Chapter 2

Literature Survey

2.1 Introduction

A critical review of cast metals treated with vibration, specifically Al-Si alloys, is presented in this chapter. In this review, we aimed to gather relevant information for the present work that will help our experimental work. It can also benefit from knowing the fundamental ideas of various vibration treatments and their impact on Al-Si alloys' physical, metallurgical, and mechanical characteristics.

2.2 Al-Si alloys and their applications

Castings made of Al-Si alloys are cost-effective for various uses. Al-Si alloy castings were commercially used in various structural components, especially in the automotive and aerospace industries. Due to its many benefits, including its formability, conductivity, resistance to corrosion, strength-to-weight ratio, and lower density. Numerous other applications include mechanical devices, house appliances, cooking utensils, covers for storage devices, and housings for electronic equipment. These are some typical applications of hypoeutectic Al-Si alloys such as A356 and A319 [1].

2.2.1 Application of A308 alloys

In the present investigation, A308 aluminium alloy has been taken as an experimental alloy due to its availability, excellent castability and extensive application in structural components. Appropriately, these alloys are preferred to make engine parts, engine blocks and cylinder heads, gearboxes, crankcases, oil pans, fuel & oil tanks, pipe fittings, and aviation parts [4].

2.3 Metallurgy of cast Al-Si alloys

The die-casting process uses metal alloys, mixtures of two or more metals. The most common metals are aluminium, zinc, magnesium or, in some cases, lead or tin. Depending on the alloy's chemical properties, die castings must conform to several structural and performance specifications. The alloy's constituents, impurities, patterns of solidification, and post-casting treatments all affect these properties. Pure metals cool distinctly as they change from liquid to solid. As it melts, heat is released, and the temperature drops. While the metal solidifies, the temperature does not change even though the heat is removed. The die-casting process is well suited for metals because they solidify quickly and maintain suitable physical properties. This behaviour for these pure metals is depicted in the Time-Temperature-Transformation (TTT) plot. A flat portion of the curve, which indicates the eutectic phase, describes the metal's heat release during fusion [7, 8].

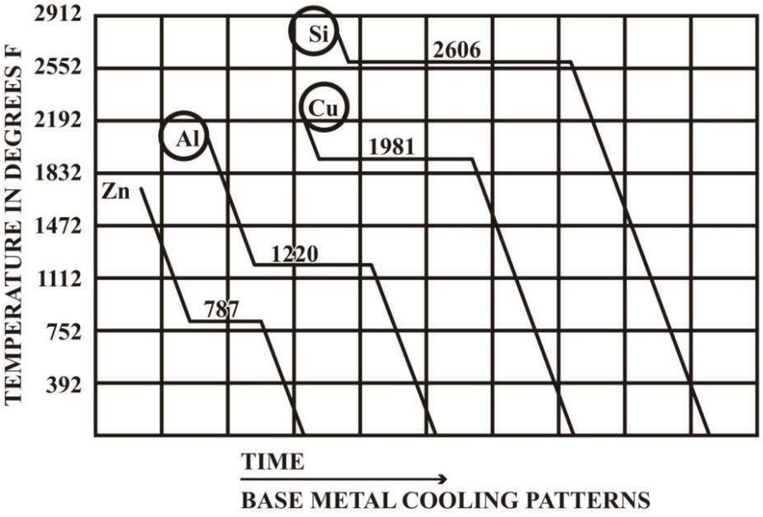

Figure 2.1: Base metal cooling pattern [7]

Figure 2.1 shows the cooling behaviour and solidifications of pure metal at constant temperature (horizontal/flat line). The solidification of aluminium metal starts and ends at constant temperature 1220 F. There is no ideal flat condition chart where base metals with other elements are alloyed, as indicated in. As the perfect metallurgical state is disrupted in die-casting alloys, a typical TTT curve will display a flat line with a down sloping angle.

For these metals, two crucial temperatures serve as melting references. Based on these data, we can better understand how base metals used in die casting behave thermally. The acute pitch of the TTT curves indicates rapid solidification. Table 2.2 demonstrates that zinc has a higher heat of fusion than aluminium. It solidifies more than four times as quickly [7].

Nevertheless, it should be noted that to keep this article brief, just the most basic casting alloy information has been provided. High-pressure die-casting differs from traditional foundry techniques because all alloys used in die-casting readily solidify under high pressure. A quick-freezing rate is necessary for crystallization when alloys go from a liquid to a solid. Due to their fine grain size, dense structure, and high mechanical properties, die castings are ideal for other casting techniques. The environment in which solidification occurs affects the structural characteristics of the cast components [9].

A castable alloy is defined by its atomic structure and how it is combined with other metals to form it. Crystals are formed by atoms, which become mostly inactive as they solidify. Each metal's atoms were aligned within the crystals in specific ways. Different patterns of particle configuration can be identified for each metal. This phenomenon, known as a lattice structure, establishes the properties of the casting alloy as a whole [10].

Table 2.1: Melting point and heat of fusion of a few typical die-casting alloy base metals [7]

Metal	**Melting Point (^oF)**	**Heat of Fusion**	
		Cal/g	**BTU/lb**
Aluminium	1220.4	94.6	170.0
Copper(brass)	1981.4	50.6	91.1
Magnesium	1202.0	89.0	160.0
Silicon	2605.0	337.0	607.0
Zinc	787.03	24.09	43.36

Even in the solid state, atomic mobility occurs into and out of crystal formations. This mobility is reduced by the quick-freezing rates of the high-pressure die-casting process and the solubility of each element in solids. This explains why finer and denser grain formations possess better mechanical properties. One metal regulates the crystal lattice structure's behaviour during solidification. As a result, each casting alloy has a unique freezing range. There are currently both liquid and solid phases. The other alloy is mushy when liquidus and solidus temperatures meet. Internal defects may show if the eutectic starts before the cavity filling is finished [10].

The earliest crystal structure had aluminium, magnesium, zinc, and other base metals. The individual crystals then come into contact with one another along the grain border, forming the grain structure. Nuclei help in the creation of crystals as well as the development of dendritic arms during solidification. The dendritic structure's size and spacing depend on the freezing rate. Due to the quick freezing, this is not an issue with die casting. The distribution is consistent with castings produced by various heat-treating techniques to the T4 level at the solution temper. Therefore, high-pressure die castings that have undergone heat treatment are uncommon. In today's competitive market, the range of alloys available has increased, and heat treatment is becoming more prevalent [10].

As casting alloys solidify, dendrites grow. Now is the time to talk about them and their grain structures. The word "dendrite" is taken from the Greek word for tree and describes their structure when grouped in grain. Dendrites with the same nucleolus as one another make up a grain. The latent heat of fusion is repelled from the liquid-solid boundary by the finger-like form of dendrites. The fingers on your hand begin to become cold, and a more well-known but connected heat transfer occurs. Since they don't have fingers, mittens are preferable to gloves, but gloves can still trap some heat. When dendrites start forming, which ignites the alloy's quick solidification during die casting, it depends on its constituent composition.

Dendrite arms are the metallurgical word for tree-like structures. The complicated network of arms constrains the movement of the remaining liquid alloy during solidification. Tiny spaces between the liquid's arms must account for shrinkage as it hardens. The cross-hatched region denotes microporosity, and these spaces are where two dendrites have joined. Between the arms of aluminium alloys is eutectic silicon. A great place to start learning about liquid and solid is with the TTT chart, which displays the thermal behaviour of pure base metals. The temperature is said to have reached liquidus when the metal is entirely liquid. Die-casting alloys are not pure metals because they often consist of two (binary) or three (ternary) base metals. This combination regulates how a particular alloy behaves. Dendrite fragmentation and multiplication of nucleation sites are illustrated in Figure 2.2 (a) & (b). Figure 2.2 (a) & (b) shows the formation of dendrites on the solidification front. The rate of growth is quite different in Figure 2.2 (a) and figure 2.2 (b) due to the variation of the intensity of frequency. The high intensity vibration effect during dendritic growth, fragmentation, and subsequent nuclei formation is depicted in Figure 2.2(a). The flow intensity surrounding the dendrites increases as the vibration frequency goes up. As a result, dendrites are more vulnerable to the drag forces brought on by viscous drag. As a result, the nucleation rate rises and the grain becomes even more refined. Figure 2.2(b) illustrates the impact of low intensity vibration on the formation, fragmentation, and nucleation of dendrites. The dendritic structures consists of primary and secondary dendritic arms and remelting of dendritic arms are illustrated in the figure 2.3 before and after liquid metal flow. In Liquid metal flow on dendrite multiplication and generation of new nucleation sites can also be depicted in Figure 2.3. The junction of two successive dendrites is the preferential cite for microporosity as shown in Figure 2.5, and nucleation and growth of the dendrites during solidification is shown in Figure 2.4 [12].

