

## Hydrodynamic analysis of different impellers used in the stir casting process

### Analisis hidrodinámico de diferentes impulsores utilizados en el proceso de stir casting

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#### Abstract

In this work, the hydrodynamic behavior of four types of impellers used in the manufacture of metal matrix composites (MMC) through the stir casting process is analyzed, in order to determine which of them is adequate to generate a uniform flow in the metal. Liquid and thereby achieve a uniform distribution of reinforcing particles. The impellers analyzed are the belt type, the vane type, the propeller type and the turbine type. As a first part, the parameters of each one of them were determined to later carry out the modeling in SolidWorks. Some properties of liquid aluminum were also determined, such as density and viscosity for a melting temperature. These characteristics were assigned in the software used. As results, the flow velocities and turbulences that occur with each impeller were obtained, being the propeller-type impeller the one that shows a more uniform distribution in terms of velocities.

**Impeller, Stir Casting, metal matrix composites**

#### Resumen

En este trabajo se analiza el comportamiento hidrodinámico de cuatro tipos de impulsores utilizados en la fabricación de compuestos de matriz metálica (MMC) mediante el proceso de stir casting, con el objetivo de determinar cuál de ellos es adecuado para generar un flujo uniforme en el metal líquido y con ello lograr una distribución uniforme de partículas de refuerzo. Los impulsores analizados son el de tipo cinta, las paletas, el de hélice y el de turbina. Como primera parte se determinaron los parámetros de cada uno de ellos para posteriormente realizar el modelado en SolidWorks. También se determinaron algunas propiedades del aluminio líquido como son la densidad y la viscosidad para una temperatura de fusión. Estas características se asignaron en el software utilizado. Como resultados, se obtuvieron los regímenes de velocidades de flujo y las turbulencias que se presentan con cada impulsor, siendo el impulsor tipo hélice el que muestra una distribución más uniforme en cuanto a velocidades.

**Impulsor, Stir Casting, Compuestos de matriz metálica**

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## Introduction

The stir casting process is used to obtain metallic matrix compounds (MMC) and was developed in 1968 when alumina particles were added to the aluminum casting. The stages in which it develops are three: the fusion of the metal, the addition of particles and stirring.

In the agitation system used, several components are necessary for its operation, these consist of a crucible which will contain the matrix material and a mechanical mixer that consists of an impeller mounted on a shaft connected to a drive unit.

Agitators are classified into axial flow and radial flow. The first allows a flow that emerges from the impeller at approximately 45 ° presenting a recirculation, returning to the central area of the impeller, creating a flow field back and forth parallel to the axis of rotation. This type of flow occurs with a Reynolds of between 200 to 600, and it becomes radial flow when the Reynolds number decreases. The second generates radial flow for any Reynolds and provides high tangential velocity but very low drive capacity.

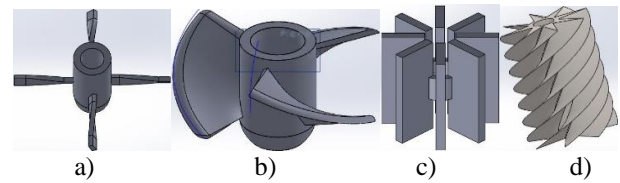
The types of axial, radial and tangential flow will depend on the type of impeller, the characteristics and size of the fluid, as well as the proportions of the container (crucible). The velocity of the fluid at any point in the crucible has three components, and the predominant flow will depend on the variations in motion and the velocity of each component.

The radial flow is the first component of the fluid velocity, this velocity is radial and acts perpendicular to the axis of the impeller.

Longitudinal or axial flow is the second component, and it acts in a direction parallel to the axis.

Tangential or rotational flow is the third, this component acts in a tangential direction to the circular path described by the impeller.

The impellers are classified as propeller, turbine and blade (Figure 1), which are related to the types of flow already mentioned.



**Figure 1** Impellers a) blades b) propeller, c) turbine and d) tape.

Source: Self-made

## Methodology

The work was carried out by implementing numerical simulations by the finite element method by means of SolidWorks (CFD) 2018 software, where the hydrodynamic behavior of the three-dimensional flow within the stirred container (crucible) was resolved. This from the solution of the continuity equations (Eq. (1)) and Navier-Stokes (Eq. (2)) in each of the cells into which the volume under study was divided.

$$\nabla \vec{V} = 0 \quad (1)$$

$$\rho \frac{\delta \vec{V}}{\delta t} + (\vec{V} * \nabla) \vec{V} = -\nabla p + \rho \vec{g} + \mu \nabla^2 \vec{V} \quad (2)$$

The materials chosen for study were the aluminum alloy A60061 reinforced with Al<sub>2</sub>O<sub>3</sub> (alumina) particles. The mean particle size was 15.3 μm.

The parameters considered in the oven are those shown in table 1.

