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RESEARCHPAPER

An overview of the effect of stirrer design on the mechanical properties of Aluminium Alloy Matrix Composites fabricated by stir casting

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A B S T R A C T:
Aluminum Matrix Composites are widely utilized in a variety of applications, and their popularity is growing due to their excellent performance, low cost, and low environmental footprint. Metal Matrix Composites are made in a variety of ways, including liquid and solid states, but stir casting is the most common because of its flexibility, inexpensiveness, and offeringa diverse range of materials and manufacturing conditions. The key challenge in the procedure is the homogeneous dispersion of reinforcing particles. The homogeneous dispersion of particles inside the metal matrix determines the microstructure and mechanical properties of the composites. Stirrer design has a vital role and it can be more effective through optimizing it. All available literature was reviewed from 1968 which stir casting method was initiated to produce Aluminium matrix composites. Mixer designs and mixing efficiency were also investigated in other related studies. The scope of this paper explores the experimental contributions of stirrer design in the production of composites. There are many variables in stir casting The large number and overlap of parameters appear to have an impact on the uniform distribution of reinforcing particles. Researchers on their path to the appropriate technique have had promising results with only their circumstances, without being able to generalize their findings. In this article, previous findings and contributions have been collected, organized, compared, and presented. Finally, several conclusions have been raised and scopes for the new research have been identified.

KEYWORDS:Aluminium Alloy Matrix Composite, stir casting, stirrer design, mechanical properties of Aluminium Alloy matrix composites.
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Nomenclature

Al	Aluminium
MMC	Metal matrix composites
AMC	Aluminium matrix composite
AAMC	Aluminium Alloy matrix composites

1.INTRODUCTION :

Aluminum and its alloys are the most often matrix materials that are used in MMC manufacturing because of their favored advantages. Researchers and industrialists have moved from monolithic materials to advanced composite materials to respond to the global request for lighter, greener, high performance, wear, and erosion-safe materials.Aluminum matrix composites (AMCs) are vital weight-economical structural materials, which have multiple fields of industrial application(Rana, Purohit and Das, 2012)(Suresh, Mortensen and Needleman, 2013)(Meen, Prior and Lam, 2015)(Idrisi and Mourad, 2019)(P Sharma, G Chauhan, 2020)(Upadhyay and Saxena, 2021)

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Aluminum alloy metal matrix composites have great importance due to their high-temperature ability as well as thermal stress resistance with their lightweight. Due to the metal matrix compounds' lack of structural simplicity, their analytical method is complex. Moreover, the sharing of numerous parameters that affect the composite properties makes the experiments so difficult(Sijo and Jayadevan, 2016).

Liquid casting has gotten a lot of attention in the last few decades for the fabrication of aluminum alloy composites for different applications. Aluminum alloy composites were successfully fabricated by the liquid stir casting technique by adding different kinds of discontinuous reinforcement in the Al alloy matrix (Rozhbiany and Jalal, 2019). Stir casting is one of the most essential routes to produce metal matrix composites. The term stir casting is the process that involves mechanical stirring of the reinforcement particulates into a molten metal bath. In the next step, the constituent materials pour into the mold. The particles in the stir casting method often tend to form agglomerates, which can be only dispersed by strong stirring with high temperatures (Sable and Deshmukh, 2012)(Ramesh, Vinayak and Hemanth, 2017).Based on a survey of the literature, the table (1) following lists a number of multiple and interrelated factors that influence the dispersion of particles in the molten matrix.

2. Stir casting challenges

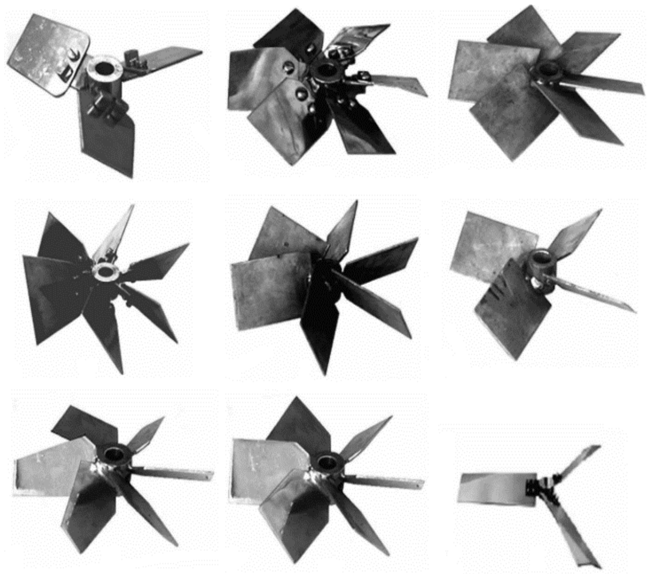
The complexity of in achieving a uniform reinforcing particle distribution, the retention of non-metallic particles in molten metals or alloys, porosity in the cast metal matrix composites, poor wettability between the particles and matrix, particle clustering, gravity segregation, interfacial reactions, and formation of detrimental secondary phases and chemical reactions between the reinforcement material and the matrix alloy(Ghosh and Ray, 1988), (Greifzu *et al.*, 2016), (Ravi *et al.*, 2005), (Prabu *et al.*, 2006), (Hashim, Looney and Hashmi, 2002b), (Hashim, Looney and Hashmi, 2001), (Ourdjini, Chew and Khoo, 2001), (Sahu and Sahu, 2019), (P Sharma, G Chauhan, 2020)

Among other difficult challenges in the casting of metal matrix composites is non-homogeneous particle distribution which happens because ceramic materials have different densities, melting, and boiling points(Naher, Brabazon and Looney, 2003). Among the challenges were reported the stagnant zone, dead zone, the excessive turbulence near to the liquid level in the stirred crucible(Su *et al.*, 2010). In addition, the dendritic microstructure is not desirable as it results in poor mechanical properties which encourage researchers to treat it by the electromagnetic force field (Girot *et al.*, 1987)(Greifzu *et al.*, 2016).

The lack of a device to quantify the uniform distribution of particle reinforcements or any undesirable defect in AAMCs during the process makes dealing with all previous challenges are difficult. The mixing process has a critical role among a wide range of chemical and industrial processes. Many factors influence mixing efficiency, but one of the most important is impeller design (Jaszczur, Młynarczykowska and Demurtas, 2020). Attaining homogeneity in mixing processes is a demanding task for efficient and economical use. Less stirring leads to non-uniform distribution of particles and in addition to wasting energy, excess stirring forms clustering of particles at some place(Ourdjini, Chew and Khoo, 2001).