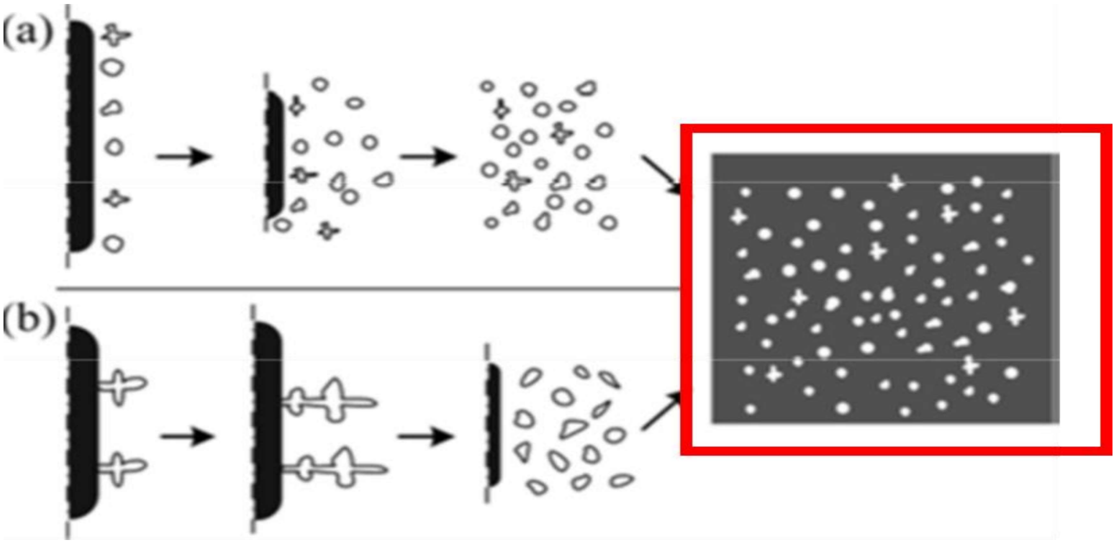

Figure 2.2: Effect of vibration on dendrite fragmentation and multiplication of nucleation sites [12]

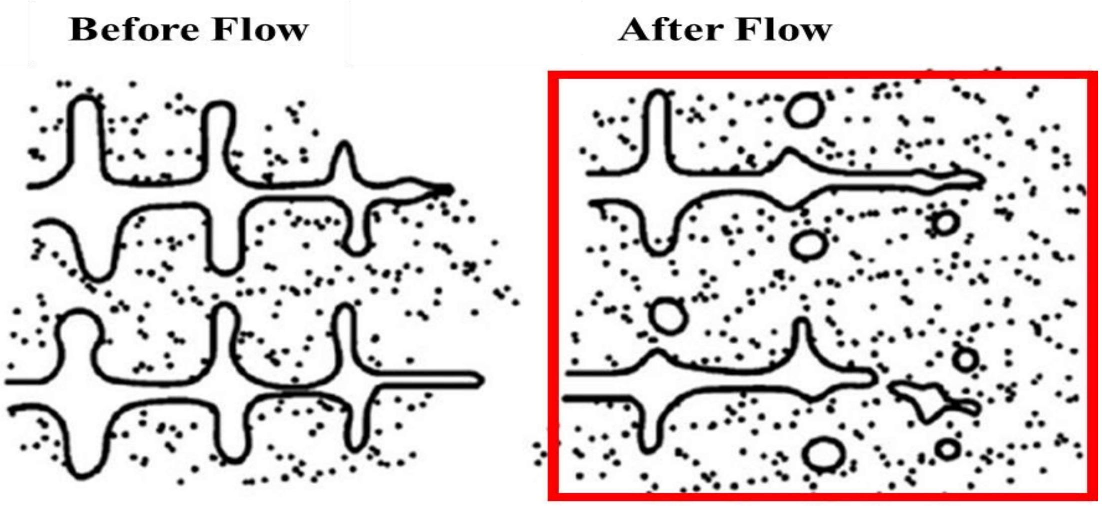

Figure 2.3: Effect of liquid metal flow on dendrite multiplication and generation of new nucleation sites [13]

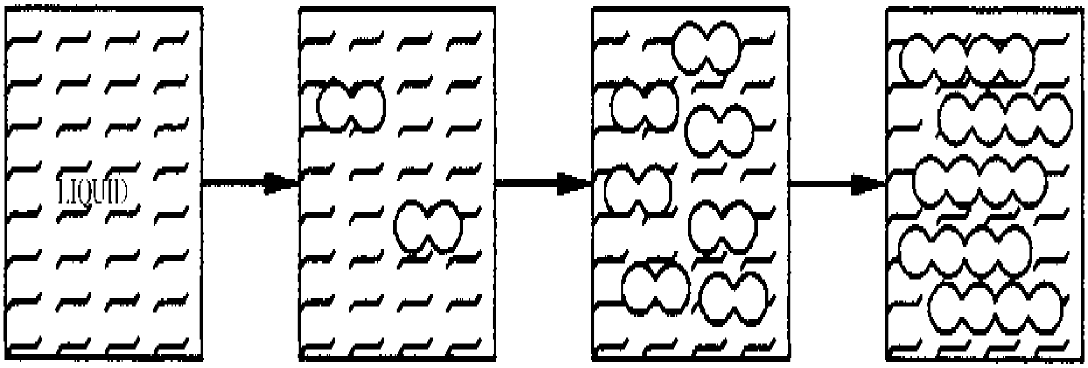

Figure 2.4: Progression of dendrite formation during solidification [14]

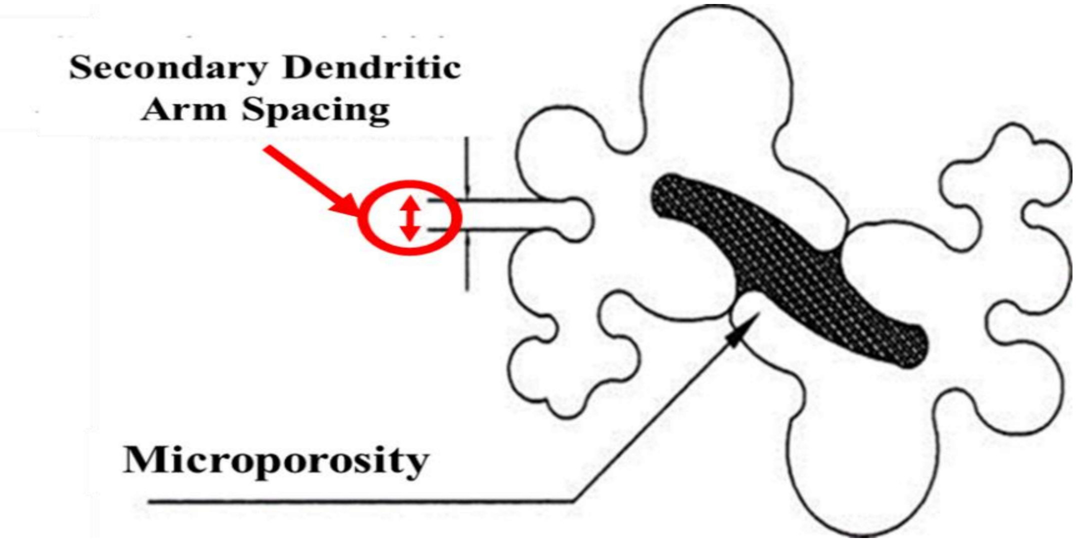

Figure 2.5: Microporosity as depicted [15]

When the melting point or freezing temperature is reached, the latent heat of fusion, also known as the heat of transformation, occurs. Even when heat energy is wasted, the TTT chart defines a constant temperature as solidification progresses. The length of the cooling curve's flat region affects the energy lost during freezing. This energy exchange causes the transition from the liquid state to the solid state. The precise heat output is expressed in BTUs per pound or calories per gram. This is referred to as the latent heat of fusion. Figure 2.6 shows the equilibrium phase diagram of Aluminium – silicon alloy, the x axis represents the percentage of silicon in Aluminium, whereas y axis shows the temperature at degree centigrade. The metal in an alloy system having the lowest melting point is called eutectic. The eutectic arrest is the term used to describe the flat area of the TTT curve. Due to the effect of the 12.6% Si concentration on the liquidus temperature, aluminium alloy A13 is frequently referred to as the eutectic alloy [10].

It's crucial to keep in mind that the fluidity of Si fluctuates throughout the eutectic line. Eutectic alloys are homogenous mixtures of the combining metals in the solid state and exhibit freezing properties comparable to pure metals. The metal reactions can also be regarded as isothermal reversible reactions because the liquid mixture freezes into two intimately mixed solids as it cools. The chemical composition of die castings is used to build secondary alloys from scrap aluminium instead of primary material processed from bauxite ore, which is the source of aluminium [11].

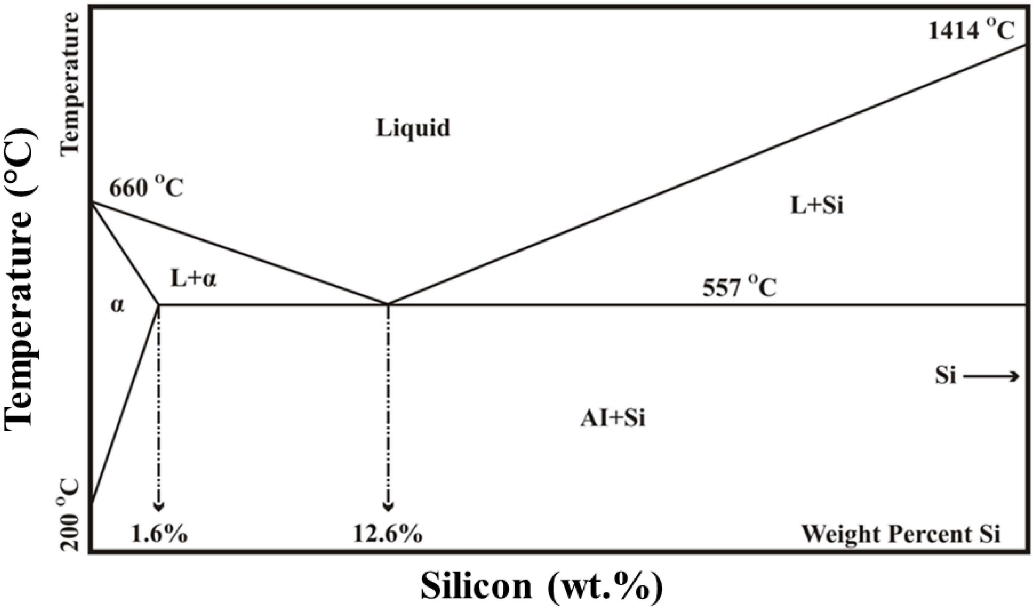

Figure 2.6: Al-Si equilibrium diagram [7]

2.3.1 Solidification processes of Al-Si Alloy

The morphology of microstructure of Al-Si alloy consist of alpha Al dendrites, eutectic Al-Si, Primary silicon as shown in Figure 2.7. Primary aluminium solidifies dendritically and expands in the 100>direction in hypoeutectic Al-Si alloys. For cubic structures, each junction results in the formation of four subsidiary arms by dendrites surrounding the parent stem [16]. On the other hand, the cooling rate, the concentration of the alloying elements, and the type of alloying elements impact undercooling most. It is widely known that undercooling increases with alloying elements' cooling rate and concentration [17].

