In order to investigate the impact of wider bends on fluidity, Design 3 was built. The fluid distance in the no-vibration case was 155 mm, which was somewhat longer than Design 2, yet rather constrained. The fluid length increased as vibration frequencies increased, reaching 666 mm at 80 kHz, which is comparable to Design 2. Nevertheless, Design 3's broad bends resulted in substantial distinction of flows and vortex generation, in contrast to Design 1's acute zigzag. Instead of propelling forward velocity, some of the liquid metal's kinetic energy was lost in recurrent regions as it approached each large curve. Volatility and energy loss were encouraged, which limited the total flow length. Full mold filling was prevented by geometry-caused obstruction, even if ultrasonic vibration added velocity.

The contrast of all three designs makes it abundantly evident how channel shape and vibration frequency work together to determine the fluidity of molten metal. Due to design limitations, Designs 2 and 3 trailed farther back, whereas Design 1 performed best at higher frequencies and achieved full mold filling with its lengthy route.

The greatest effectiveness was attained by Design 1, which transferred ultrasonic energy into forward momentum efficiently, achieving 1215 mm at 80 kHz. In design 2, kinetic energy loss from constant rotation limited flow; it achieved only 666 mm at 80 kHz. And design 3, likewise restricted to 666 mm at 80 kHz, instability and swirl generation resulted in a considerable loss of momentum.

These findings show that while ultrasonic vibration can significantly improve fluidity, geometry has a significant impact on how successful it is. Specifically, designs that provide significant twisting reluctance or swirling flow restrict the amount of fluid length improvements, whereas designs that encourage forward-directed momentum gain most from ultrasonic activation.

The results show that when trying to increase fluidity in casting operations, channel shape optimization is just as crucial as vibration frequency adjustment. Higher ultrasonic frequencies provide the molten metal with more kinetic energy, but these advantages might be countered by suboptimal geometry that causes fast energy loss. Thus, to optimize fluid length and guarantee full mold filling, a combination approach including the use of ultrasonic vibration and the development of flow channels that have low twisting reluctance and decreased vortex generation can be employed. This has important ramifications for casting parts with complex designs, as it might be difficult to achieve full mold filling.

All designs benefit from ultrasonic vibration in terms of fluidity, albeit the extent of the enhancement varies greatly depending on the shape. At 80 kHz, Design 1 showed the maximum fluid length of 1215 mm, whereas Designs 2 and 3 could only reach 666 mm. These results demonstrate that mold shape continues to be a major determinant of fluidity, even when ultrasonic vibration improves the flow characteristics of the hot metal.

4.3: Numerical Comparison of flow length for three different channels

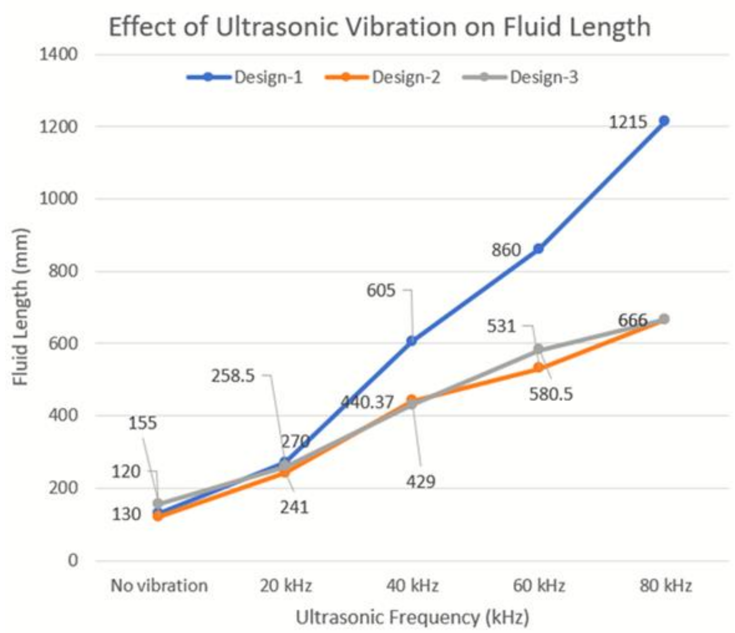


Figure 16**:** Comparison of flow length for 3 mold designs

A numerical comparison of the flow length has been provided in this figure. The general pattern for all three designs indicates that as the ultrasonic vibration frequency rises, the flow length steadily rises. This demonstrates that by providing greater kinetic energy, encouraging more even flow, and lowering barriers to solidifying, ultrasonic vibration considerably improves the fluidity of molten metal.

Three primary processes—cavitation, acoustical streaming, and decreased solidification resistance—are responsible for the increases in flow length brought about by ultrasonic vibration.

- Cavitation: confined impact waves are created when gas due to cavitation inside the molten metal develops and bursts. The liquid metal may move effortlessly and farther in the mold cavity thanks to those shockwaves, which temporarily reduce its actual stiffness.

- Acoustic Streaming: Constant flow streams produced by the Ultrasonic vibration's oscillating waves of force aid in uniformizing the melting substance's speed dispersion. This encourages constant, consistent progressive motion of the metal and reduces standstill regions.
- Decrease in Solidification Resistance: Ultrasonic waves slow down dendritic development and lower the barrier to heat at the approaching solidifying edge. Because of this, the molten metal may fill larger channel distances without solidifying since it stays in its gaseous form longer.

The substantial beneficial relation between transmitted ultrasonic frequency and flow length shown in all three mold geometries may be explained by these processes taken together.

Comparing the three designs provides crucial information on how channel shape and ultrasonic vibration interact to affect the flow of molten metal:

Design 1: The design with the greatest exposure to ultrasonic vibration, which showed an increase in flow length from 150 mm to 1215 mm across the frequency range. The extra speed with Ultrasonic Vibration was especially useful for the tight corners.