3. Stirrer design components and classification

The stirrer is the heart of the stir casting. Stirrer design is a vital aspect of stirring parameters. It has a significant impact on the final microstructure and mechanical properties, and it can be improved by optimizing it, but only a few studies have looked into this possibility. The term stir casting names comes from its process which involves mechanical stirring of the reinforcement particulates into a molten metal bath.In stir casting, the particles often tend to form agglomerates, which can be only dissolved by strong stirring at high temperatures(Sable and Deshmukh, 2012)(Ramesh, Vinayak and Hemanth, 2017), Jaszczur et al. (2020) concluded that many factors influence mixing efficiency, but one of the most important is impeller shape and also the distance between the impeller and the vessel bottom(Jaszczur, Młynarczykowska and Demurtas, 2020). Homogeneous distribution of the particles is required to optimizing the mechanical properties that can be achieved by the proper impeller as the main part of the stir casting route. The performance of different impellers and their effects have not been reported in the majority of literature about stir casting(Paul and Sijo, 2015),(Prajapati and Kumar, 2018). Generally, ignoring the basic rules, will take a long time or waste enormous amounts of energy. Driven by environmental protection, modern stirring necessitates a reduction in fuel use. Nowadays stirrer noble design is a response to these requirements. Ramani et al.(1991) explained that in the former technique an impeller is used to create a vortex in the fully liquid matrix melt (Ramani *et al.*, 1991). Harnby et al. (1985) (as cited in Hashim et al., 1999) The formation of a vortex during stirring seems essential in the transfer of particles into the matrix melt, as the pressure differential between the melt's inner and outer surfaces sucks the particles into the molten metal (Hashim, Looney and Hashmi, 1999). A continuous liquid phase is required for an impeller-type mixer or agitator to blend and mix liquids with liquids, liquids with scattered particles, liquids with dispersed gases, or liquids with both dispersed solids and gases. By driving and shearing the fluid in a crucible, a mixing impeller generates flow and turbulence. The equipment comes in a variety of shapes and sizes, but they always include an impeller coupled to a revolving shaft (*Mixing Equipment (Impeller Type)*. 3rd edn, 2001). Kumaresan and Joshi (2006) mentioned the blade angle, number of blades, blade width, blade twist, blade thickness as impeller components that determine flow pattern and power number in the stirred vessel. An impeller is defined by a set of physical and geometric factors including diameter, number of blades, the contour of blades (blade shape), the width of blades, angle of blades, and thickness of blades(*Mixing Equipment (Impeller Type)*. 3rd edn, 2001).Paul et al. (2003) concluded that the most effective impeller selection is based on an understanding of process requirements and physical properties(Paul, Atiemo-obeng and Kresta, 2003). The effects of the impeller design on the flow pattern on mixing quality in stirred tanks at different viscosity levels have been investigated. They explained that the relative distribution of mean and turbulent kinetic energy determines the mixing quality. Figure (1A) gives several photographic views of the pitched blade turbine impeller provides both radial and axial flow and generates high shear levels. (Kumaresan and Joshi, 2006) Figure (1B) gives several photographic views of the narrow and broad blade hydrofoil which normally low and medium viscosity range.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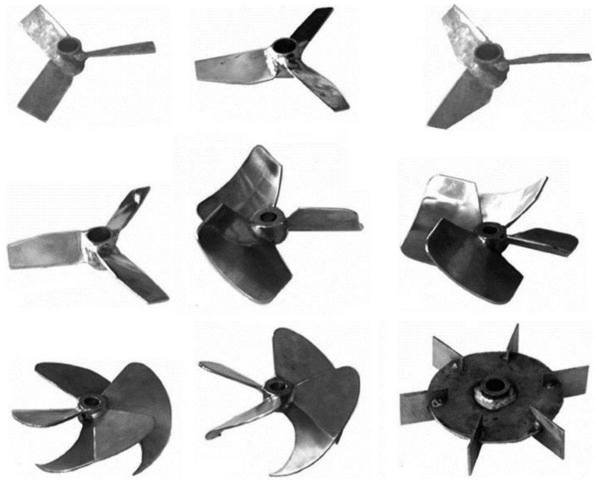
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Figure (1):A) Impeller design: Pitched blade turbine. B) Impeller design: the narrow and broad blade hydrofoil (Kumaresan and Joshi, 2006)

Axial and radial flow impellers are the two types of impellers that are often used. The radial flow category includes the Rushton turbine, straight-blade turbines, curved-blade turbines, Brumagin, and others(Joshi *et al.*, 2011b)There are four types of turbine impellers, which are characterized by the flow patterns and level of shear they create: axial flow, radial flow, hydrofoil, and high-shear impellers as demonstrated in figure (2) (A, B, C, D) respectively. They have the widest use in low and medium viscosity liquid applications, solids suspension, liquid-liquid emulsification, and gas dispersion(Paul, Atiemo-obeng and Kresta, 2003). Paul et al. (2003) stated that axial flow impellers are used for blending, solids suspension, solids incorporation.