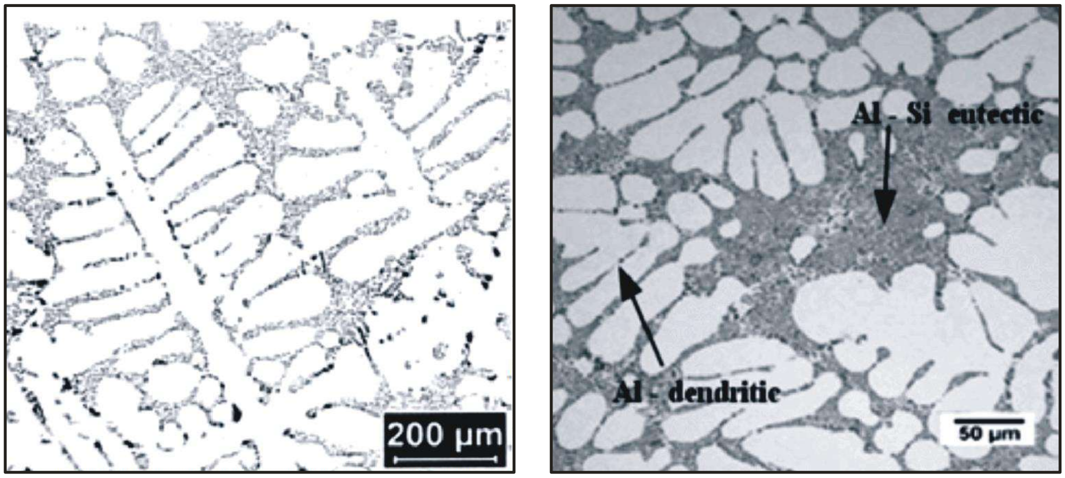

Figure 2.7: Solidification structure of hypoeutectic Al-Si alloy [18]

The formation of the Al-Si eutectic mixture occurs before the alloy solidifies. Two phases of Al and Si concurrently precipitate from the liquid at a set temperature during eutectic solidification[17]. The Al-Si system with a eutectic point is depicted in a phase diagram as shown in Figure 2.6. The eutectic temperature is 577 °C, and the eutectic point is 12.6 wt% Si. Aluminium has a maximum solubility of 1.6 wt% in Si, while Al is practically insoluble in Si [17]. Eutectic alloys provide a natural composite that gives the alloy desired qualities [17]. In addition to other alloying components like Cu and Mg, Si is frequently used in commercial aluminium alloys. These alloys' eutectics may be more intricate than those observed in the binary system. Typically, intermetallic phases with Cu and Mg are produced after eutectic development [19].

2.3.2 Effect of alloying elements

Aluminium is used for electrical motor rotors only because of its low strength, hardness, and machinability. As a result, aluminium is mixed with different materials to enhance its qualities. Copper, silicon, and magnesium are the most popular components of aluminium alloys, and they have a big impact. Manganese, iron, zinc, and nickel are alloyed in smaller quantities. Usually, an element can only be added to aluminium in amounts of 15% or less. After this point, alloys become brittle and lose some engineering value.

- **Silicon:** By adding silicon to aluminium alloys, casting flowability is improved. While fluidity is continually improving, hot cracking is gradually decreasing. When solidification shrinkage incidence falls to the eutectic threshold of 12.6%, it becomes easier to manufacture castings free of shrinkage and cracks. As a result, the Al-Si system alloy is a good choice for castings that are pressure-tight. The Al-Si system, on the other hand, is an expensive alloy.
- **Copper:** Copper gradually increases in hardness and strength until it achieves a hardness of about 4%. Above this point, the alloy becomes too fragile. It considerably improves machinability and high-temperature properties. It decreases corrosion resistance while raising fluidity. Copper causes a 4% rise in the incidence of hot cracking, although more additives reduce the likelihood of it.
- **Magnesium:** Increasing strength and hardness leads to a reduction in ductility. On the other hand, rapid solidification strengthens these qualities. Strength is steadily increased by magnesium up to the point of 6%, although hardness is not affected until a point of 10%. The binary Al-Mg aluminium systems have excellent machinability, exceptional mechanical characteristics,

and corrosion resistance. They have good ductility and impact resistance and keep these outstanding properties at high temperatures.

Castability is a massive concern because of the lack of fluidity. These alloys' solidification ranges are likewise very limited, which causes early freezing. Due to its interaction with iron in bauxite ore and its strong desire to dissolve in aluminium, iron is a naturally existing component in aluminium alloys. Aluminium has even been referred to as the "universal solvent" by certain metallurgists. Iron crucibles cannot hold liquid aluminium because the bath will eventually dissolve the pot and release the aluminium.

- **Iron:** A eutectic with a solidification point of 1211 F is created when iron and aluminium mix at a rate of 1.7%. Even though iron is generally regarded as an impurity, it has a positive effect when the concentration is less than 1.7%. It increases strength and hardness while lowering the likelihood of hot cracking. Iron content in castings may not exceed 1.7%; iron content in ingot or liquid alloys may not exceed 1% without reducing soldering.

The alloy simply provides a few passes of aluminium before remelting is required because it reacts with steel dies and shot sleeves to turn into iron. In the presence of manganese and chromium, the iron content shouldn't be more than 1.5–2.0% to avoid excessive concentrations of $Fe–Al_3$ needles in the microstructure. Manganese and chromium are helpful in tiny proportions, but if levels rise too high, they tend to create sludge, which can be harmful. The loss of control must be avoided since it can result in excessive sludging. It significantly affects metal melting losses [8, 11].

2.4 Methods of grain refinement

Aluminium alloy castings can exhibit large variations in metallurgical and mechanical characteristics, even when the same alloy is selected. To achieve the best metallurgical and mechanical properties, a high-quality molten metal must be processed, gates must be effectively gated and filtered, solidification must be directional, cooling rates must be faster, risers must be competent, and grain modification must be competent.

The as-cast microstructure is created during solidification in the casting process. It follows the microstructure that develops during solidification since various cast components are employed in the as-cast form (without extra thermal and mechanical processing). It also follows that the solidification process controls the casting's mechanical properties, which depend on the microstructure.

There is an ongoing need to reduce the cost and weight along with high-strength cast aluminium alloys. The aforesaid goal can be obtained by using the grain refining technique during the solidification of aluminium alloy. Refining cast structure needs nucleation to happen at a significant number of sites so that the voluminous growth of the crystal is avoided.

Existing knowledge of grain refinement can be mainly categorised into three types such as chemical, physical and post-processing methods as shown in Figure 2.8[3, 4, 5, 6, 8].

1. **Chemical method:** Grain refinements by chemical method involve adding elements, improving nucleation and controlling the growth of grains. Inoculation is a common example of this method. Al-Ti-B ternary master alloys are used to obtain fine equiaxed grain in aluminium and aluminium alloy casting. However, TiB_2 agglomerates can lead to problems, including damage to aluminium foil production.

2. **Physical method:** It involves stirring the molten metal during solidification using mechanical, electromagnetic and ultrasonic. Most techniques need detailed processing. They are generally employed in semi-solid metal processing due to the long processing time and high processing cost.
3. **Post-Processing method:** Grain refinements by thermal method involve a high cooling rate and variation of process parameters. Detailed classification is shown below in Figure 2.1.

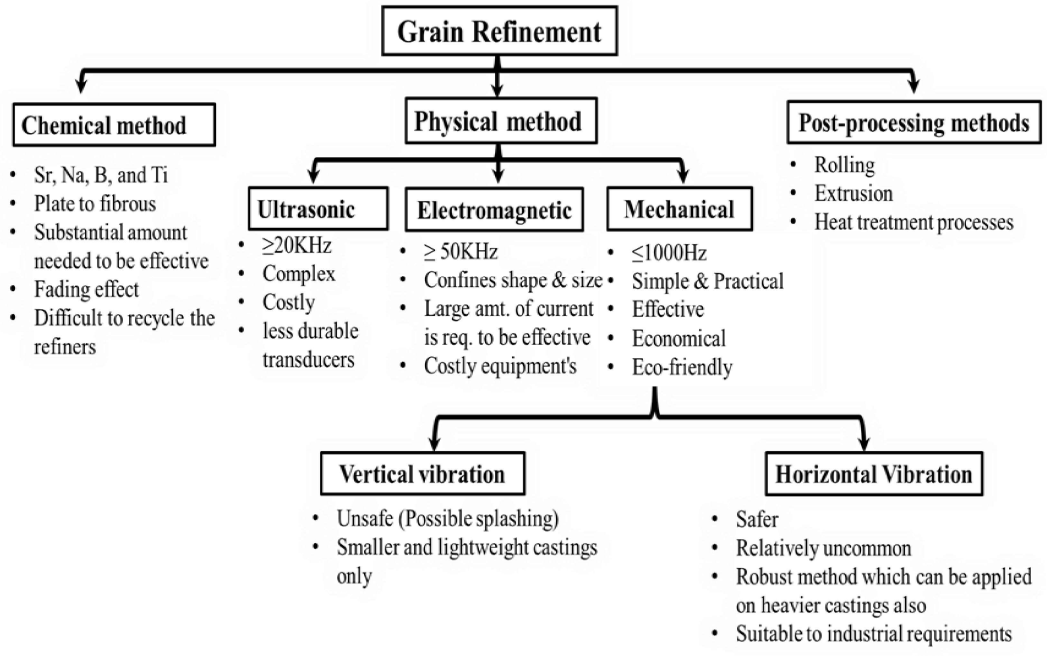

Figure 2.8: Classification of the grain refinement methods [3, 4, 5, 6, 8]

Aluminium alloys with high strength can be extremely strong but lack ductility. The confluence of two microstructural characteristics, an interdendritic network of intermetallic particles and randomly distributed microporosity, is considered to be the root cause of the lack of ductility. The microstructural characteristics of the alloy's solidification give it these characteristics.