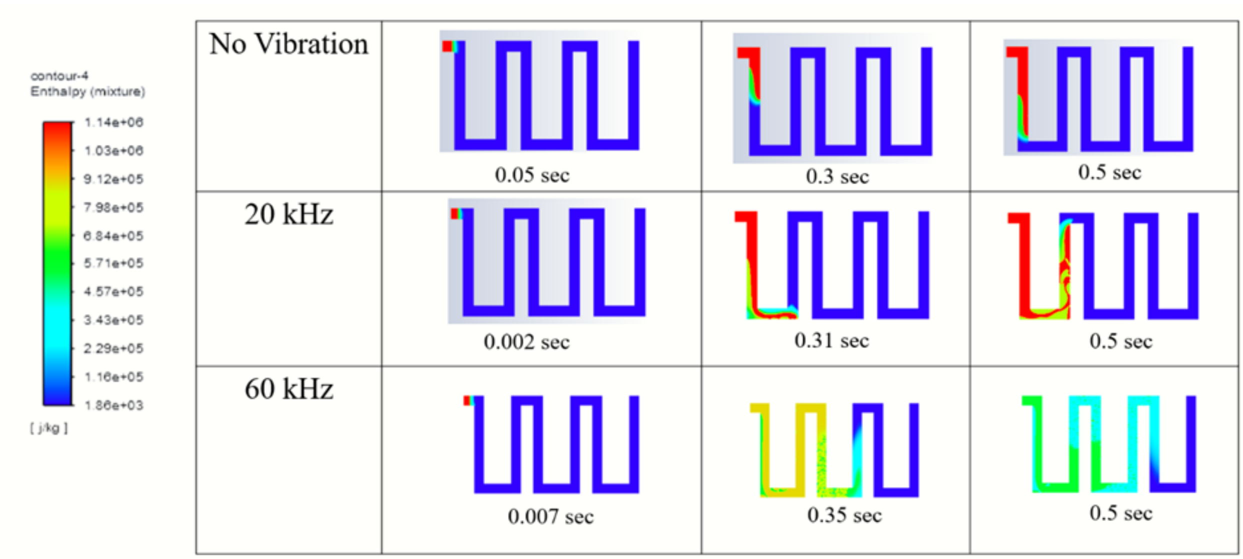
Design 2: The flow length increased from 140 mm to 666 mm, but additional progress was limited by the substantial energy loss produced by the constant curve.

Design 3: Although the flow length rose from 155 mm to 666 mm, the efficient fluid transport was limited by the turbulence and vortex production caused by the large bends.

4.4: Temperature Distribution Analysis

Temperature contour plots were studied for molten aluminum across three separate vibration circumstances: no vibration (0 kHz), moderate vibration (20 kHz), and high-frequency vibration (60 kHz) in order to gain a clearer understanding of the function of ultrasonic vibration in the mold-filling procedure. The aforementioned contour diagrams give light on the rate of temperature dissipation, the distribution of heat across the mold chamber while filling, and the progression of the solidifying phase as time passes. The relationship among vibration frequency, fluid flow, and thermal stability is shown through these contour plots because foundry success is highly reliant on preserving a good temperature differential and avoiding early solidification.

Table 6: Temperature contour plots at different time steps for Design-1



This comparison table is provided for Design-1.

Case 1: No Vibration

Just a tiny, isolated red zone (an elevated heat) was visible at the chamber's entry at 0.02 seconds. This implies that the molten aluminum gathered close to the pouring gate and had not moved very far into the hollow. A delayed early filling procedure was suggested by the restricted heat penetration.

The temperature contours showed the beginning of solidification at 0.3 seconds, when clear yellow-to-green areas appeared in the flow route. The liquid edge was clearly moving ahead, but the pace of filling was far slower than the pace of heat loss.

While more hot metal was entering the hole at 0.5 seconds, sizable portions of the red zone were beginning to solidify. The temperature dispersion of the hollow was not even, with hot metal near the entry and colder, partially solidified areas downstream. In increasingly complicated geometries, this implies a slow filling pattern, a greater likelihood of cold closes, and partial fills.

The majority of the cavities showed a quick change from red to green during the first few hundred milliseconds, indicating that the heat penetration duration was statistically restricted. This suggests that without vibration, the flow would not be able to sustain enough temperature equilibrium, increasing the likelihood of faults.

According to quantitative estimates, the penetration length increased by 0.3 seconds when compared to the no-vibration condition, indicating that acoustic streaming and ultrasonic-induced cavitation greatly improved the transmission of heat and preserved progress.

Case 2: Moderate Vibration (20 kHz)

Overall flow and temperature constancy significantly improved with the use of 20 kHz ultrasonic vibration. A sizable red zone was seen close to the entry at 0.002 seconds, suggesting a far higher initial heat intake than in the no-vibration scenario. This initial distribution of heat demonstrated that molten aluminum flowed more quickly and evenly in the cavity thanks to ultrasonic radiation.

The contour plots showed that, compared to the no-vibration scenario, the molten metal had entered the hole far more deeply by 0.31 seconds. Despite slower changes from red to yellow and green, the temperature dispersion was more even. This implies that the molten metal held onto its heat for prolonged periods of time, postponing the onset of solidification. Improved continuity in laminar flow is indicated by the lack of sudden temperature dips.

The interior cavity filling seemed far more consistent at 0.5 seconds, with a balanced distribution of temperature zones across the mold. The molten core remained red or orange, indicating continuous fluidity, but certain surrounding areas started to take on green outlines (the beginning of solidification). This suggests that the best balance between heat retention, smooth flow, and a lower likelihood of flaws such as partial filling or porosity is offered by 20 kHz vibration.