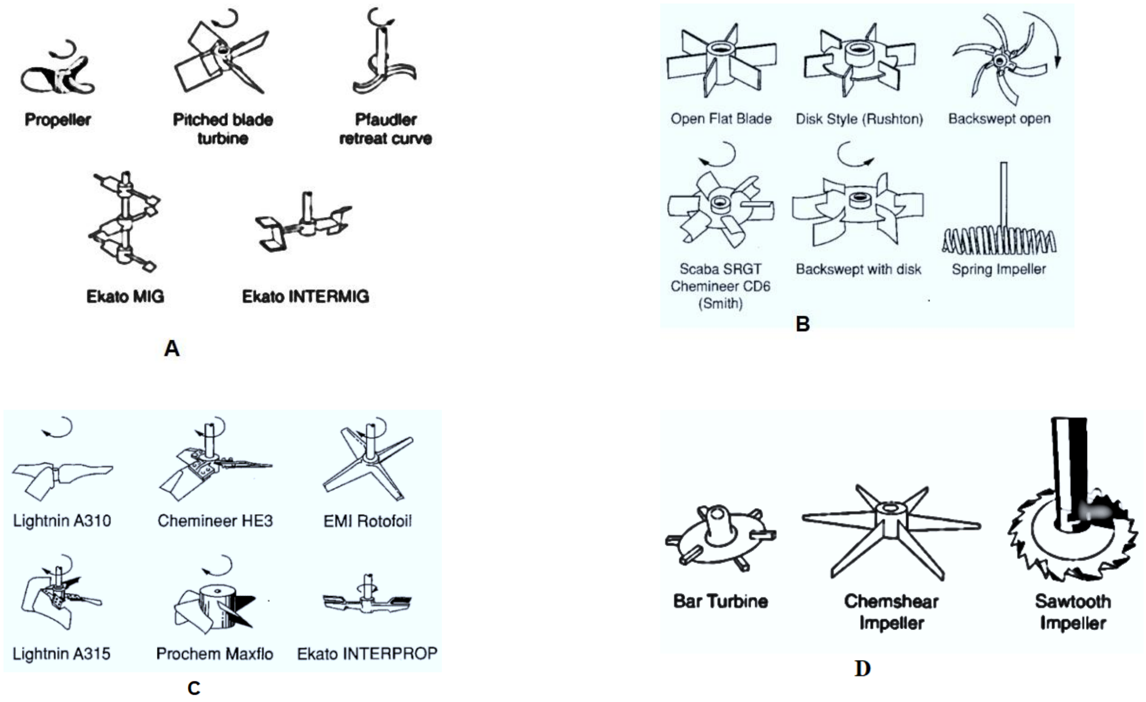


Figure (2): A-Axial flow impellers , B- Radial flow impellers , C- Hydrofoil impellers , D- High-shear impellers (Paul, Atiemo-obeng and Kresta, 2003).

One of the most important variables in determining the flow characteristics and achieving the aim of mixing in stirred tanks is the impeller type (Ge *et al.*, 2014). Thomas et al. (2014) focused on designing, manufacturing, different stirrer designs testing, and utilizing them in stir casting for the manufacturing of AMC s materials. Then the significance of individual stirrers is compared and the best one is recognized by testing the specimen(T. Thomas *et al.*, 2014). Su et al.(2010) reviewed the effects of stirrer geometry, the blade angle, and the diameter of the impeller as important stirring process parameters to achieve the effective flow pattern to uniformly disperse the ceramic particles in the molten matrix in the stirred crucible during stir casting(Su *et al.*, 2010).

The stirring promotes uniform distribution of reinforcement partials and interface bond between matrix and reinforcement(Ramesh, Koppad and Hemanth, 2017). According to Ramanathan et al., impeller design is critical for forming a vortex and achieving optimum melt mixing, but it is hard to calculate a numerical number for stirring speed generalized to all types for all types of stirrers since it is impacted by the geometry of each impeller blade(Ramanathan, Krishnan and Muraliraja, 2019).

4. Stirrer material

The major problem associated directly with stirrer design is replacing impeller frequentlydue to erosion, especially for mass production, since it would halt production and increase consumable costs. A stainless steel stirrer blade coated with zirconia or a high-temperature lubricant was often applied manually to prevent the stirrer from erosion and to avoid melted sticking to the stirrer(Ramanathan, Krishnan and Muraliraja, 2019). For stirrer material, themajority of researchers used steel or any material like graphite which has a high melting point and it does not interact with the compound so the compound remains pure(Naher, Brabazon and Looney, 2005)(Sable and Deshmukh, 2012).(Sozhamannan, Prabu and Venkatagalapathy, 2012)(Ramesh, Koppad and Hemanth, 2017)(Ramanathan, Krishnan and Muraliraja, 2019).To reduce blade disintegration in molten metal, the impeller blades were coated with a zirconium-based coating (Prabu *et al.*, 2006).

5. Experimental contributions:

Kala et al (2014) in their review referred to previous authors like Harnby et al. (1985); Girot et al. (1987) who mentioned the role of the geometry of the mechanical stirrer in the distribution of particles in the molten matrix (Kala, Mer and Kumar, 2014). Harnby et al. (1985) (as cited in Hashim et al., 1999) studied different designs of mechanical stirrers, as shown in figure (3), they concluded that stirring during stir casting helps to transferring particles into the liquid metal, and maintaining the particles in a state of suspension (Hashim, Looney and Hashmi, 1999).

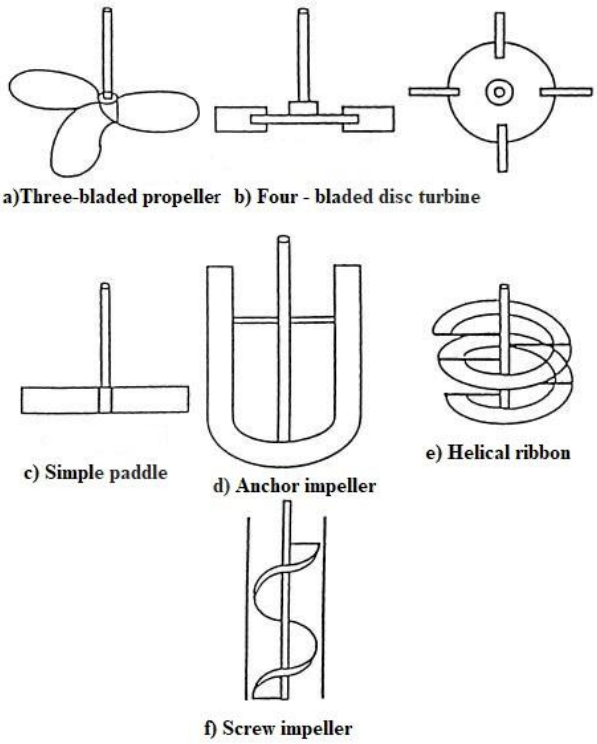


Figure (3):Mechanical stirrer designs (Hashim, Looney and Hashmi, 1999).

Hashim (2001) stated that the results of the experiments demonstrate the opposite of theoretical, mechanical properties like micro hardness is not uniform at the top, the bottom, and the middle of the ingot because of different parameters such as particle dispersion, cooling rate, and gravitational influence (Hashim, 2001).

Prabu et al. (2006) whereas they studied the impact of stirring speed and stirring time on the particles distribution in cast MMCs and they confirmed the stirrer design role in creating vortex to achieve the particle mixing without mention the details(Prabu *et al.*, 2006). The effect of stirrer design on the mixing time and the power consumption has been studied by several researchers. They concluded that mixing time is determined by the impeller design due it is a function of impeller design. It has been stated that the time required to attain a particular ratio approach to the ultimate mean concentration is said to be dependent on the impeller design (Joshi *et al.*, 2011a).

Su et al. (2010) used the finite element approach to explore the flow behavior of particles throughout the mixing process in the crucible, looking at factors such as blade angle, rotating speed, impeller diameter, and stirrer design. In addition, the authors proposed varying parameter levels to achieve uniform dispersion in the stir casting process (Su *et al.*, 2010).

In the preparation process of this approach, constant stirring of the molten metal matrix in a graphite crucible in a coal-fired furnace produces a homogenous mixture of composites that is immediately placed into the sand mold to solidify. Coal is used as a fuel for preparation. Figure (4) shows a schematic of a coal-fired furnace (Sable and Deshmukh, 2012).