The primary phase and the eutectic phase are the two main elements that coexist in the microstructure of hypo-eutectic Al-Si alloys. The eutectic structure is found between the arms of the primary aluminium dendrites and is composed of an aluminium-rich solid solution of silicon and essentially pure silicon. The primary phase contains Al containing around 1.67% Si as a solid solution [2, 8].

2.5 The mechanical vibration and its effects

This study's primary goal is to find the dominant critical parameter combination (frequency, amplitude) in the vibratory casting experiments. Changing the frequency and amplitude of mould vibration can enable vibratory casting technology to be scaled up for commercial applications. Due to vibration, huge nucleation sites are created during solidification than stationary casting. Mould vibration can enhance the casting quality for degassing, microstructure modification, and grain refinement during solidification.

Mould vibration processing has the following primary impacts:

1. **Mould vibration induced degassing:** Tiny bubbles are created during the solidification, and the alloying element and Al dendrites fracture due to vibration within the melt. These bubbles and fracture elements can act as nuclei for hydrogen and vapour bubbles formation. Hydrogen will escape from the liquid so that the degassing efficiency is proportional to the vibration frequency.

2. **Mould vibration lowers the size of the particles:** Mould vibration applied during solidification effectively reduces the particle size of many substances and has been widely used for producing small, uniform crystals. Ingots made with solidifying metals are dense, fine-grained, and homogeneous.

3. **Crystallisation:** Mould vibrations result in faster crystallisation, smaller crystals, and an increased number of nuclei during the crystallisation of super cooled melts.

4. Grain nucleation: Mould oscillation can modify grain nucleation in several ways. The vibration in a melt during solidification causes a change in the liquidus temperature of the melt. As a result, some of the melt is superheated, while some are undercooled. The number of nuclei entering the melt increases due to this phenomenon at high frequencies.

5. Dendrite fragmentation: Dendrites normally begin to melt at the root due to segregation and local temperature rise. Strong convection and shock waves are produced by mould oscillation in the melt, which may stimulate dendrite breakup. Because convection alters the local composition and temperature, it can cause dendritic fragmentation. The melting root will fracture due to shock waves [20].

2.6 Mechanism of grain refinement

The refinement of the grains is critical to the cast alloys. Controlling grain size is necessary for a variety of reasons. Firstly, when the consistent as-cast grain size is not achieved, lower mechanical characteristics have been observed in structural cast components [21].

Twinned columnar grains have been found to reduce yield strength, fabricability and tensile elongation to fracture [22]. Second, a coarse-grained structure can result in various surface defects in architectural alloys that are rolled or extruded [23]. Third, hot cracking in the shell zone is worse if the grain structure of a D.C. cast ingot is not equiaxed. A higher casting rate is possible using an equiaxed technique before hot cracking appears. Grain refinement in cast alloys has several benefits, such as enhanced mechanical properties that are uniform throughout the casting, fine-scale distribution of second phase and microporosity, improved feeding to eliminate shrinkage porosity and enhanced ability to achieve a uniform anodised surface, enhanced strength, and fatigue life [24, 25].

2.6.1 Nucleation

In casting solidification, the nucleation process during melting plays a critical role. Al-Si alloy casting grain structures become more refined as more nuclei form. Understanding nucleation processes and the statement mentioned above may refer to several textbooks' theoretical concepts of nucleation processes [19, 26]. The majority of them had a clear understanding of the fundamentals of homogeneous and heterogeneous nucleation. The formula for the critical nuclei size and driving force in the solidification of pure metal has been expressed using equations (1) and (2).

$$r^*_{\mathrm{homogeneous}} = \frac{-2\gamma_{sL}}{\Delta G_v} \tag{1}$$

$$\Delta G^*_{\mathrm{homogeneous}} = \frac{16\pi\gamma^3_{sL}}{3\Delta G^2_v} \tag{2}$$

ΔG_v stands for the force that causes an alloy to solidify, and γ_{sL} stands for the surface energy of the solid-liquid interface in J/m^2. Assume that the liquid's and solid's specific temperatures are equivalent.

$$\cong \Delta T \Delta S = \frac{\Delta H_f \Delta T}{T_m} \tag{3}$$

The entropy change for a liquid to solid phase transfer is ΔS in $J/K/m^3$, where undercooling below the liquidus temperature K is considered as ΔT, ΔH_f is the solidification enthalpy, and T_m is the melting temperature. If the solid embryo's radius is greater than the crucial radius, $r^*_{\mathrm{homogeneous}}$, it will survive and develop into a nucleus. In heterogeneous nucleation, the critical nucleus size is

$$r^*_{\mathrm{heterogeneous}} = \frac{-2\gamma_{sL}}{\Delta G_v} \tag{4}$$

Eqn (1) and (4) are identical for homogeneous and heterogeneous nucleation, and the free energy barrier is

$$\Delta G^{*}_{\text{heterogeneous}} = \frac{16\pi\gamma_{sL}^{3}}{3\Delta G_{v}^{2}} f(\theta) \tag{5}$$

The contact angle, or angle at which nucleation takes place on the substrate, determines how f (θ) behaves. Solid nucleation on a substrate in liquid is seen in Figure 2.9 and Figure 2.10 shows the relation of f (θ) with (θ) and illustrate that as the (θ) values increases f (θ) values also increases. f (θ) is always ≤1, as seen in Figure 2.10, the binding free energy for heterogeneous nucleation is always lower than or equal to that for homogeneous nucleation. Contrarily, heterogeneous solid substrates have a θ value close to zero. The values of undercooling, T, for observable nucleation rates in commercial aluminium alloys with grain refiners, are 1-2 K. Consequently, heterogeneous nucleation occurs. The heterogeneous nucleation rate per unit volume in m^{-3} s^{-1} can be expressed as follows.

$$I^{v}_{\text{heterogeneous}} = 10^{18} N_{v}^{p} \exp\left[\frac{-16\pi\gamma_{sL}^{3} f(\theta)}{3K_{B}\Delta S^{2}\Delta T^{2}}\right] \tag{6}$$

N_V is the number of nuclei/m^3, K_B is the Boltzmann constant, J/K and $I^V{}_{\text{heterogeneous}}$ are the rate of heterogeneous nucleation of nuclei/m^3.sec. Therefore, wetting of the substrate for nucleation is promoted, and the nucleation rate increases when the contact angle is close to zero.

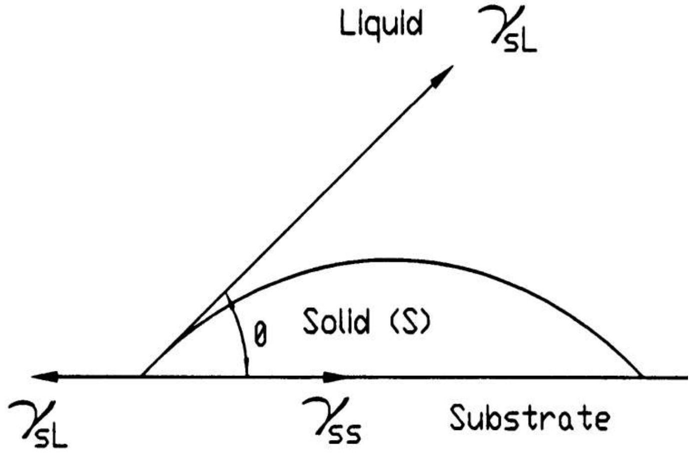

Figure 2.9: Graphical representations of the contact angle and surface tension forces are shown with the formation of a solid (s) spherical cap on a substrate [25]

2.6.2 Growth of nuclei

The development front of the nuclei is rarely planar after nucleation occurs, especially heterogeneous nucleation. Constitutional supercooling occurs as the solute is rejected at the contact and given the condition [27].

$$\frac{G_L}{R} \geq \frac{-m_L C_0 (1-k)}{k D_L} \tag{7}$$

G_L is the temperature gradient in the liquid ahead of the solid-liquid interface (K/m), R is the rate at which the solid-liquid interface grows (m/sec), and mL is the liquidus slope of the phase diagram (K/wt.%). C_0 represents the bulk alloy composition in liquid (wt%), k represents the solid-liquid partition coefficient, and D_L represents the solute diffusion coefficient in liquid (m^2/sec). Usually, in casting, we typically have a core portion with equiaxed crystals and a columnar zone [9]. The columnar dendrites develop in the cubic system in [1 0 0] directions, with the growth direction antiparallel to the direction of heat flow. Equiaxed dendrites grow outward in a radial pattern parallel to the direction of heat flow. Equiaxed crystals are created when the dendritic arm, which serves as the nucleus for them, melts [25].