Case 3: High-Frequency Vibration (60 kHz)

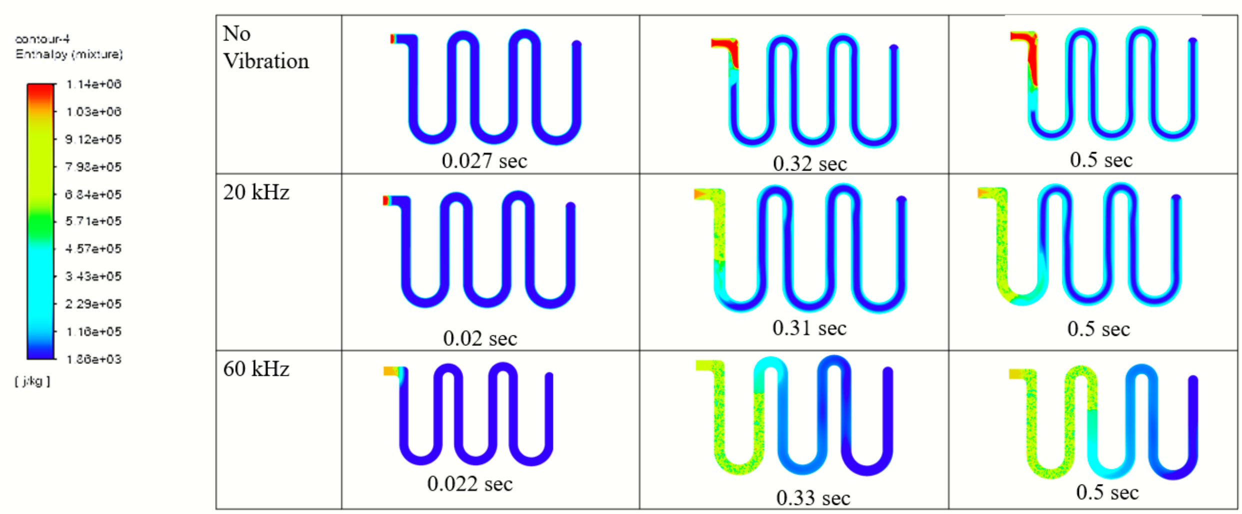
The hot metal entrance is extremely quick at 0.022 s, and the intake contains an elevated level of red. Molten metal moves swiftly along the straight tube by 0.35 s, yet the temperature contour exhibits abrupt changes to blue and green, indicating fast cooling. While the cavity is not fully filled at 0.5 s, the majority of the filled areas are already green-blue in color, suggesting early solidification and substantial heat loss. This suggests that although high-frequency vibration speeds up filling, it can additionally diminish thermal resistance and raise the possibility of flaws like permeability or contraction because of turbulent and quick heat loss.

Because the straight channel creates less flow resistance than more complicated geometries, all instances of Design 1 exhibit comparatively better filling. Nonetheless, vibration has a significant impact on filling quality:

- In the no Vibration case, cooling is noticeable at the tailing edge of the fluid length, but filling proceeds gradually.
- The ideal balance is provided by 20 kHz vibration, which guarantees an even spread of temperatures, continuous fluidity, and full cavity filling.
- The quickest filling is achieved with 60 kHz vibration, although instabilities and faster cooling are the trade-offs.

Therefore, medium vibration (20 kHz) works best even in Design 1 since it enhances flow and heat preservation while not creating undue turbulence.

Table 7: Temperature contour plots at different time steps for Design-2



This Table demonstrates the temperature distribution for Design-2.

It offers a thorough comprehension of the behavior of molten aluminum during mold filling under various ultrasonic vibration settings (0 kHz, 20 kHz, and 60 kHz). The contour's colors show the hot metal's thermal state at various filling phases and correspond to energy variation that is closely correlated with temperature.

Case 1: No Vibration

When there is no vibration, the molten metal flows slowly and solidifies quickly. The recently injected hot liquid metal is represented by a small red area close to the entrance during the first phase (~0.027 s). Nevertheless, the development of yellow and green patches further down the channel indicates a large drop in thermal energy as the flow continues (~0.32 s). Most of the cavity is characterized by green to blue hues at the finish of the filling time (0.5 s), which indicates substantial solidifying. This suggests that the molten metal rapidly loses its fluidity in a sinusoidal channel in the absence of any outside stimulation, resulting in an imperfect or partial filling process.

Case 2: 20 kHz

A noticeable increase in fluidity and heat retention is seen when exposed to a moderate frequency vibration of 20 kHz. The molten front extends farther in the early stage (~0.02 s) than in the no-vibration condition, indicating that vibration aids in the melt's ability to get past the sinusoidal bending impedance. The cavity fills more evenly by ~0.31 s, and the orange and red areas spread farther into the channel. This shows a smoother temperature difference and slower solidification, which makes the filling procedure relatively stable. A sizable section of the cavity stays in the yellow-orange region even after 0.5 s, demonstrating that vibration slows down the temperature reduction in addition to accelerating the filling. This equilibrium improves fluidity and lowers the risk of misruns and cold shuts.

Case 3: 60 kHz

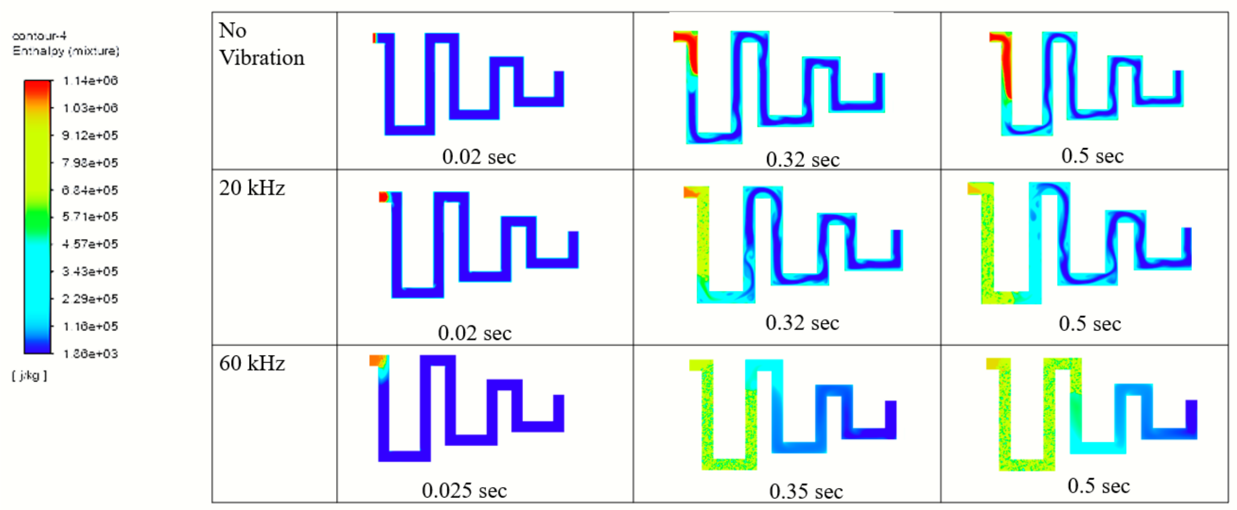
The liquid aluminum first shows quick entry into the channel at elevated vibration frequencies (60 kHz). The molten entrance zone is highly electrified at ~0.022 s, and the melt front moves swiftly forward. But even if the fluid length further enhances by ~0.33 s, the contours show a sharp change from red to green zones, suggesting that the melt begins to lose heat more quickly. Most of the cavity had been in the green to blue range at the last step (0.5 s), suggesting fast solidification. This implies that although greater frequencies improve the velocity of the early flow, they may also cause more turbulence and accelerate the loss of energy. Therefore, although quicker filling, the 60 kHz case is susceptible to flaws like cold shuts, porosity, or shrinkage cavities because of rapid cooling.