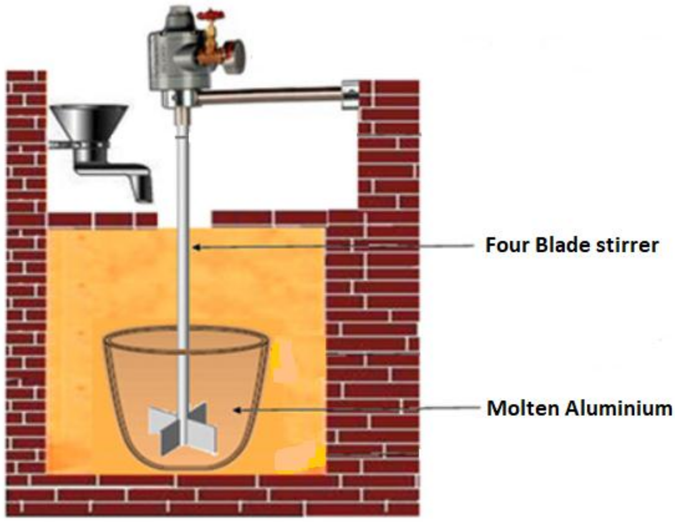


Figure (4):Experimental diagram of fabrication of AAMC (Sable and Deshmukh, 2012).

Sozhamannan et al. (2012) used the stainless steel four-blade stirrer without mention the dimensions as shown in figure (5)which was designed to produce the adequate uniform particle distribution. It is coated with zirconia to avoid the reaction between the stirrer and Al alloys at higher temperatures. The axial and radial flows are provided to avoid different stagnant zones in the liquid melt by stirrer(Sozhamannan, Prabu and Venkatagalapathy, 2012).

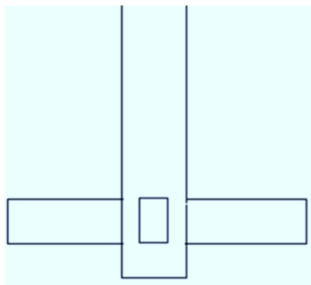


Figure (**5**):Four-blade stirrer (Sozhamannan, Prabu and Venkatagalapathy, 2012).

Haque et al. (2014) investigated experimentally the effect of pouring temperature and stirring speed on mechanical, microstructure, and machining properties of AAMC. They discovered via using the Taguchi Method that the ideal stirring speed for greater particle reinforcing homogeneity is 400 rpm for 10 minutes stirring. They conducted two steps of mixing manually at the first step when the alloy was in a semi-solid state and at the second step the composite slurry was reheated to a fully liquid state at (800°C) and then automatic mechanical mixing was carried out. They used the multi-blades stirrer as shown in Figure (6) and to avoid poor wettability between SiC particles and molting Aluminium alloy, they employed two-step stirring and added 4% Cupper as an agent without taking stirrer design, geometry, or dimensions into account (Haque, Ansari and Bharti, 2014).

Figure (6):Schematic view of multi-blades stirrer(Haque, Ansari and Bharti, 2014).Tony Thomas et al. (2014) studied impeller geometry, to find a solution for the most important MMC stir casting problems like uneven distribution, poor wettability between SiC reinforcements and melting Aluminum alloy LM6 , and cluster formation reasons(T. Thomas *et al.*, 2014). They modified the stirring process in two ways to yield the strength of AAMMC. The first way is by modified geometry to make various flow patterns to achieve uniform distribution. The second mechanism by modified of stirrer dimensions to increase the stirring force which cluster formation can be reduced, and the third mechanism is modified the ceramics reinforcements feeder (T. Thomas *et al.*, 2014). The stirrer has two blade assemblies, which are namely upper blade assembly and lower blade assembly. This two-blade assembly is arranged in a counter-clockwise direction. This geometry as shown in figure (7) makes molten aluminum form various flow patterns. This complicated flow pattern makes the SiCparticles mix evenly and reduces cluster formation (A. T. Thomas *et al.*, 2014).

Figure (7): Three kinds of stirrers (A. T. Thomas *et al.*, 2014).

El-Kady*et al.*, (2014) stated that the position of the stirrer has practically no significant influence on the hardness. A simple mechanical stirrer with two, three, or four blades, as seen in figure (8A), was inserted into the melt, and stirring began. The stirrer was made of stainless steel coated with Bentonite clay and had a defined diameter. The stirrer was installed in a special fixture that allowed the (h/H) high of immersedimpeller to ratio of the stirrer to be adjusted as shown in figure (8B). They observed that the porosity will decrease as the number of stirrer blades, the location ratio (h/H), and the diametric of impeller width to cruciblewidth ratio (d/D) increased. (El - Kady *et al.*, 2014).

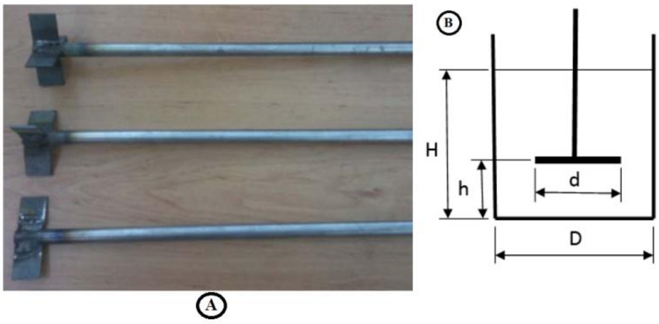


Figure (8): A: three kinds of stirrers B: The crucible and stirrer relative positions and dimensions (El -Kady *et al.*, 2014).

K. Paul andM.Sijo (2015) designed stainless steel impeller with two blades, four blades, and five blades. The results indicated that composite manufactured by a four-blade stirrer shows better properties than two blades and five blades. According to microstructure analysis results to get optimal mechanical properties the angle of the blades should be 30°, 45°, 60°, or 90°, and there should be four blades during the stirring process. This stirrer design as shown in figure (9) could avoid the formation of the vortex at the surface of the melt as much as to achieve uniform reinforcements particle dispersion.(Paul and Sijo, 2015)

Figure(9): Stirrer Blade (Paul and Sijo, 2015).

Shinde et al. (2015) attempted to optimize the stir casting method to manufacture AMC. The stirrer design, reinforcement feed rate, and the distance between mold and crucible during pouring metal were among the investigated parameters. They concerned on stirrer design especially the blade angle and number of blades as a very important parameter in stir casting which is required for the flow pattern, vortex formation, uniform reinforcement distribution in liquid metal, perfect interface bonding, and cluster avoidance. Also, they used different levels of reinforcement feed rate (Shinde, Kulkarni and Kulkarni, 2015).