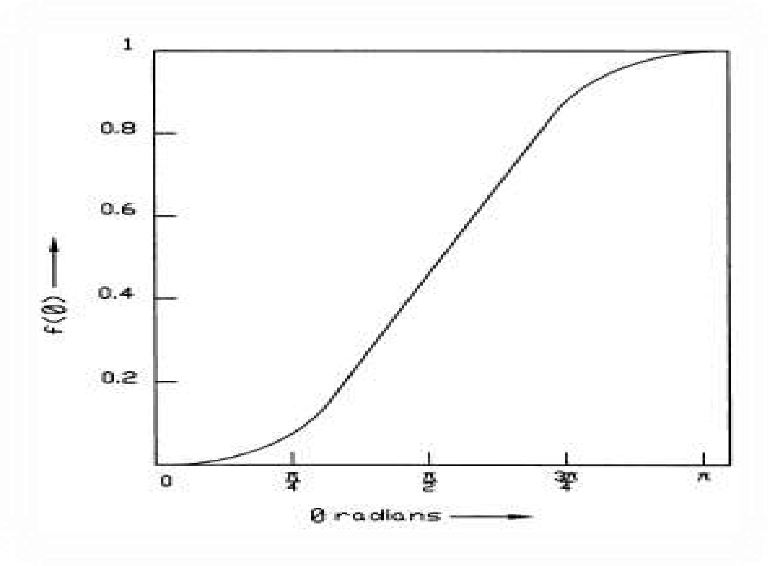

Figure 2.10: Demonstrating the fluctuation of f(θ) with θ where f(θ) is equal to (2 – 3 cosθ + cos3θ)/4

Due to unmodified, coarse grains, cast Al-Si alloy may contain eutectic Si, rough primary Si, and other intermetallic phases. The DAS structure needs to be reduced and uniformly distributed for improved microstructures. Al-Si alloys demonstrate an as-cast microstructure dominated by large grains, primary Al, acicular eutectic Si, coarse primary Si, and other undesired intermetallic phases such as needle-like Al_5FeSi with uncontrolled and unevenly distributed porosities [28]. Table 2.2 [29] summarises the phases that precipitate in hypoeutectic Al-Si alloys in order. The primary Al dendrites in untreated alloys share crystalline properties as Al in the eutectic [30]. A schematic showing the microstructure of a hypoeutectic Al-Si, a) Three basic components (grains, Al dendrites, DAS, and eutectic Si);b) Perfect grain refiner particles (squares) with one-to-one one lattice matching to Al atoms (points); c) Poor lattice matching is shown in Figure 2.11(a) It consists of grains (typically sized at 1^{-10} mm), dendrites (typical DAS 10^{-15} m), and eutectic Si, which can take the form of acicular forms up to 2 mm in length or spherical particles as small as 1 µm. In acicular Si, heterogeneous nucleation could occur, the most common way of refining grains. On some of the foreign nuclei sites, they develop a nucleus and grow slowly as the melt advances. Effective grain refiners, such as $TiAl_3$ and TiB_2, must match their lattice coherencies to the Al matrix Figure 2.11 (b). On the other hand, particles with poor lattice matching have little impact on grain nucleation Figure 2.11(c), leading to coarse grain structure [29]. Figure 2.12 depicts the refinement of microstructure with the addition Sr, and Sb.

Table 2.2: Hypoeutectic Al-Si alloy phase precipitation sequence [31]

Temperature (°C)	Phase precipitated	Suffix
650	Primary $Al_{15}(Mn, Fe)_3Si_2$ (sludge)	Pre-dendrite
600	Aluminium dendrites and ($Al_{15}(Mn, Fe)_3Si_2$) and /orAl_5FeSi	Dendritic Post-dendritic Pre-eutectic
550	Eutectic Al+Si And Al_5FeSi	Eutectic Co-eutectic

	Mg_2Si	
500	$CuAl_2$ and more complex phases	Post-eutectic

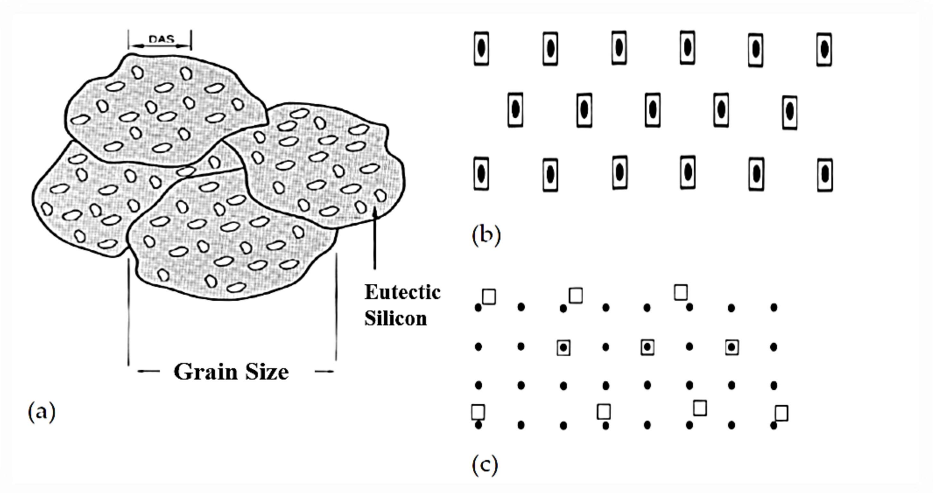

Figure 2.11: A schematic showing the microstructure of a hypoeutectic Al-Si, a) Three basic components (grains, Al dendrites, DAS, and eutectic Si);b) Perfect grain refiner particles (squares) with one-to-one one lattice matching to Al atoms (points); c) Poor lattice matching [31].

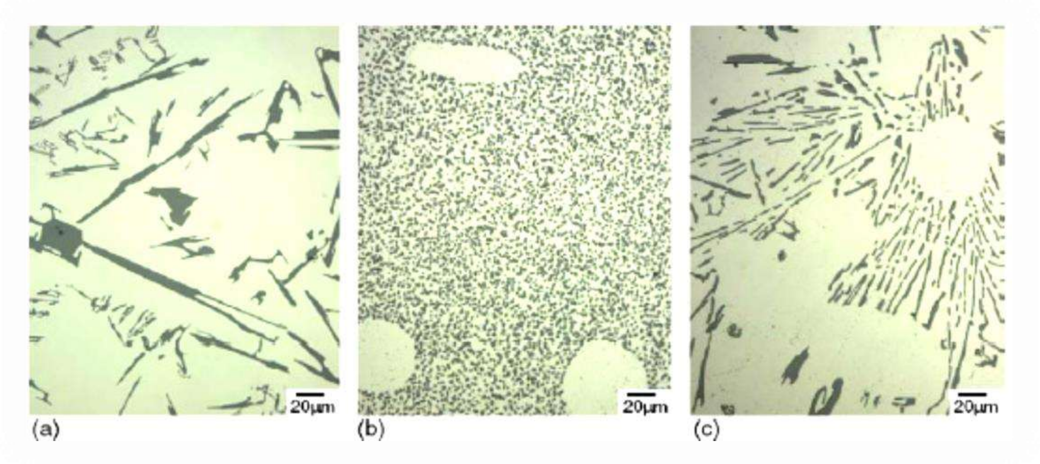

Figure 2.12: Hypoeutectic aluminium-silicon alloys with different silicon morphologies comparison: (a) unmodified; (b) Sr-modified (300 ppm Sr); and (c) Sb-modified (2400 ppm Sb) [30]

A phase called Al_2Cu is formed during the solidification of copper and aluminium. The Al_2Cu precipitates act as precipitates and alternate with lamellae composed of Al_2Cu [32]. Several copper-containing phases, such as $FeAl_7$ Cu_2 or Q-$Al_5Cu_2Mg_8Si_6$, form during solidification in the presence of iron [33]. The Al_2Cu phase can appear blocky or as finely dispersed Al and Al_2Cu particles inside the interdendritic zones, as seen in Figure 2.13. When $FeSiAl_5$ platelets or rapid cooling rates are present during solidification, fine Al_2Cu particles may form [32].

In contrast to the small Al_2Cu phase particles, which can dissolve in 2 hours during solid solution heat treatment, the blocky Al_2Cu phase particles are hard to dissolve. Al-Si-Mg alloys contain magnesium as Mg_2Si if it is not present in the solution. In the Al-319 alloy, Mg can combine with other alloy elements to form the full quaternary complex $Cu_2Mg_8Si_6Al_5$. High Fe and Mg concentrations in the absence of Cu lead to the generation of $FeMg_3Si_6Al_8$. It is hard to dissolve the phase during solid solution heat treatment [34].