The following conclusions can be drawn from the comparison analysis:

- Poor penetration and early solidification are the outcomes of no vibration case.
- The best results are obtained at a frequency of 20 kHz, where filling is greater and more thermally resistant while retaining fluidity.
- Despite having the quickest filling rate, 60 kHz sacrifices thermal equilibrium, resulting in too much cooling and less fluidity altogether.

Therefore, 20 kHz ultrasonic vibration frequency seems to be the best option for a Design-2, guaranteeing adequate filling length and preventing too much heat loss. This lends credence to the theory that ultrasonic vibration improves the fluidity of molten metal; however, only inside a certain frequency range; extremely high frequencies might negate the advantages by encouraging quick cooling.

Table 8: Temperature contour plots at different time steps for Design-3



The table displays the temperature (enthalpy) contour plots for Design 3 at three different vibrational frequencies: no vibration, 20 kHz, and 60 kHz. These outlines show the flow pattern, temperature propagation, and solidifying properties of molten aluminum as it moves across the mold channel and the effects of ultrasonic vibration as time goes by. The color legend goes from blue (low enthalpy, cooled/solidified metal) to red (high temperature, heated liquid metal).

Case 1: No Vibration

The molten metal first enters the channel at its earliest stage (0.02 s), creating a little red area close to the intake, but the cavity is left empty. The hot metal continues to move forward by 0.32 s, but notable yellow-green areas show ahead of the way, suggesting premature cooling and partial solidification. The metal flow is obviously irregular at 0.5 s; a large portion of the cavity has already become green-blue, indicating thermal loss and solidification, while some small red zones remain close to the inlet as a result of constant influx. This illustrates how the design 2 limits flow in the absence of vibration, resulting in slow filling and early solidification, which increases the likelihood of inadequate filling and defect development.

Case 2: 20 kHz

The flow pattern of molten metal is much improved when vibrated at 20 kHz. In comparison to the no-vibration example, the entry area shows a wider red zone at 0.02 s, indicating improved transfer of energy and early penetration. By 0.32 s, the liquid aluminum flows further into the chamber, and the form reveals a larger appearance of yellow-orange areas, signifying improved fluidity and delayed cooling. A straighter trend from red to green is shown at 0.5 s, indicating that the cavity is getting filled more evenly with smaller, sudden temperature changes. This implies that even in a complicated shape, 20 kHz vibration supports seamless filling by promoting steady flow, lowering the possibility of early solidification, and maintaining fluidity throughout the cavity.

Case 3: 60 kHz

Vibrating molten metal at 20 kHz significantly improves its flow pattern. The entrance region displays a bigger red zone at 0.02 sec compared to the no-vibration sample, suggesting better energy transmission and early penetration. By 0.32 seconds, the shape shows a greater presence of yellow-orange regions, and the liquid aluminum flows deeper into the cavity, indicating more fluidity and postponed cooling. With less abrupt temperature fluctuations, the cavity is filling more uniformly, as seen by a straighter trend from red to green at 0.5 s. This suggests that by encouraging constant flow, reducing the likelihood of early solidification, and preserving fluidity throughout the cavity, 20 kHz vibration allows smooth filling even in complex shapes.

It is clear from the aforementioned observations that:

- No vibration: Early solidification and gradual, irregular filling.
- 20 kHz vibration: The most regulated state is vibration, which maintains the appropriate temperature, encourages even flow, and guarantees steady cavity filling.
- 60 kHz Vibration: Quick entry that also causes volatility and quick cooling, which raises the possibility of casting flaws.

Thus, out of all the examples that were examined, Design 3 benefits greatest from 20 kHz ultrasonic vibration, which guarantees better molten metal fluidity and lowers the possibility of partial filling in the path. This outcome further supports the conclusion drawn from earlier designs that while extremely high vibration frequencies might cause unstable conditions, mild ultrasonic vibration maximizes flow and heat preservation.

4.4.1: Comparative discussion on thermal analysis on Design 1, Design 2, and Design 3

The outcomes of the three mold designs (Design 1, Design 2, and Design 3) show how shape impacts the filling behavior, distribution of temperature, and general fluidity of liquid aluminum when combined with ultrasonic vibration.

Case 1: No Vibration

Filling relies heavily on the mold shape when vibration is absent. Although an extremely smooth entry is possible with Design 1, there is a chance of inadequate filling since partial cooling takes place at the exit. The liquid metal in Design 2 experiences extra resistance at every curve, which results in early solidification and uneven variation in temperature. With huge blue-green areas suggesting rapid solidification and premature cooling at the bends, Design 3 shows the slowest flow. Therefore, without vibration, fluidity and filling efficiency are immediately decreased by geometric complexity, with Design 1 outperforming Design 3 in this regard.