Adat et al. (2015) considered the blade design of the stirrer as one of the important stirring parameters during manufacturing AAMC (Adat, Kulkarni and Kulkarni, 2015). The researchers simply specified the dimensions displayed in figure (4), the stirrer blade angles (45° & 60°), and the number of blades (three to four) in order to determine the flow pattern of the liquid metal during stirring and to provide homogenous distribution(Adat, Kulkarni and Kulkarni, 2015). They stated that the blade pattern significantly affects the flow pattern. Stirrer blades play the main role in forming the vortex of the molten matrix then the vortex creation guarantees bonding characteristics of matrix and reinforcement (Adat, Kulkarni and Kulkarni, 2015).

Figure (10)**:** Impeller (Adat, Kulkarni and Kulkarni, 2015).

Ramesh et al. (2017) showed a photo of a used stirrer in figure (11) without mentioning the dimensions. Its front end is attached with a graphite fan. The stirrer is inserted vertically into the crucible about one-third of its height after adding the ceramic particles. Appropriate methods have been provided for stirring through external means that can be attached to the oven at any point from above.The flow pattern of liquid metal is determined by the blade angle and number of blades (Ramesh, Koppad and Hemanth, 2017).

Figure (11)**:** Stirrer for uniform distribution (Ramesh, Koppad and Hemanth, 2017).

Singh et al. (2017) attempted to design and develop a novel cost-effective casting method for the production of MMCs. They used melt-stir-squeeze-bottom pouring to yield MMCs. Figure (12) shows the used impeller blades in both experiment and ANSYS Fluid simulation (Singh, Singh and Dvivedi, 2017). They confirmed the fact that the impeller design (blade angle) is a key issue for creating axial flow and uniform distribution of reinforcing elements.

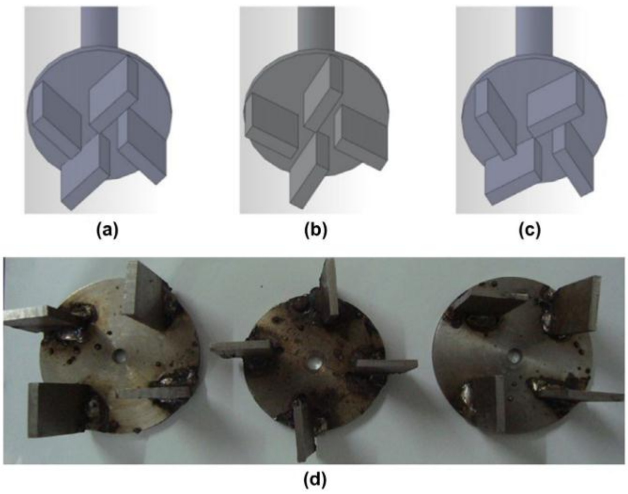


Figure (12): (a) 30° (b) 45° (c) 60° (d) Experimental impeller blades (Singh, Singh and Dvivedi, 2017).

Sharma et al. (2017) studied the influence of fly ash particles with aluminum melt on the wear of aluminum metal matrix composites. They specified the dimensions of the employed stirrer as 95 cm in length and a plus sign blade with a zigzag angle of 90 degrees on each side. Each side of the stirrer blade measured 9 cm in length. as shown in figure (13). But they didn't mention any effect of the stirrer design on the output of the stir casting (Sharma, Singh and Chaudhary, 2017).

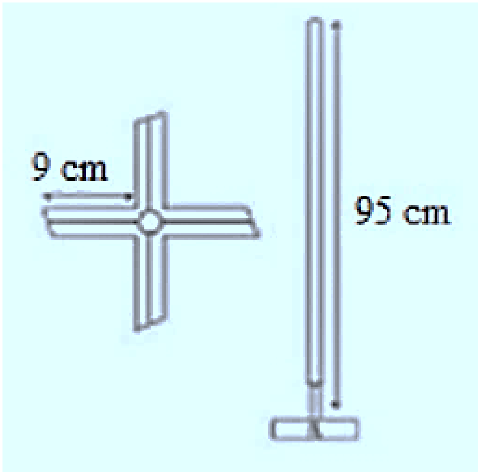


Figure (13):Four-blade stirrers (Sharma, Singh and Chaudhary, 2017).

Ramanathan et al. (2019) concluded that it is impossible to determine the preferred stirring speed without specifying the blade shape. The optimum speed is 600 rpm or a conventional stirrer profile with two blades which is shown in figure (14) (Ramanathan, Krishnan and Muraliraja, 2019).

Figure (14):Impeller (Ramanathan, Krishnan and Muraliraja, 2019).

Kumar et al. (2020) investigated at the micro-level; the particle dispersion by different stirrers where shown in figure (15) four-bladed stirrers and four-blade disc turbine stirrers is almost identical, but when we look at the microstructure of particles in composites, the result reveals that the microstructure of particles in composites by turbine stirrer is superior than simple stirrers (Kumar, Rana and Purohit, 2020).

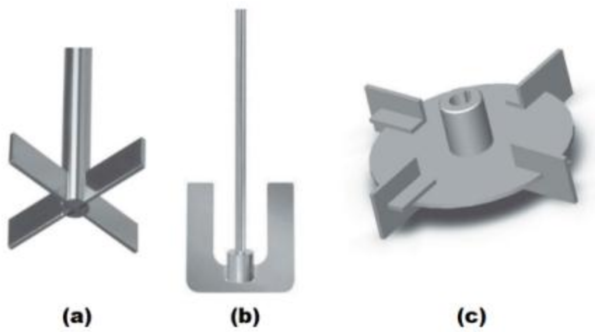


Figure (15):(a) Four-bladed stirrer, (b) U-shaped stirrer, (c) four-bladed disc turbine stirrer. (Kumar, Rana and Purohit, 2020)

The influence of stirring process parameters on the dispersion of silicon carbide particles is investigated by Mehta and Sutaria (2020). They confirm that the stirrer blade angle is the most important parameter for particle dispersion (Mehta and Sutaria, 2020). Stirrer geometry (blade angle) as 45°, 60°, 90° is shown in figure (16). Figure (17) shows the bottom pouring arrangement used topouring molten metal into a mold. (Mehta and Sutaria, 2020).