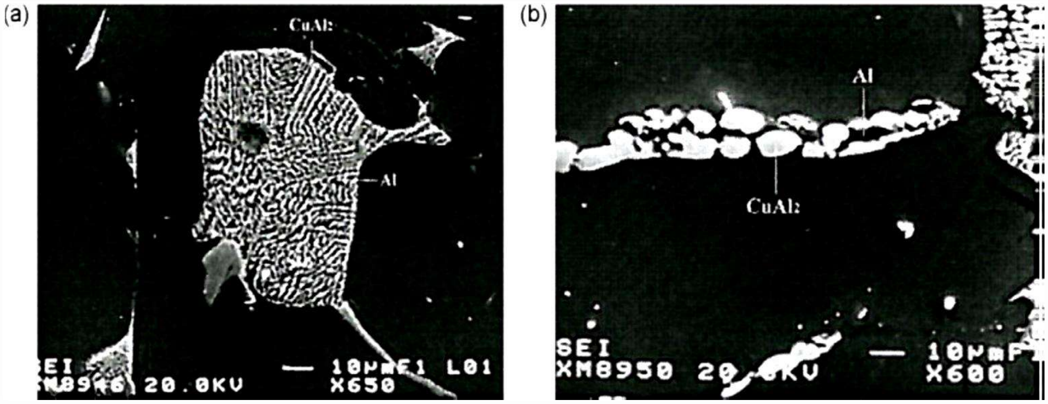

Figure 2.13: As-cast 319 alloys contain two Cu-rich phases: (a) Eutectic Al_2Cu and (b) Blocky Al_2Cu [33]

A comparative study of the mechanical properties of Al-Si-Cu-Mg alloys was carried out by Cáceres et al. [35] to investigate the effects of Si, Cu, Mg, Fe, and Mn, as well as the solidification rate. The authors observed that increasing the Cu and Mg content generally resulted in an increase in strength and a decrease in ductility. In contrast, an increased Fe content (at a Fe/Mn ratio of 0.5) dramatically lowered the ductility and strength of low-Si alloys. They also reported that the Cu + Mg content of the alloys determines the precipitation strengthening and the volume fraction of the Cu rich and Mg rich intermetallics obtained.

Yi F. [33] uses his model's enhanced Cu solid diffusion coefficient. The Cu diffusion coefficient quadruples in the Al phase. Cu diffusion in the matrix is also significantly impacted by the presence of the Si-phase. The diffusion coefficient of Cu is thought to increase by a factor of 20 in the presence of the Si-phase. Due to enhanced Cu diffusion in the matrix, Mg and Si are distributed differently throughout the dendritic arm spacing. The diffusion process is responsible for the modification in the solidification path.

2.6.3 Effect of mould vibration on metallurgical properties during solidification

On a semisolid slurry of hypoeutectic Al-Si alloy, GUO Hong-min et al. [36] observed that the primary (Al) particles grow finer and rounder as the vibration frequency increases. The vibration generated from the bulk melt's free surface and extends below can cause intense convection in the melt, which causes convection in bulk. With increasing, vibration, non-dendrite primary (Al) crystals become smaller and more rounded. Under the vibration of 20 Hz, the slurry can be made with EPD (equivalent particle diameter) of primary (Al) approximately 90μm and ASC (average shape coefficient) over 0.5.

With an increase in Fe content from 2% to 5% in the Al−17Si−xFe alloys, Chong LIN et al. [37] research on the impact of Fe-containing and ultrasonic vibration suggested that the amount of plate-like or coarse needle-like δ-Al_4FeSi_2 phase increases while the amount of long needle-like β-Al_5FeSi phase decreases. Al4$FeSi_2$ is formed and refined as a result of the USV effect. The generation of fine δ-Al_4FeSi_2 particles is facilitated by the acoustic streaming and cavitation of USV, which homogenise the solute field and temperature field and increase the start-freezing temperature of the δ-Al_4FeSi_2 phase.

S. Wu et al. [14] created a semi-solid slurry by holding hypoeutectic A356 Al alloy at an isothermal temperature. In the method mentioned above, mechanical vibration was utilised to stir the melt while keeping it in a crucible at a temperature below its liquidus. Melt convection caused by mechanical vibration and undercooling of melts resulted in the development of the nucleation and creation of a non-dendritic microstructure inside the semi-solid slurry.

WU Shu-sen et al. [38] examined the microstructural properties of an alloy made via the-squeeze casting after being subjected to ultrasonic vibration treatment. When copper moulds are utilised, a tiny number of non-equilibrium (Al) dendrites in Al–20%Si alloys may occur due to the faster cooling rate. In squeeze-cast Al20%Si alloy, the production of non-equilibrium (Al) dendrites is mainly caused by the quick cooling rate. Acoustic cavitation's effects encourage the production of non-equilibrium (Al) particles in the semi-solid RSC Al–20% Si alloy during ultrasonic vibration treatment.

When considering the microstructure evolution of Mg_9AlZnY alloy with vibration in lost foam casting during semi-solid isothermal heat treatment, ZHAO Zhong et al. [39] concluded that vibration solidification and rapid cooling in lost foam casting could produce nearly equiaxed grains of Mg_9AlZnY alloy. Using SSIT at 530°C and 570°C, a semi-solid microstructure with high roundness may be made. When grains are subjected to semi-solid isothermal heat treatment (SSIT), dendritic grains experience a distinct microstructure evolution than equiaxed grains. Small grains tend to melt, and large equiaxed grains likely to develop and spheroidize, according to the evolution of these grains.

According to research by C. Limmaneevichitr et al. [40] on the metallurgical structure of A356 aluminium alloy solidified under mechanical vibration, dendrites naturally formed in the liquid alloy during the solidification process were subsequently disturbed and fragmented by the mechanical vibration introduced into the melt. This impact was amplified when the vibration was added to an alloy with a higher solid fraction, as was the case with solidification at lower pouring temperatures. It was demonstrated that successfully introducing mechanical vibration into the A356 melt with a sufficient solid fraction before full solidification produced an as-cast structure with a semi-solid shape.

In their report on the solidification of horizontally continuous casting, ZHANG Xiao-wei et al. [41] described how a super-thin pure tin (Sn-10%Pb alloy) is greatly refined, and the extent of grain refinement is increased. The growth of equiaxed grains in the centre of the super-thin slab is encouraged by an increase in the magnitude of alternating current.

To study how cooling conditions in various temperature ranges affected the microstructure of the semi-solid AZ91 slurry created using an ultrasonic vibration technique, ZHANG Liang et al. [42] conducted research. The findings demonstrate the nucleation of tiny and spherical-Mg particles, mainly ascribed to cavitation and acoustic streaming brought on by ultrasonic vibration.

When electromagnetic forces and ultrasonic vibration were mixed during the casting of Al-Pb base alloys, changed macro and microstructures were produced, according to observations by V.O. Abramov et al. [43] .

To determine the effectiveness of ultrasonic treatment, H. Puga et al. [44] investigated the microstructure and mechanical behaviour of an Al-Si-Cu alloy under indirect ultrasonic vibration.

N. Abu-Dheir et al. [5] investigated how mechanical mould vibration affected the silicon morphology in the eutectic Al-Si alloy. Compared to gravity casting, the microstructure responsible is where the lamellar spacing tends to narrow, and the silicon morphology takes on a fibrous appearance. However, it is also claimed that silicon tends to coarsen when vibration amplitude exceeds a threshold point.

The electromagnetic vibration of the mould core region can significantly refine the solidification structures, according to experimental results from Zhiqiang Zhang et al. [45]. They also discovered that the average grain size of AZ80 alloys in the mould core region decreased initially before increasing as the electromagnetic vibration frequency increased.

The tensile strength was found to be increased for low vibration frequencies but decreased for high frequencies by G. Chirita et al. [46] when they compared the effects of vibration on the solidification behaviour and tensile properties of an Al-18 wt%Si alloy at a fixed amplitude and different frequencies with gravity castings without vibration.

The maximum grain refinement that could be accomplished was 53% at 50 Hz and for 15 minutes of prolonged vibration, according to F. Taghavi et al. [47] studies on the density and grain refinement of the A356 aluminium alloy under prolonged mechanical vibration.

To develop feedstock materials for semi-solid metal formation of A356 aluminium alloy under mechanical vibration, F. Taghavi et al. [48] investigated the thixotropic microstructure, size, and morphology of the primary solid phase. It was discovered that the size of the primary solid phase was 173 μm, and the maximum grain refinement degree, or 53%, was attained at 50 Hz and 15 minutes of vibration.

The good semisolid slurry of A356 Al alloy could be created within 50 seconds near its liquidus temperature, and the average diameter and shape coefficient of primary-Al particles were 75 µm and 0.62, respectively, according to S. Wu et al. [49] observed the impact of indirect ultrasonic vibration on the microstructure and properties of rheocasting aluminium alloy.

When aluminium alloy A356 melt formed at a temperature close to its liquidus and rapidly cooled, X. Jian et al. [50] examined the impact of ultrasonic vibration on the nucleation and growth of the melt. When the samples were heated to isothermal temperatures in the mushy zone, globular grains could not form. The generation of globular grains in the paper may be influenced more by cavitation-induced heterogeneous nucleation than by dendritic fragmentation.

The combined effects of cobalt addition and ultrasonic vibration on the microstructure and mechanical characteristics of hypereutectic Al-Si alloys with 0.7% Fe were investigated by M. Sha et al. [51]. The findings demonstrate that the Fe-containing compounds altered from long acicular β-Al_5(Fe, Ni)Si phases to Chinese-script, granular, or rod-like α-Al_{15}(Fe, Co, $Ni)_3Si_2$ phases with the addition of 0.3%, 0.7%, 0.91%, and 1.05% Co, respectively, into the alloy.

Low-frequency electromagnetic vibration was used by S. Guo et al. [52] to optimise the microstructure of DC-cast AZ80 Mg billets, and the results of the experiment demonstrate that this process considerably improved grain quality. Under particular electromagnetic vibration circumstances, the grains across the billet's cross-section have a tendency to become homogeneous.

F. Wang et al. [53] investigated the effects of vibration on the temperature profiles and changes in solidification characteristics for the liquid in front of the solid-liquid interface. Casting that was uniform and fine-grained was produced.

When alternating electric and stationary magnetic fields interact to form electromagnetic vibrations during the solidification of aluminium alloys, C. Vives [54] investigated the results and found that the structures were well-refined.