Case 2: 20 kHz

Considerable gains are shown in all designs with mild shaking (20 kHz). Vibration encourages more equal entry and postpones solidification in Design 1, guaranteeing almost the whole cavity fills with persistent reddish-orange areas even at later phases. In contrast to no vibration, Design 2's vibration eliminates the obstruction of sinusoidal curves, resulting in gentler variations in temperature and a longer flow of molten metal. Vibration improves diffusion into subsequent turns in Design 3, where flow was otherwise severely constrained. This lessens the influence of green-blue zones and prolongs the fluidity of molten metal. In all designs, 20 kHz produces the most consistent filling performance in general, offering the optimum trade-off amongst decreased casting flaws, retained heat, and penetration.

Case 3: 60 kHz

In all configurations, the molten metal penetrates forcefully and progresses more quickly with a greater vibration frequency (60 kHz). But volatility and faster cooldown are the price for this.

Although the hole fills quickly in Design 1, early green-blue shifts show a considerable loss of heat. In Design 2, whereas penetration is extremely fast, temperature changes occur, resulting in rapid solidification and danger of turbulence-triggered flaws. The greatest impact is shown in Design 3, where the chamber is filled with low-temperature areas that show poor thermal stability due to the molten metal's rapid penetration and excessive cooling at the turns. Therefore, even while 60 kHz increases speed, it also decreases consistency and raises the chance of defects, particularly in molds with intricate geometry.

- Design 1 has fewer obstacles and faster filling by nature. Though less important than in complicated geometry, vibration is nevertheless helpful.
- In design 2, vibration greatly enhances fluidity and guarantees better filling; relatively simple.
- The highest impedance is seen in Design 3, which also benefits greatly from vibration, especially around 20 kHz, which makes steady fill otherwise impractical.

Fluidity is greatly influenced by geometry. Designs 2 and 3 provide obstacles to flow and encourage rapid cooling, whereas straight channels encourage seamless filling. Heat preservation and liquid aluminum penetration are improved by ultrasonic vibration, but only in a specific frequency range. In all configurations, 20 kHz turns out to be the ideal frequency since it balances temperature stability with flow speed. While 60 kHz speeds up filling, it also causes instability and quick cooling, both of which are especially harmful in complicated mold geometries. Therefore, the ideal circumstances for enhancing the fluidity of molten metal and guaranteeing flawless casting are provided by the integration of mold shape and ideal ultrasonic vibration (20 kHz).

4.5: Impact of Laminar and Turbulent Flow in Defect Formation

Based on the applied vibration frequency and the associated flow rate, it was found that the molten metal's flow behavior fluctuated across laminar and turbulent phases throughout the simulation. These flow regimes clearly affected the mold cavity's filling pattern, which in turn affected the product's overall quality and homogeneity.

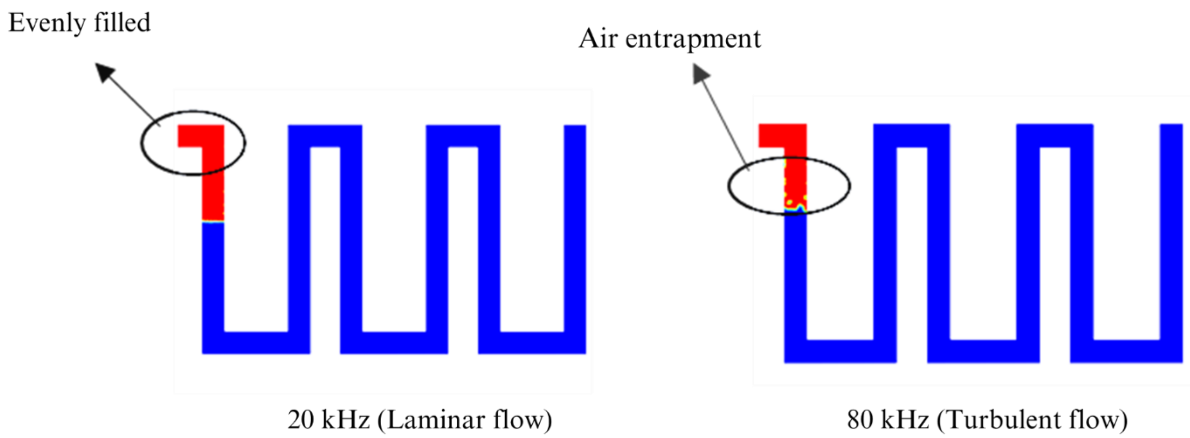


Figure 17: Cavity filling behavior in laminar and turbulent flow

The liquid aluminum exhibited a laminar flow model at 20 kHz and without vibration. The fluid molecules travel in uniform, flawless layers with little interaction when there is laminar flow. Therefore, the molten metal moves gradually into the cavity during a very consistent and regulated filling process. By lowering the possibility caused by turbulence gaps, the smooth flow pattern guarantees that the cavity is filled uniformly with less air entrapment. In casting, this kind of action is quite desired as it helps the final consolidated product have a better surface polish and less permeability.

In contrast, the molten metal displayed an unstable flow phase in the 40 kHz to 80 kHz vibration situations. Eddies, unpredictable rate variations, and uneven fluid motion are characteristics of turbulent flow. In contrast to laminar flow, this results in a less uniform filling process. Volatility causes irregular liquid flow progress and increases the likelihood of air trapping in the cavity during the early stages of mold filling. These holes could first seem like flaws, but when additional molten metal pours into the cavity, the trapped voids progressively disappear because turbulent flow's increased kinetic energy assists in spreading the fluid and filling the empty spaces.

The overall research indicates that laminar flow is more effective for creating defect-free castings, especially throughout the vital filling step. When contrasted to the no-vibration scenario, the 20 kHz vibration scenario produced the best outcomes among the examples under study since it preserved laminar flow while simultaneously increasing the fluidity of molten metal. This frequency provided the best compromise between maintaining continuous filling characteristics and enhancing the molten metal's flexibility.