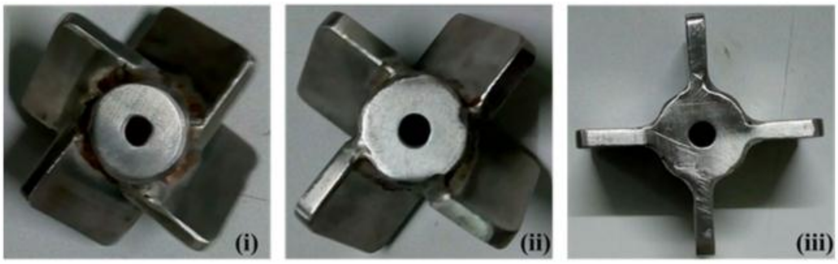


Figure (16):(i) 45 (ii) 60° (iii) 90° (Mehta and Sutaria, 2020)

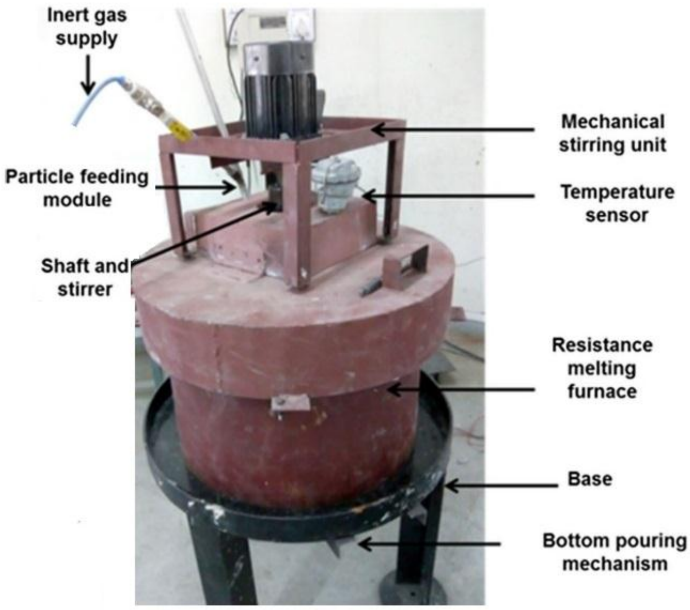


Figure (17): Bottom pouring arrangement (Mehta and Sutaria, 2020).

Finally, Krishnan et al. (2021) employed a stir casting method with a squeeze. Experiments have been conducted to verify the influence of blade geometry on the characteristics of metal matrix composites. The composite formed by the four-blade stirrer had the most consistently distributed reinforcing particles and the lowest porosity of the five different blades profiles evaluated, according to the microstructural examination. The composite formed by a four-blade flat mixer (B4) as illustrated in figure (18) has an overall tensile strength of 206 MPa, compressive strength of 642 MPa, and maximum hardness of approximately (45 HRB) (Krishnan *et al.*, 2021).

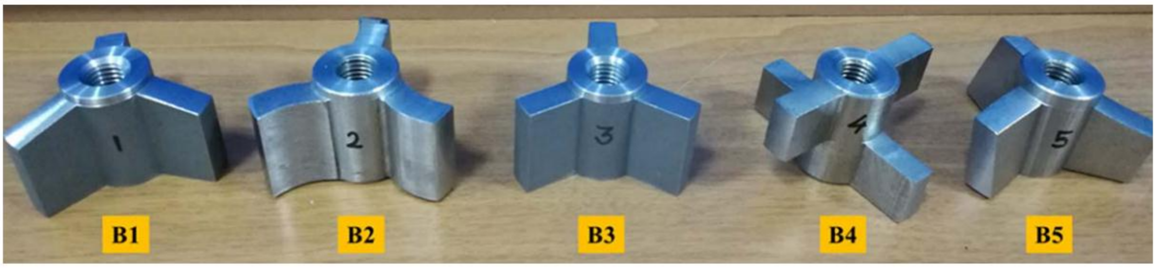


Figure (18):Five different stirrers profiles (Krishnan *et al.*, 2021).

6. The most related experiments parameters

The most related parameters classified according to what extent authors paid attention to them. Among the parameters which did not receive enough attention from the authors is a rate of reinforcement's particles feed which was 0.5 gram per second at (Shinde, Kulkarni and Kulkarni, 2015), stirrer stage (only a single stage), the pouring technique into the molds which was bottom pouring arrangement at (Mehta and Sutaria, 2020), and the using two-step mixing of reinforcement particles has only been observed on a few occasions like at (Auradi, Rajesh and Kori, 2014). The two-step mixing means the incorporation of reinforcing particles into the matrix includes the addition of partial reinforcement into the matrix followed by stirring and again the addition of the remaining reinforcement material followed by stirring another time. While the material of stirrers was stainless steel coated for example with a zirconium-based coating at (Prabu *et al.*, 2006) or not coated like at (Ramesh, Koppad and Hemanth, 2017), stirrer position was 2/3 of the height of the molten metal from the bottom of the crucible like at (Prabu *et al.*, 2006)(Shinde, Kulkarni and Kulkarni, 2015), or blade should be 20 mm above the bottom of the crucible is at (Adat, Kulkarni and Kulkarni, 2015) and reinforcement's size unit that was micron in all experiments that reviewed. The following table (2) explained the most mentioned parameters that work to optimize stirring parameters according to modifiedstirrer design.