According to B.J. Zhang et al. [55], a low electromagnetic frequency is required for large-scale billet casting to produce a uniform temperature field in the sump.

C. Vives [56] observed the effect of the vibration, which primarily originates inside the electromagnetic skin depth area and is propagated throughout the melt due to the medium elasticity, and experimentally discovered that cavitation effects are also minimal because the magnetic-field strength and amplitude of the vibrating electromagnetic pressure is very small.

According to K. Kocatepe [6], low-frequency vibration of sodium-modified LM25 and LM6 alloys increases the number and size of pores. In unmodified LM25 and LM6 alloys, the quantity and size of pores increased with increasing vibration intensity. When eutectic Al-Si alloy was modified with metallic sodium, discovered that the large pore volume percentage was formed by vibration at low frequency and amplitude in the modified alloy. The modification fades if the melt modified with sodium is stirred more often than necessary due to sodium losses.

By arguing that the gas bubbles are nucleated at the solid-liquid interface with increasing peak acceleration and are trapped between the aluminium and silicon phases by the advancing solidification front, Shukla DP et al. [57] explained the porosity formation in Al-11.8%Si alloy under low-frequency vibration.

Grain refining was achieved by pulsed discharge vibrations, according to J. Hua et al.[58] under various pulsed discharge frequencies, the β-phase of the Sn–Pb20% alloy had smaller grains.

The governing microstructures of the magnesium alloy AZ31 were discovered by M. Li et al. [59] using an electromagnetic vibration approach during solidification. The development of coarse structures with dendritic morphologies may result from this.

By preventing the formation of the solidifying shell and encouraging dendrites to break off and shower down not only from the free liquid surface but also from the chilling solid surface, W. Wang et al. [60] research on the crystal nucleation and detachment from a chilling metal surface with vibration discovered that exerting vibration to a chilling solid surface is an effective way to produce many nuclei for forming equiaxed grains microstructure. It is important to raise both the synchronous vibration frequency and amplitude to produce finer equiaxed grains.

According to J. Wannasin et al. [61], an injected melt improves dynamic nucleation's electiveness, resulting in a finer microstructure of cast samples.

The vibration successfully divided the dendritic structure into tiny islands of aluminium, according to V. S. Mudakappanavar et al. [62]. Additionally, silicon needles were broken apart by creating vibration, and silicon flakes were distributed evenly, improving the material's characteristics.

By including mechanical vibration in the solidification of AZ91D magnesium alloy, Ji et al. [63] addressed the flaws of a coarse microstructure and poor mechanical properties. Mechanical vibration created the microstructure with tiny, homogeneous dendritic grains. They explained this by cavitation and melt flow brought on by mechanical vibration.

When Tamura et al. [64] looked into the influence of the frequency of electromagnetic vibrations on glass-forming ability in Fe-Co-B-Si-Nb bulk metallic glasses, they discovered that the electromagnetic pulses directly caused an increase in cooling rate and a decrease in the number of crystal nuclei. They came to the conclusion that vibrations cause the melt to be significantly stirred up, causing the newly generated nuclei to be disseminated throughout the solidifying pool and causing uniform crystallization over the entire volume.

Jiang W. et al. [65] discovered that mechanical vibration significantly improved the mechanical properties, density of A356, size, morphology, and distribution of α-Al primary phase, eutectic silicon particles, and SDAS. They also discovered that the grain size and SDAS continuously decreased with increasing vibration frequency, and the shape factor gradually increased.

A. J. Plotkowski [66] proposed that physical refinement results from mechanical vibration. This technique involves mechanically vibrating the mould at a specific frequency and amplitude. The dendritic arms are sheared by this vibration, which causes them to float into the melt and encourages further nucleation.

According to Radjai, A., Miwa, & Nishio [67], electromagnetic vibrations impact the structure of metallic alloys as they solidify. The goal is accomplished by creating vibrations in a melt of a hypereutectic Al-Si alloy containing suspended silicon particles and stopping the process at various temperatures both before and after the beginning of solidification. The removal of effects resulting from variations in cooling rates and the recognition of effects only due to electromagnetic vibrations have been made possible by establishing the parameters for obtaining similar cooling rates in trials with various experimental settings. As the solidification process begins, particles are agglomerated and ejected toward the surrounding walls due to a combination of electromagnetic vibrations and pinching forces. The resulting structure comprises an almost entirely eutectic matrix encircled by silicon agglomerates along the surface.

In their investigation, Mizutani, Y. et al. [68] used temperature gradients and electromagnetic vibrations to refine the grains of pure aluminium (99.7 mass%). The crystal grain has gotten smaller as the vibration frequency has increased, while the pure aluminium melt has been exposed to electromagnetic vibrations with a frequency range between 150 and 500 Hz. The total average grain size of the non-vibrated specimen is about 700 µm, with the average grain sizes of each cross-section widely dispersed. On the other hand, applying electromagnetic vibrations with low frequencies up to 500 Hz steadily lowers the average grain size, and dispersion for each cross section reduces. Mainly, crystal grains, with an average grain size of about 200 µm, are most polished at frequencies of 500 Hz.

Jianbo Yu et al. [69] used electromagnetic vibration to investigate the experimental solidification structure of a eutectic Al-Si alloy. The eutectic structure is discovered to have been refined by imposing a high magnetic field alone, whereas it is coarsened by electromagnetic vibration. Polyhedral Si grains and non-dendritic α-Al were seen when the electromagnetic vibration was strong enough. Strong convection may disrupt the eutectic phases' cooperative growth, resulting in polyhedral Si grains and non-dendritic α-Al.

According to Jia, S., and Nastac, L. [70], UST causes the melt to experience intense convection and shock waves, which may facilitate dendritic fragmentation. Convection can cause dendritic fragmentation because it alters the local composition and temperature and encourages solute transport. The melting root will snap due to shock waves. Under UST processing, a melt's liquidus temperature changes and pressure oscillations occur. As a result, some of the melt is overheated while others are undercooled. The number of nuclei entering the melt increases due to this process, which happens at high frequencies. Very tiny bubbles are produced at low pressure during the cavitation process. These bubbles have the potential to serve as the building blocks for hydrogen and vapour bubbles. The liquid will let hydrogen out. The ultrasonic intensity directly relates to the degassing effectiveness.

Any factor that boosts the number of nucleation sites or slows down the growth rate, according to Zhang L. et al. [71], produces refined grains in as-cast aluminium alloys. Based on this, numerous methods of grain refining are used in casting processes, including quick solidification, the purposeful injection of inoculants, and forced action upon melt using ultrasonic vibration and mechanical or magneto-hydrodynamic stirring. These methods' primary mechanism is to produce more nuclei through heterogeneous nucleation as they solidify.

In order to improve the globular structure in aluminium A356 alloy, Akhlaghi, F., and Taghani, A. [72] used the vibrating cooling slope (VCS) method. They discovered that the main impact of vibration on the structure of solidifying metals and alloys is the suppression of columnar growth by fragmentation of the growing dendrites. They also suggest that several mechanisms, including (i) increased flow of the liquid metal around dendrite arms, (ii) bending stresses caused by vibration-induced movement of the liquid between them, and (iii) dendrite arm remelting at the necks due to increased temperature fluctuations as a result of strong liquid motion, can explain grain refinement. These crystals grow in the mould based on three mechanisms, they explained. They form by weak dendritic arms detaching along the cooling plate. According to experimental findings, the vibration of the slope causes significantly more pronounced dendritic arm breakup and enhanced detachment from the cooling plate, resulting in more locations for heterogeneous crystal nucleation. In this instance, the applied shear force was enough to globularize the structure. Therefore, the vibration frequency impacts the number of seed crystals and the intensity of the shear stress placed on them. As a result, the higher vibration frequency boosts the number of nucleated crystals and speeds up their disintegration, reducing the size of globules. Due to the increased vibration frequency, more spherical globules are produced due to increased shear stress being applied to the forming crystals in the solidifying melt.

According to Gibb, F. G. [73], the mechanical effect is the ability of agitation or vibration to cause supercooled liquids to crystallise as a result of the mechanical motion helping the rearrangement of the atoms required to make an embryo. Due to the challenges of creating a vibration-free environment in a busy laboratory, the possibility that vibration may be significant in influencing plagioclase crystallisation in experiments between the liquidus and solidus temperatures has not been investigated. However, it may be more than a coincidence that during a time when construction work was being done in the laboratory (resulting in significant vibration), a noticeably higher proportion of the experiments.

W. Dai et al. [74] examined the effects of the rheo-squeeze casting parameters on the microstructure and mechanical properties of AlCuMnTi alloy, and indirect ultrasonic vibration was used to create the semi-solid slurry of $AlCu_5MnTi$ alloy (IUV). Tensile strength and elongation were 326.5 MPa and 11%, respectively, which were increased from conventional squeeze casting samples by 6.5% and 47%.

By extending the ultrasonic treatment period, YAO Lei et al. [75] got a fine globular structure and the refining effect of Mg-8Li-3Al alloy. With ultrasonic vibration, the solidification structure, alloy characteristics, and morphology of the phase are changed from a coarse rosette-like structure to a fine globular one. It appears that the mechanical qualities increased with ultrasonic vibration. With 170 W of ultrasonic treatment for 90 s, the tensile strength and elongation of the alloy increase by 9.5% and 45.7%, respectively.

The UTS (ultimate tensile strengths) of the A1 and A2 alloys is increased by 24.3% and 22.5%, respectively, at room temperature, compared to those of the alloys without USV treatment.

According to research by Chong Lin et al. [76] on the effects of ultrasonic vibration and manganese on microstructure and mechanical properties of hypereutectic Al-Si alloys with 2%Fe. Their respective UTS values are 271 MPa and 289 MPa. After USV treatment, the UTS at 350ºC and the hardness of the A1 and A2 alloys are marginally enhanced.