In conclusion, the findings highlight how crucial it is to regulate flow regimes when filling molds. Improved casting consistency, homogeneous filling, and less air entrapment are guaranteed when laminar flow conditions are maintained. According to the study, applying ultrasonic vibration at 20 kHz produces the optimum effective conditions for uniformly filling the cavity, exceeding both the higher-frequency scenarios when turbulence predominates and the no-vibration scenario.

Chapter 5: Conclusion and Recommendations

5.1 Conclusion:

This research used numerical simulations in ANSYS Fluent to examine how ultrasonic vibration affected the fluidity of molten aluminum throughout the casting process. The main goals were to assess the impact of mold cavity structure on casting quality and examine the ways in which various vibration frequencies affect mold filling, flow behavior, and the spread of temperature. Three mold designs were examined, and simulations were run using ultrasonic frequencies of 20 kHz, 40 kHz, 60 kHz, and 80 kHz without any vibration.

The use of ultrasonic vibration greatly increased the molten aluminum's fluidity; the success of this technique was highly dependent on the vibration frequency and mold design. In order to achieve homogeneous mold filling with no significant turbulence, moderate frequencies—in particular, 20 kHz—improved flow length, maintained a smooth temperature gradient, and encouraged laminar flow. On the other hand, extremely high frequencies, like 80 kHz, enhanced heat loss, created turbulence, and resulted in air trapping, porosity, and possible surface flaws while also increasing flow velocity. Consequently, choosing the right vibration frequency is essential to striking a proper balance between improved flow and reduced flaws.

- **Design 1:** Several vibration frequencies showed that this design had the longest flow length. A steady, laminar flow with little flaw generation was shown by the heat distribution's progressive solidification, demonstrated as red to yellow/green to blue, at 20 kHz. Fast cooling at higher frequencies (≥60 kHz) resulted in turbulence, uneven temperature gradients, and possible porosity; nonetheless, the design still showed the least number of dead zones and the most consistent mold filling.
- **Design 2:** Compared to Design 1, this design has a somewhat shorter flow length. At higher frequencies, variation in temperature remained a little more irregular, which led to isolated early solidification. Fluidity was enhanced by moderate ultrasonic frequencies, although significant turbulence and possible flaws were brought on by higher frequencies. The presence of small dead zones demonstrated how geometric constraints might impact flow efficiency.

- **Design 3:** Because of the geometric constraints, this design exhibits the lowest flow length and the most flow stagnation, making it the least efficient. Even under modest vibration, temperature contours showed partial penetration of molten metal, with early solidification in a number of areas. High frequencies decreased the efficacy of ultrasonic vibration by causing turbulence, fast cooling, and an increased chance of defects. As a result, Design-3 had the highest likelihood of porosity, air entrapment, and incomplete filling.

All things considered, 20 kHz is the best frequency for improving the fluidity of molten metal and accomplishing regulated mold filling. Surface roughness, microstructural development, and defect analysis of the cast products will offer more useful insights into casting quality, but experimental confirmation is necessary to determine the genuinely best cavity design.

5.2 Recommendations:

Several suggestions may be made in light of the results of the research to improve casting performance and the usefulness of ultrasonic vibration-assisted casting:

- **Experimental validation:** To verify the effects of ultrasonic vibration at various frequencies on the fluidity of molten metal and mold filling, as well as to confirm the numerical simulation findings, field experiments are advised.
- **Extension to Complex Geometry:** Upcoming studies should look at how ultrasonic vibration affects the fluidity of molten metal in more intricate and complex mold geometries, wherein flow behavior is more difficult and defect development is more probable.
- **Alloy and Material Variations:** To comprehend material-specific reactions, future research should examine how various alloys and mold materials are affected by ultrasonic vibration.
- **Industrial applications:** To assess actual viability and scalability, the study's findings should be applied to large-scale casting processes with more intricate designs and bigger molds.

These suggestions serve as a roadmap for further study and practical implementation with the goal of creating superior, flawless castings with enhanced mechanical and mold filling capabilities.

References

6006. (n.d.).

Abdul-Karem, W., Green, N., Al-Raheem, K. F., & Hasan, A. H. A. (2013). Effect of vibration after filling on mechanical reliability in thin wall investment casting with fillability filling regime—Part 1. *The International Journal of Advanced Manufacturing Technology*, *67*(9–12), 2075–2082. https://doi.org/10.1007/s00170-012-4632-z

Akhyar, Husaini, Ali, M., Ali, N., & Ahmad, F. (2020). Effect of Different Gating Systems and Sand Mold Binder on the Cast-Quality of Bicycle Frame Produced through Sand Casting Method. *Defect and Diffusion Forum*, *402*, 100–107. https://doi.org/10.4028/www.scientific.net/DDF.402.100

Al-Mallak, A. A., & Doos, Q. M. (2021). Fluidity of Al-Si Alloy in Metal Mold Casting under Vibration. *IOP Conference Series: Materials Science and Engineering*, *1090*(1), 012081. https://doi.org/10.1088/1757-899X/1090/1/012081

Ammar, H., Samuel, A., & Samuel, F. (2008). Porosity and the fatigue behavior of hypoeutectic and hypereutectic aluminum–silicon casting alloys. *International Journal of Fatigue*, *30*(6), 1024–1035. https://doi.org/10.1016/j.ijfatigue.2007.08.012

Anglani, A., & Pacella, M. (2018). Logistic Regression and Response Surface Design for Statistical Modeling of Investment Casting Process in Metal Foam Production. *Procedia CIRP*, *67*, 504–509. https://doi.org/10.1016/j.procir.2017.12.252

Armillotta, A., Fasoli, S., & Guarinoni, A. (2016). Cold flow defects in zinc die casting: Prevention criteria using simulation and experimental investigations. *The International Journal of Advanced Manufacturing Technology*, *85*(1–4), 605–622. https://doi.org/10.1007/s00170-015-7959-4

Campbell, J. (1995). Review of fluidity concepts in casting. *Cast Metals*, *7*(4), 227–237. https://doi.org/10.1080/09534962.1995.11819183