Element	Parameter	Value
Aluminum	melting temperature	620°C
	casting temperature	750°C
	density	2700 kg/m <sup>3</sup>
Melting pot	material	grafito
	capacity	3.68 m <sup>3</sup>
	thickness	25.4 mm
	Diam. upper D	0.78 m
	Diam. Lower d	0.53 m
	Height H	0.90 m
Agitator	Impeller type	Paleta, hélice, turbina o cinta
	Flow type	Num. de Reynolds

**Table 1** Characteristics of the oven

Source: Self-made

The volume of the crucible was determined with equation 3.

$$Vr = \pi * H * (D^2 + d^2 + D * d) \quad (3)$$

Taking into account the data in table 1, the volume of the crucible obtained is  $V_r = 3.69 \text{ m}^3$ .

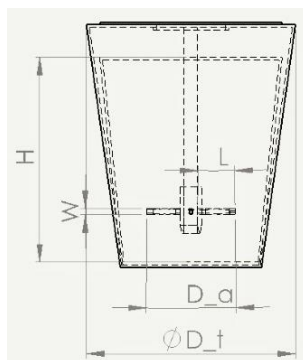
Since only 75% of the crucible capacity must be used at most to avoid breakdowns, the maximum mass that can be entered is  $m_{max} = 2,500 \text{ kg}$ .

For the sizing of the different impellers analyzed in this study, the relationships in Table 2 were used.

Where  $D_a$  is the diameter of the impeller,  $D_t$  is the diameter of the crucible,  $E$  is the distance from the bottom of the crucible to the impeller,  $H$  is the height of the metal,  $W$  is the width of the impeller,  $J$  is the width of the plate,  $L$  is the length of the impeller blade and  $f$  is the space between the plate and the crucible (Figure 2).

Impeller type			
Pallas	Propeller	Turbine	Headband
$\frac{H}{D_t} = 1$	$\frac{H}{D_t} = 1$	$\frac{H}{D_t} = 1$	$\frac{H}{D_t} = 1$
$\frac{D_a}{D_t} = 0.33$	$\frac{D_a}{D_t} = 0.33$	$\frac{D_a}{D_t} = 0.33$	$\frac{D_a}{D_t} = 0.33$
$\frac{E}{D_t} = \frac{0.17}{0.34}$	$\frac{E}{D_t} = 0.33$	$\frac{E}{D_t} = 0.33$	$\frac{E}{D_t} = 0.33$
$\frac{W}{f} = 0.177$		$\frac{W}{D_a} = 0.2$	
$\leq 45^\circ$	$\leq 25^\circ$	$\frac{g}{D_a} = 0.25$	$\leq 25^\circ$
$\frac{J}{D_t} = 0.1$	$\frac{J}{D_t} = 0.1$	$\frac{J}{D_t} = 0.1$	$\frac{J}{D_t} = 0.1$
	$\frac{f}{J} = 0.02$	$\frac{f}{D_t} = 0.02$	$\frac{f}{J} = 0.02$

**Table 2** Relationships between parameters for the different drivers  
Source: Self-made



**Figure 2** Parameters of a stirring system  
Source: Adapted from Castillo

The density of aluminum at melting temperature (933 K to 1190 K) was determined with equation (5) proposed by Preston-Tomas

$$\rho = c_1 - c_2(T - T_{ref}) \tag{5}$$

Using data from  $c_1 = 2377,23 \frac{\text{kg}}{\text{m}^3\text{K}}$ ,  $c_2 = 0,311 \frac{\text{kg}}{\text{m}^3\text{K}}$ ,  $T_{ref} = 933,47\text{K}$  y  $T = 1073 \text{ K}$ , the density was  $\rho = 2333,84 \frac{\text{kg}}{\text{m}^3}$ .

Another property to take into account during the simulation was the viscosity, which was determined by equation (6).

$$\text{Log}_{10} \mu = \frac{\mu}{\mu_o} = -a_1 + \frac{a_2}{T} \tag{6}$$

Where  $\mu_o = 1\text{mPa s}$ ,  $a_1 = 0,7324$ ,  $a_2 = 803.49\text{k}$  and the resulting value was  $\mu = 0.001035 \frac{\text{kg}}{\text{m s}}$