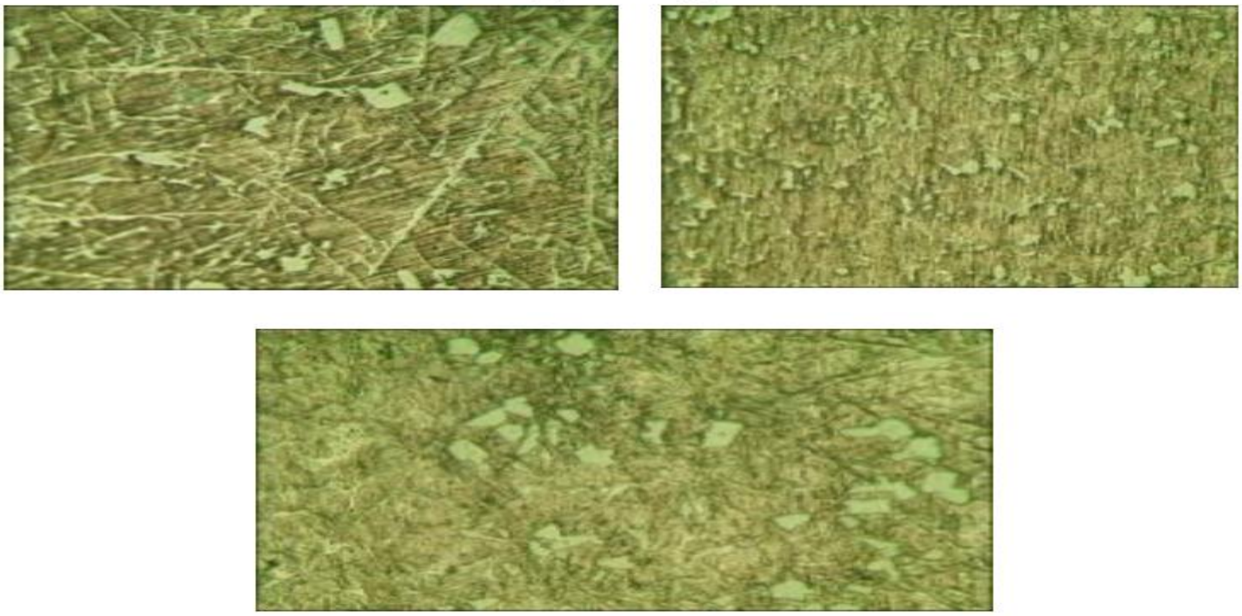
7. Responds and output measurements

One of the challenges facing researchers is that the direct response and results of the experiment, which is what extent uniform of particles reinforcements distribution is qualitative data, not measurable and therefore they remedy the challenge by measuring the quantitative indirect outcomes of the experiment such as mechanical properties like density, tensile strength, and hardness, etc.

The influence of stirring parameters on particle dispersion inside the crucible was evaluated by the microstructure analysis. The microstructural analysis was performed with a metallurgical microscope equipped with image analysis software(Mehta and Sutaria, 2020). The uniform distribution of the reinforcement particles can be viewed in all the composites produced. Researchers have attempted to analyze what is happening in the neighbors of each particle by using visual inspection to understand the effect of stirring parameters and among them stirrer design.

Paul and Sijo (2015) investigated the number of blades as a stirrer parameter of stir casting. Optical microscopy was used to observe the microstructures of the polished and etched specimens as shown in figure (19). The tendency to form a particle cluster was found to be higher in four blade stirrers(Paul and Sijo, 2015).

(a) (b)



(c)

Figure (19):Visual inspection of composite with (a) 2 Blades, (b) 4 Blades, and (c) 5 Blades stirrer (Paul and Sijo, 2015).

Su et al. (2010) used typical scanning electron microscopy (SEM) micrographs of the composite prepared at the different stirring parameters to shows that the additives in composites are ingredients and the effect on the distribution of particles of carbide silicon is considerable (Su *et al.*, 2010).On the other hand, by comparing the measured data with their theoretical measurements, the density, and percentage of porosity volume and grain size of the composites were determined to optimize mechanical properties(Kumar *et al.*, 2010)(Sajjadi, Ezatpour and Torabi Parizi, 2012).

8. Visualization experiments

To better understand what happens in the stir casting process, which is carried out in a closed crucible, and before adopting the numerical method, the researchers used the simplest simulation method by using materials with similar properties at room temperature. Ghosh and Ray (1988) used the cold model experiment by mixing plastic beads in water to visually observe the role of stirring speed and the size of the impeller on the retention of beads in water. (Ghosh and Ray, 1988)Hashim et al. (2002) depended on visualization experiment results by using glycerol and polystyrene particles in a perspex crucible(Hashim, Looney and Hashmi, 2002a). Naher et al. (2003) replaced semisolid aluminum and SiC reinforcement particulate with other fluids with similar characteristics and that used in aluminum MMCs when three different stirrer types provided agitation (Naher, Brabazon and Looney, 2003)(Sun *et al.*, 2017).

9. The stirring parameters optimizing

The researchers agree that stirrer geometry, stirring speed, stirrer position, and stirring holding are among the most important stirring parameters. The influence of such parameters on particle distribution in the matrix has been explored either by sectioning the casted samples according to different conditions or by evaluating the flow field using computational methods with assuming that fluid properties remain unchanged (Mehta and Sutaria, 2020). The stirring parameters optimizing has been offered to solve these mentioned stir casting problems. The researchers admitted that optimizing stirring parameters such as stirring speed, rotation of stirrer, blade angle to stirrer axis caused avoidance of particle segregation and clustering(Ravi *et al.*, 2005). Homogeneous distribution of the particles is required to optimizing the mechanical properties. This can only be achieved by the proper impeller as the main part of the stir casting route. The performance of different impellers and their effects have not been reported in the majority of literature about stir casting(Paul and Sijo, 2015),(Prajapati and Kumar, 2018).

Almadhoni and Khan (2015) reviewed the different stirring process parameters among them stirrer design, however, they mentioned stirrer design without the proper shape and size analysis (Almadhoni and Khan, 2015)(N. S. Kalyankar, R. D. Shelke, 2016). In this paper, stirrer design, impellers shapes, sizes, and materials will be reviewed within stir casting literature and what is related to the topic even in the literature about the chemical stirred vessel. Finally, hundreds of articles were accessed but were not included in this review to stay within this paper scope.

10. Experimental limitations

According to George et al. (2015), experimental methods do not provide a clear understanding of the stir casting process because it is extremely dangerous to handle high-temperature molten metals manually. As a result, the majority of research work done to date has relied on a random selection of parameters rather than a proper design of experiments.

As a result, using a design of experiment that includes all important characteristics is predicted to produce superior findings(Sijo and Jayadevan, 2016). The stirring action in a cast MMC must spread the reinforcing particles effectively and uniformly. Stirring is usually done in a closed vessel or crucible, where efficiency can't be assessed, hence Numerical simulation approaches are needed to guide experimental study(Hashim, Looney and Hashmi, 2002a). To inform experimental study on what happens in a closed crucible where mixing efficiency cannot be seen, simulation approaches are necessary. The use of numerical simulation to aid experimental investigation is a powerful technique(Su *et al.*, 2010).

11. Conclusions

1. Firstly, the uniform dispersion of reinforcement particles is still a dependent variable alone which most researchers have focused on to obtain the desired mechanical properties. And because their output, the dependent variable is difficult to measure, so the researchers shifted their focus to outcomes, the desired mechanical properties.
2. There are many parameters in stir casting so it is normal to anticipate few reliable cumulative findings from literature

reviews. It appears that the vast number and overlapping of parameters affect the uniform distribution of reinforcement particles although researchers on their way to the right approach have obtained promising outcomes with their specific cases.