Chadha, U., Selvaraj, S. K., Pant, H., Arora, A., Shukla, D., Sancheti, I., Chadha, A., Srivastava, D., Khanna, M., Ram Kishore, S., & Paramasivam, V. (2022). Phase Change Materials in Metal Casting Processes: A Critical Review and Future Possibilities. *Advances in Materials Science and Engineering*, *2022*, 1–14. https://doi.org/10.1155/2022/7520308

Chandra Kandpal, B., Johri, N., Kumar, B., Patel, A., Pachouri, P., Alam, M., Talwar, P., Sharma, M. K., & Sharma, S. (2021). Experimental study of foundry defects in aluminium castings for quality improvement of casting. *Materials Today: Proceedings*, *46*, 10702–10706. https://doi.org/10.1016/j.matpr.2021.01.513

Chen, J. C., & Buddaram Brahma, A. R. (2014). Taguchi-Based Six Sigma Defect Reduction of Green Sand Casting Process: An Industrial Case Study. *Journal of Enterprise Transformation*, *4*(2), 172–188. https://doi.org/10.1080/19488289.2013.860415

Chen, W., Wu, S., & Wang, R. (2022). Effect of Mechanical Vibration on the Mechanical Properties and Solidification Feeding in Low-Pressure Sand Casting of Al-Cu-Mn-Ti Alloy. *Materials*, *15*(22), 8243. https://doi.org/10.3390/ma15228243

Chirita, G., Stefanescu, I., Soares, D., & Silva, F. S. (2009). Influence of vibration on the solidification behaviour and tensile properties of an Al–18wt%Si alloy. *Materials & Design*, *30*(5), 1575–1580. https://doi.org/10.1016/j.matdes.2008.07.045

Eslamian, M., & Zabihi, F. (2015). Ultrasonic Substrate Vibration-Assisted Drop Casting (SVADC) for the Fabrication of Photovoltaic Solar Cell Arrays and Thin-Film Devices. *Nanoscale Research Letters*, *10*(1), 462. https://doi.org/10.1186/s11671-015-1168-9

Goenka, M., Nihal, C., Ramanathan, R., Gupta, P., Parashar, A., & Joel, J. (2020). Automobile Parts Casting-Methods and Materials Used: A Review. *Materials Today: Proceedings*, *22*, 2525–2531. https://doi.org/10.1016/j.matpr.2020.03.381

Gomes, I. V., Grilo, J., Carneiro, V. H., & Puga, H. (2023). Impact of the Ultrasonic-Assisted Casting of an AlSi7Mg Alloy on T6 Heat Treatment. *Metals*, *13*(2), 255. https://doi.org/10.3390/met13020255

Goswami, S. S., Jena, S., & Behera, D. K. (2022). Selecting the best AISI steel grades and their proper heat treatment process by integrated entropy-TOPSIS decision making techniques. *Materials Today: Proceedings*, *60*, 1130–1139. https://doi.org/10.1016/j.matpr.2022.02.286

Ha, M., Kim, W.-S., Moon, H.-K., Lee, B.-J., & Lee, S. (2008). Analysis and Prevention of Dent Defects Formed during Strip Casting of Twin-Induced Plasticity Steels. *Metallurgical and Materials Transactions A*, *39*(5), 1087–1098. https://doi.org/10.1007/s11661-008-9496-3

Han, Q., & Zhang, J. (2020). Fluidity of Alloys Under High-Pressure Die Casting Conditions: Flow-Choking Mechanisms. *Metallurgical and Materials Transactions B*, *51*(4), 1795–1804. https://doi.org/10.1007/s11663-020-01858-0

Han, Z., Wang, Z., Sun, Z., Zhang, B., & Rao, W. (2022). Influence of non-uniform ultrasonic vibration on casting fluidity of liquid aluminum alloy. *China Foundry*, *19*(5), 380–386. https://doi.org/10.1007/s41230-022-2039-5

Han, Z., Wang, Z., Sun, Z., Zhang, B., & Rao, W. (2023). Application of ultrasonic vibration to shape-casting based on resonance vibration analysis. *China Foundry*, *20*(4), 339–346. https://doi.org/10.1007/s41230-023-2171-x

Hanumanth, G. S., Scott, D. M., & Smith, T. J. (1989). A numerical study of heat transfer during flow of melt in a cylindrical mould. *Applied Scientific Research*, *46*(4), 323–333. https://doi.org/10.1007/BF01998549

Http://www.tms.org/pubs/journals/JOM/9802/Vives/. (n.d.).

Hua, Q., Gao, D., Zhang, H., Zhang, Y., & Zhai, Q. (2007). Influence of alloy elements and pouring temperature on the fluidity of cast magnesium alloy. *Materials Science and Engineering: A*, *444*(1–2), 69–74. https://doi.org/10.1016/j.msea.2006.08.060

Huang, P.-H., Chen, Y.-T., & Wang, B.-T. (2014). An effective method for separating casting components from the runner system using vibration-induced fatigue damage. *The International Journal of Advanced Manufacturing Technology*, *74*(9–12), 1275–1282. https://doi.org/10.1007/s00170-014-6077-z

Jiang, W., Chen, X., Wang, B., Fan, Z., & Wu, H. (2016). Effects of vibration frequency on microstructure, mechanical properties, and fracture behavior of A356 aluminum alloy obtained by expendable pattern shell casting. *The International Journal of Advanced Manufacturing Technology*, *83*(1–4), 167–175. https://doi.org/10.1007/s00170-015-7586-0

Kumar, D., Kumar, D., Tigga, A. M., & Sagar, D. (2023). Synthesis of Al-B4C Functionally Graded Materials by Sound-Wave-Assisted Vibrational Casting Methodology. *Journal of Materials Engineering and Performance*, *32*(16), 7234–7247. https://doi.org/10.1007/s11665-022-07640-4

Kund, N. K. (2018). Effect of tilted plate vibration on solidification and microstructural and mechanical properties of semisolid cast and heat-treated A356 Al alloy. *The International Journal of Advanced Manufacturing Technology*, *97*(5–8), 1617–1626. https://doi.org/10.1007/s00170-018-2063-1