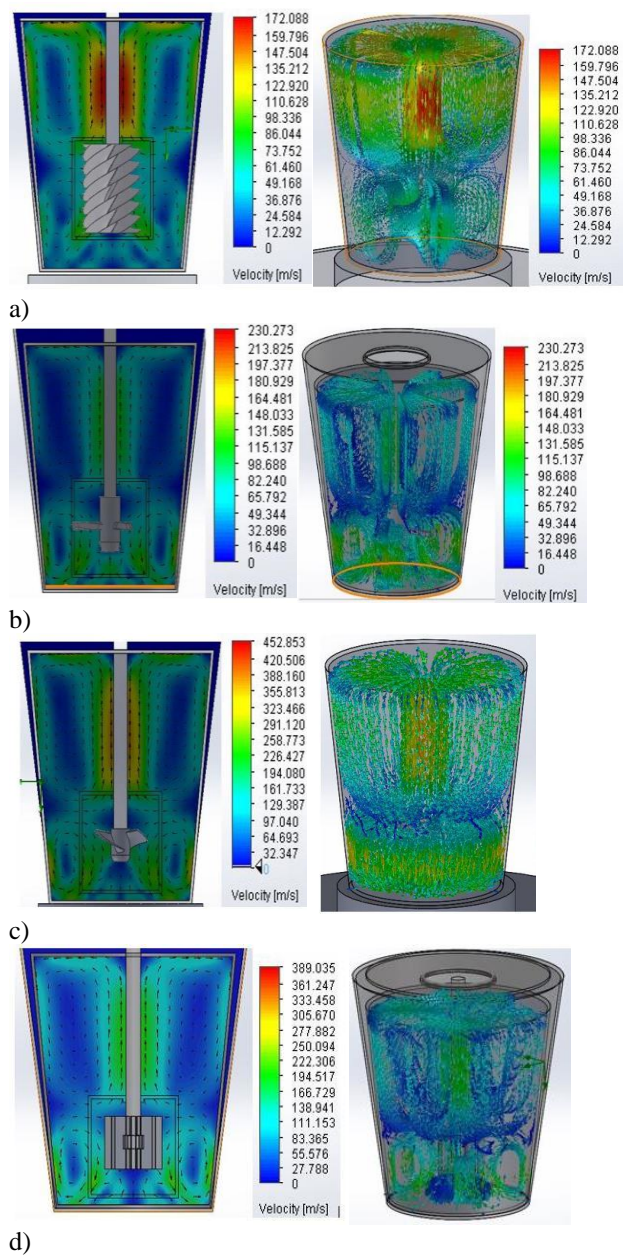
In order to carry out the simulation of the study and that the parameters have a limit border, three extra pieces were developed: Two cylinders and a solid that simulated the liquid inside the crucible. One of the cylinders surrounds the impeller in all its geometry and was used to indicate the rotating section. The second cylinder is a larger one that is enveloping and containing the crucible and the entire system to be simulated. Its purpose was to contain the area where environmental forces such as pressure and gravity act.

**Results**

After having made the models, having entered the parameters for the simulation, and running the simulation, the resulting velocity values are shown in Figure 4 for the different impeller models analyzed.

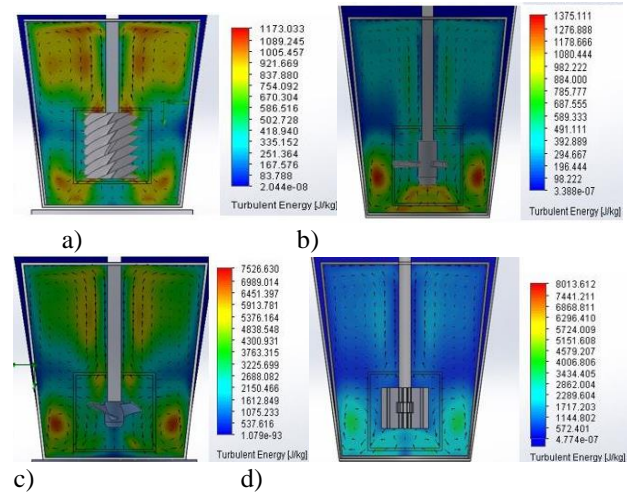
As observed in each of the analyzes, a vortex is generated above the impeller and a vortex below it. This is most marked in the situation where the turbine impeller and the belt impeller are used.

In contrast, the impeller that generates more homogeneous flow lines is the propeller impeller.



**Figure 3** Speeds (m / s) obtained during the dynamic simulation with the different impeller models. a) Belt, b) Vane, c) Propeller and d) Turbine  
Source: Self-made

Although the turbulence energy can be predicted in Figure 3, the values of this variable can be observed more clearly in Figure 4. The impellers that generate the highest concentrations of turbulence energy are the blades and propellers.



**Figure 4** Turbulence energy (J / kg) obtained from the simulation when applying the various impellers. a) Belt, b) Blades, c) Propeller, d) Turbine  
Source: Self-made

In the case of the turbine impeller, even when the turbulence energy values are shown constant, their values are high compared to those resulting in the other analyzes.

**Conclusion**

The various impeller models and the various parameters that define them, as well as the physical characteristics of the molten metals and the particles added to generate metal matrix composites, complicate the process of selecting a good stirring system for the Stir process. Casting.

However, the various finite element computer programs have come to be a great support for obtaining approximations of hydrodynamic behavior.

For this work, the SolidWorks simulation part allowed to solve the continuity equations of a stirring system with different impellers, to determine the speed and turbulence regimes inside the crucible.

The results of the simulation indicated that the propeller type impeller is the one that generates flow lines with more homogeneous speeds and that, therefore, would generate a better distribution of the particles.

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