3. Stirrer designs will have changed with the densities of reinforcements.
4. A number of the images of the stirrer are blurred although research indicates that the design of the stirrer plays a significant effect to avoid stir casting problems such as uneven distribution, low wettability, and cluster formation.
5. The researchers mentioned the stir casting problems without specifying the cause and effect relationship and without ranking themost Influential factors. Nonhomogeneous reinforcement particle distribution is might cause by other issues such as weak stirrer design, poor wettability, or if it is a problem per se.
6. Stir casting was done in a variety of ways, the authors recommended it different parameters according to different situations, however, Stirring time range was from 5 to 30 minutes, stirring speeds were from 350 to 700 r.p.m, and with different design of stirrer includes blades number, profile, shape, size, blade angles, positions. Also, the stirrer position was 2/3 of the height of the molten metal from the bottom of the crucible.
7. The design of the profile of the impeller blade and its numbers affect both the stirring time and stirring speed as independent variables so without knowing the stirrer design, it is difficult to generalize any recommended stirring parameter.
8. Although the particle distributions produced by different stirrers may appear to be similar, the Metallography Analysis results demonstrate that the physical microstructure of particles in composites produced by complicated stirrers is distinct and maybe superior than those produced by simple stirrers.
9. Based on a survey of the literature, the following lists a number of multiple and interrelated factors that influence the dispersion of particles in the molten matrix. As a result, any experiment with factor optimization without the use of numerical or statistical methods would be extremely difficult and unattainable.
10. This article discovered that there are several gaps in experimental research for optimizing steering parameters, including:

- Analyzing the effect mechanisms of the impeller on the flow patterns, vortex size, power number that have an impact on the performance of the impeller.
- The specified adjustments that should be made to stirrer designs for different densities of reinforcements that have a lower or higher density than the melted Aluminum, such as Silica floating or silicon carbides sinking, to avoid the extra vortex at the surface or bottom of the melt.
- The impact of rotation directions, rate of reinforcements feed and its location, stirrer position, and the variable distance of the stirrer to the bottom of the crucible are potential scopes for future work.

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Table (1): Factors influence particle dispersion in a molten matrix

No.	Influencing factors	References
1	The geometry of the mechanical stirrer,	(Sijo and Jayadevan, 2016)(Annigeri and Veeresh Kumar, 2017)(Mehta and Sutaria, 2020)
2	Position of the mechanical stirrer in the melt,	(Singh, Soni and Rana, 2020)(Muhammad and Jalal, 2021)
3	Various stages of impeller stirrer.	(Biswas*et al.*, 1999)(Sahu and Sahu, 2018)
4	Stirrer material	(Naher, Brabazon and Looney, 2005)(Sable and Deshmukh, 2012).(Sozhamannan, Prabu and Venkatagalapathy, 2012)(Ramesh, Koppad and Hemanth, 2017)(Ramanathan, Krishnan and Muraliraja, 2019)(Prabu*et al.*, 2006)
5	The feed rate of reinforcements	(Sahin, 2003)(Almadhoni and Khan, 2015)(Dhavamani and Alwarsamy, 2012)

6	Stirring temperature	(Haque, Ansari and Bharti, 2014)(Kumaraswamy, Bharat and Krishna Rao, 2018)
7	Constituent material properties (viscosity an density)	(Sozhamannan, Prabu and Paskaramoorthy, 2010)(Arya and Telang, 2020)(Ceschini*et al.*, 2017)
8	Stirring speed	(Vishnu Prasad and Jayadevan, 2016)(Sahu and Sahu, 2017)(Mehta and Sutaria, 2020)
9	Reinforcement particles types and properties (density, wettability, flotation ability)	(Ray, 1993)(Khelge*et al.*, 2021)
10	Reinforcement volume fraction	(Uyyuru, Surappa and Brusethaug, 2006)(Rozhbiany and Jalal, 2019)
11	Stirring time (Holding time)	(Bisane*et al.*, 2015)(Almadhoni and Khan, 2015)(Yüksel, AYBARÇ and Ertuğrul, 2020)
12	Reinforcement particles size and shape	(Kim and Hahn, 2006)(Shirvanimoghaddam*et al.*, 2016)(Balasubramanian and Maheswaran, 2015)
13	Wetting agents	(Malaki*et al.*, 2021)(Clyne TW, 1993)
14	Preheat temperature of reinforcements	(Almadhoni and Khan, 2015)(Bharath*et al.*, 2014)(Aybarc*et al.*, 2019)
15	Melting and pouring temperature	(Ramanathan, Krishnan and Muraliraja, 2019)(Ravikumar, Reddappa and Suresh, 2018)
16	The preheated temperature of the mold	(Bharath*et al.*, 2014)(Almadhoni and Khan, 2015)(Shankar *et al.*, 2013)(Almadhoni and Khan, 2015)(Rozhbiany and Jalal, 2019)
17	Solidification rate and behavior	(Yang *et al.*, 2017)(Zhou *et al.*, 2020)

Table (2): The most optimized mentioned parameters

No.	Year	Stirring speed RPM rotations per minute	Stirring time (holding time) Minutes	Stirrer- Impeller blade	Figures Number	References
1	1985	not too high or too low	*N.A	Different types of stirrer have explained	figure (3)	(Hashim, Looney and Hashmi, 1999)
2	2006	600	10	N.A	without figure	(Prabu*et al.*, 2006)
3	2012	450	10 -20	four blade Stirrer	figure (5)	(Sozhamannan, Prabu and Venkatagalapathy, 2012)
4	2014	600	10	The blade is 18 mm width and 25 mm breadth are twisted 45°	figure (7)	(T. Thomas *et al.*, 2014)
5	2014	500	6	Four blades	figure (8)	(El -Kady*et al.*, 2014)
٧	2014	400	10	Multi blades	figure (6)	(Haque, Ansari and Bharti, 2014)
٨	2015	300	7-10	3-4. Blade - blade angles are (45° & 60°)	figure (10)	(Adat, Kulkarni and Kulkarni, 2015)
9	2015	600	10	Blades should be 30°, 45°, 60°, or 90°, and there should be four blades.	figure (9)	(Paul and Sijo, 2015)
10	2015	300	5	Multi blades	without figure	(Shinde, Kulkarni and Kulkarni, 2015)
11	2017	100	*N.A	Blade having zigzag angle 90° of each side. The length of every side of stirrer blade was 9 cm each.	figure (13)	(Sharma, Singh and Chaudhary, 2017)
١٢	2017	550	6	4 blades	figure (12)	(Singh, Singh and Dvivedi, 2017)
13	2020	350-400	15	Four-bladed disc turbine stirrer	figure (15)	(Kumar, Rana and Purohit, 2020)
14	2019	600	5-10	A typical two-blade stirrer profile.	figure (14)	(Ramanathan, Krishnan and Muraliraja, 2019)
15	2020	400	6	4 blades stirrer blade- blade angle as 45°, 60°, 90°	figure (16)	(Mehta and Sutaria, 2020)
16	2021	550	5	a four-blade mixer	figure (18)	(Krishnan *et al.*, 2021)

***N.A:** Not available

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