Li, A., Wang, Z., & Sun, Z. (2023). Effect of Ultrasonic Vibration on Microstructure and Fluidity of Aluminum Alloy. *Materials*, *16*(11), 4110. https://doi.org/10.3390/ma16114110

Liang, G., Shi, C., Zhou, Y., & Mao, D. (2016). Numerical Simulation and Experimental Study of an Ultrasonic Waveguide for Ultrasonic Casting of 35CrMo Steel. *Journal of Iron and Steel Research International*, *23*(8), 772–777. https://doi.org/10.1016/S1006-706X(16)30119-4

Lin, C., Wu, S., Lü, S., An, P., & Wan, L. (2013). Effects of ultrasonic vibration and manganese on microstructure and mechanical properties of hypereutectic Al–Si alloys with 2%Fe. *Intermetallics*, *32*, 176–183. https://doi.org/10.1016/j.intermet.2012.09.001

Murakami, Y., Miwa, K., Kito, M., Honda, T., Kanetake, N., & Tada, S. (2016). Fluidity Evaluation of the AC4CH (A356) Aluminum Alloy Semi-Solid Slurry Made by Mechanical Vibration Method. *MATERIALS TRANSACTIONS*, *57*(2), 168–173. https://doi.org/10.2320/matertrans.F-M2015838

Niu, G., Wang, Y., Zhu, L., Ye, J., & Mao, J. (2022). Fluidity of casting Al–Si series alloys for automotive light-weighting: A systematic review. *Materials Science and Technology*, *38*(13), 902–911. https://doi.org/10.1080/02670836.2022.2068274

Omura, N., Murakami, Y., Li, M., Tamura, T., Miwa, K., Furukawa, H., & Harada, M. (2009). Effects of Mechanical Vibration on Cooling Rate and DAS of AC4C Aluminum Alloy Gravity Die Castings. *MATERIALS TRANSACTIONS*, *50*(11), 2604–2608. https://doi.org/10.2320/matertrans.M2009247

Prukkanon, W., Srisukhumbowornchai, N., & Limmaneevichitr, C. (2009). Influence of Sc modification on the fluidity of an A356 aluminum alloy. *Journal of Alloys and Compounds*, *487*(1–2), 453–457. https://doi.org/10.1016/j.jallcom.2009.07.169

Qui, D. D., Trung, P. Q., & Nguyen, T.-H. (2022). EFFECT OF ULTRASONIC VIBRATION ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF ADC12 ALUMINUM ALLOY BY PERMANENT MOLD CASTING. *ASEAN Engineering Journal*, *12*(3), 49–56. https://doi.org/10.11113/aej.v12.17834

Ravi, B., & Datta, G. L. (n.d.). *Metal Casting: Back to Future*.

Ravi, K. R., Pillai, R. M., Amaranathan, K. R., Pai, B. C., & Chakraborty, M. (2008). Fluidity of aluminum alloys and composites: A review. *Journal of Alloys and Compounds*, *456*(1–2), 201–210. https://doi.org/10.1016/j.jallcom.2007.02.038

Sai, T. V., Vinod, T., & Sowmya, G. (n.d.). *A Critical Review on Casting Types and Defects*.

Shi-jie, G., Qi-chi, L., Zhi-hao, Z., & Jian-zhong, C. (2007). *Microstructure character of AZ80 magnesium alloy ingots cast under electromagnetic vibration*.

Siavashi, K. (n.d.). *The Effect of Casting Parameters on the Fluidity and Porosity of Aluminium Alloys in the Lost Foam Casting Process*.

Suresh, N., & Chandrasekar, P. (2014). Microstructure and Mechanical Properties of Castings under Vibration Techniques—A Review. *Applied Mechanics and Materials*, *550*, 71–80. https://doi.org/10.4028/www.scientific.net/AMM.550.71

Taghavi, F., Saghafian, H., & Kharrazi, Y. H. K. (2009). Study on the effect of prolonged mechanical vibration on the grain refinement and density of A356 aluminum alloy. *Materials & Design*, *30*(5), 1604–1611. https://doi.org/10.1016/j.matdes.2008.07.032

Tawele, P. K., & Raut, L. P. (2015). *Warpage in casting: A Review*. *2*(4).

Teke, Ç. (2022). Determination of flow distance of the fluid metal due to fluidity in ductile iron casting by artificial neural networks approach. *Open Chemistry*, *20*(1), 1019–1028. https://doi.org/10.1515/chem-2022-0210

Timelli, G., & Bonollo, F. (2007). Fluidity of aluminium die castings alloy. *International Journal of Cast Metals Research*, *20*(6), 304–311. https://doi.org/10.1179/136404608X286110

Wu, Q.-J., Yan, H., Zhang, P.-X., Zhu, X.-Q., & Nie, Q. (2018). Enhancing Wear Resistance of A356 Alloy by Adding CNFs Based on Ultrasonic Vibration Casting. *Acta Metallurgica Sinica (English Letters)*, *31*(5), 523–532. https://doi.org/10.1007/s40195-017-0680-6

Xian, X., & Lin, S. (2008). Study on the compound multifrequency ultrasonic transducer in flexural vibration. *Ultrasonics*, *48*(3), 202–208. https://doi.org/10.1016/j.ultras.2007.12.002

Xie, J., Zhou, T., Liu, Y., Kuriyagawa, T., & Wang, X. (2016). Mechanism study on microgroove forming by ultrasonic vibration assisted hot pressing. *Precision Engineering*, *46*, 270–277. https://doi.org/10.1016/j.precisioneng.2016.05.007

Yu, J., Ren, Z., Ren, W., Deng, K., & Zhong, Y. (2009). Effects of electromagnetic vibration on the structure and mechanical properties of Al-6%Si alloy during directional solidification. *Acta Metallurgica Sinica (English Letters)*, *22*(1), 35–39. https://doi.org/10.1016/S1006-7191(08)60068-X

Yuwen, X., Chen, L., & Han, Y. (2012). Numerical Simulation of Casting Filling Process Based on FLUENT. *Energy Procedia*, *17*, 1864–1871. https://doi.org/10.1016/j.egypro.2012.02.324