According to J. Campbell [8], "mechanical vibration" encourages grain refining and can expand the equiaxed zone.

The vibration of a copper alloy (Cu-32Zn-2Pb-1Sn) increased yield and tensile strengths by around 15%, with a 10% reduction in grain size from the unvibrated condition, according to R.J. Kissling et al.[77] Compared to the α-β alloys, the copper-zinc alloys (35% Zn) generally show reduced grain size and better characteristics.

According to P.A.O. Adegbuyi et al.[78] each composition of Aluminium-Copper alloys had various grain refinements that improved the qualities of the specimens during solidification (Casting). With frequency, the tensile stress (strength) grows. Vibration increases the number of smaller grains that are generated, which results in a finer grain structure and reduces the material's ductility, as seen by the % elongation and percentage reduction in area.

The mechanical properties of aluminium alloys, according to Knuutinen A. et al. [79], are highly influenced by the microstructure of the solidified material. Castings with a fine-grained and equiaxed microstructure are preferable because they have better mechanical characteristics and more uniform dispersion of secondary phases.

To comprehend how casting microstructure and mechanical properties changed during the solidification of Al-Cu alloys, Kumar R. et al. [80] looked at the impact of mould vibration. The graphite mould casting was done at 40 to 150 Hz frequencies. A casting without vibration was also produced to contrast the outcomes of castings with vibration. The experimental findings demonstrated a notable improvement in casting hardness and grain refinement using mechanical mould vibration during solidification.

According to Guo H. M. et al. [12], mechanical vibration during the solidification of AZ31 magnesium alloy casting can greatly enhance mechanical performance, increasing both strength and elongation simultaneously. The ultimate strength increased from 152 to 213 MPa, the yield strength grew from 71 to 122 MPa, and the elongation increased from 4.8 to 11.5%, increasing vibration acceleration from 2.5 to 19 m/s^2. These results align with the grain size measurements, which show that the smallest grain size attained under applied vibration acceleration corresponds to the highest strength and elongation.

In the current work, Chaturvedi V. et al. [16] demonstrated four distinct samples of the same composition of AZ91 Mg alloy were examined for their microstructure and mechanical characteristics such as hardness, tensile strength, and wear. The first sample was the alloy exactly as it was cast; the second sample only received mechanical vibration (15 Hz-2 mm); the third sample also received the addition of 2 wt percent ZnO as a grain refiner; and the fourth sample received the combined effects of the grain refiner and mechanical vibration during solidification. The fourth sample produced the best results because both mechanical vibrations and the grain refiner act as nucleating sites in the melt, restricting the growth of the grain.

Jiang, W. et al. [81] investigated how the vibration frequency affected the A356 aluminium alloy's microstructure, mechanical characteristics, and fracture behaviour.

The obtained results demonstrated that the silicon particles' average length, width, and aspect ratio decreased by 45, 6, and 42% compared to the sample without vibration. In comparison, the grain size and SDAS decreased by 32 and 19%, respectively, and the shape factor increased by 262%. In the meantime, the A356 alloy sample had tensile strength, yield strength, elongation, and hardness that were 35, 42, 57, and 28% higher than the vibration-free sample. Additionally, mechanical vibration changed the A356 alloy's fractograph from a clear, brittle fracture nature in the absence of vibration to an evident dimple fracture nature. With an increase in vibration frequency, the dimples became very deep and evenly distributed with a high density.

According to Sayuti M. et al. [82] findings, a mechanical vibration technique for inducing vibration that results in enhanced mechanical properties, such as impact properties, is developed. The solidifying particulate (TiC) reinforced aluminium alloy (LM6) matrix composite is made by varying the particulate weight fraction of titanium dioxide to various vibration sources on the resulting casting quality. The impact strength and density were determined through microstructure studies. According to preliminary research, utilising a vibration mould during solidification increased the mechanical attributes compared to gravity castings without vibration.

W Jiang et.al [83] investigated the effects of wall thickness and mechanical vibration on the microstructure and mechanical characteristics of the A356 aluminium alloy created by the disposable pattern shell casting technique were examined in the current work. Results shows, The tensile strength, yield strength, elongation, and hardness of the sample with a 40 mm wall thickness were, respectively, 35%, 42%, 63%, and 29% higher than those of the conventionally cast .

Al-Ethari H et.al [84] used stir casting to create aluminum-silicon eutectic samples with silicon contents of 12–13 weight percent. Investigated this eutectic alloy's microstructure, hardness, porosity, dendritic grain size, tensile strength, and elongation to determine how mechanical mould vibration affected it. The samples were cast with mechanical mould vibration at 5, 10, 15, 20, and 25 Hz with an amplitude of 0.5 mm. The findings demonstrated that the researched attributes are significantly influenced by the amplitude and frequency values. Dendrite grain size decreased by 15%, 26%, 32%, 42%, and 53% at 5, 10, 15, 20, and 25 Hz mechanical mould vibration frequencies. The hardness was raised by mechanical mould vibration, which increased it by 7%, 16%, 25%, 33%, and 40% at frequencies of 5, 10, 15, 20, and 25 Hz. Additionally, mechanical mould vibration was used to reduce porosity; at frequencies of 5, 10, 15, 20, and 25 Hz, the porosity fell by 35%, 46%, 58%, 69%, and 77%, respectively. Tensile strength rose by mechanical mould vibration at frequencies of 5, 10, 15, 20, and 25 Hz by 12%, 18%, 25%, 29%, and 36%, and elongation percentage increased by mechanical mould vibration at frequencies of 14%, 29%, 38%, 52%, and 71%, respectively.

N. K. Kund [4] demonstrated how plate vibration affects the solidification process as well as the microstructural and mechanical characteristics of semisolid-cast and heat-treated billets made utilising a tilted plate. There are five different plate vibrations used in this investigation (0, 15, 30, 40, and 50 Hz) on A356 Al alloy. The finest and most globular microstructure with the best mechanical characteristics was produced by plate vibration at 30 Hz. Due to insufficient shearing, which increased grain size and decreased form factor, primary α-phase percentage, and grain density, dendritic fragmentation and grain refining were delayed down. However, because of coalescence/agglomeration and Ostwald ripening, somewhat increased plate vibration led to coarsening (which is the opposite of grain refining). Due to the Hall-Petch effect, such fluctuations in grain size with plate vibration led to variations in mechanical characteristics. The results are under expectations and are in excellent agreement with those found in the literature.

Mehta, MC et al.[85] demonstrated there are five different plate vibrations used in this investigation (0, 15, 30, 40, and 50 Hz) on $Al_{4.5}Cu$ (LM11) alloy. The finest and most globular microstructure with the best mechanical characteristics was produced by plate vibration at 30 Hz. Due to insufficient shearing, which increased grain size and decreased shape factor, primary α-phase percentage, and grain density, dendritic fragmentation and grain refining were delayed down. However, because of coalescence/agglomeration and Ostwald ripening, somewhat increased plate vibration led to coarsening (which is the opposite of grain refining).

2.7 Gaps in the literature

As depicted in the literature survey, most researchers used the vertical vibration method, but due to the possibility of metal splashing and inapplicability for heavier castings horizontal vibration method was chosen for the present research work because it offers less splashing, suitability for heavier castings, has easier workmanship, is economical, and is eco-friendly.

The literature is mostly qualitative, and quantitatively measured metallurgical parameters are α-Al grain size, SDAS, to study the microstructural refinement. To make the investigation comprehensive length of the eutectic Si particle, the width of the eutectic Si particle, the aspect ratio of the eutectic Si particle, the shape factor α-Al phase, and Intermetallics (Al_2Cu, $Fe_{1.7}Al_4Si$, Mg_2Si) are also examined.

Literature shows that efforts have been made towards measuring the effects of physical and metallurgical properties individually rather than both on the mechanical properties. So, the present study examines the effect of both physical and metallurgical properties on mechanical properties.

Researchers opted to see the frequency-based vibration effect rather amplitude-based vibration effect. Therefore amplitude-based (2.5±0.5 mm) vibration effect is also investigated.

2.8 Motivation

There are various processes (chemical, physical and post processing) have been used for the modification of microstructure of the cast. These processes have their own advantages and dis advantages. Ex such as in ultrasonic process the replacement of probe (transducer) at regular interval add burden to the casting cost. Electromagnetic process has the limitation of metal casting and so it is not economically beneficial etc. Therefore on the point of economically beneficial, horizontal vibration process technique are more advantageous as compared to some other refinement processes.

2.9 Summary and outlook

It can be concluded that vibration treatments have positively affected the physical, metallurgical and mechanical properties after carefully examining the aforementioned literature review. The effects of mechanical vibrations have greatly improved the alloy's cooling rate, density, microstructure, metallurgical features, and mechanical properties. The grain size decreased to a minimum at an optimum frequency, and a refined structure was attained. The grain size refinement is enhanced through forced convection, degassing, dendrite fragmentation, structural homogeneity and modification in the morphology of metallurgical features. The mechanical properties of the alloy mainly depend on microstructural modifications. Mechanical vibrations are one of the most promising methods of introducing vibrations to solidified melts since they are simple, effective, easy to operate, economical, and eco-friendly. This process opens up many opportunities for significant cost savings and industrial applications.

There was a research gap since there was little in-depth work done in the broad frequency range from low to high. In light of this, we attempt to explore the impact of mechanical vibration throughout a broad frequency range (with in the safe and steady operation of the set up). Various advanced characterization and processing approaches that are employed to carry out the study based on the research gap are discussed in depth in subsequent chapters.