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Effects of some settings of rotational-molding process on the aeromechanical performance of an axial fan.

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Abstract. The study purposes to establish the influence of some settings of the conventional rotational-molding process on the aeromechanical performance of a hollow-blade axial fan. It is recognized that the surface state quality, the material characteristics and the blades design have an effect on the performances of the turbomachines. The use of conventional rotational-molding is an innovative method well suited for achieved hollow-blade fans, reduced cost and relatively easy manufactured. In the present work the material employed represents one grade of linear low-density polyethylene (LLDPE-3200 natural, supplied by "C4-Polymers Company"). The variables of the process studied attend the initial mass of polyethylene powder, the oven temperature and the heating time. For comparisons, a fan of similar geometry machined in an aluminium block serves additionally as a reference. The results show an optimal choice of the settings of the manufacturing process is necessary to achieve the desired aeromechanical performances for this fan.

1. Introduction

The rotational molding is distinguished since the 1950s. There has been an increasing number of researches on this issue in recent years: design research, improvement of the performance of hollow blade rotor achieved by rotational molding [1,2] and optimization of this process have been considered [3]. Crawford et al [4,5] presented the cooling method and adjusted the pressure in the mold. But this process is only suitable for pieces with ordinary details and significant size. Pieces with structural complexity represent a crucial challenge with this method. Especially in the applications related to the automotive vehicle domain [6,7]. Therefore, to seize upon the opportunity to develop this emerging market, it is necessary to endeavor to better understand the parameters in rotational molding process which can have an effect on aerodynamic performances [8]. Nowadays, the plastic fans are produced by injection molding. In this work, the several fans produced by rotational molding process have been characterized in terms of aerodynamic performances.

1.1. Reference machined aluminium fan

To measure the advantages or disadvantages of a rotational molding process to produce fans, a reference machined aluminum fan is designed with the same specifications with respect to the same design point (Figure 1). Geometric parameters of fans are defined using the MFT code (Mixed-Flow 3D Turbomachinery) developed in the LIFSE laboratory [9]. The calculation of blades shape is based on empirical and analytical laws derived primarily from the results of tests made on records NACA65.

Figure 1. Photographies of (a) a rotational moulded fan and (b) the reference aluminium machined fan

The chosen geometry is a six blade axial fans with a hub-to-tip radius ratio R_{int}/R_{max} equal to 0.365 with tip radius R_{max} equal to 179 mm and hub radius R_{int} equal to 65.4 mm. The fan is built up from blades with modified NACA-65 profiles with a mean chord equal to 74 mm (Table 1).

Table 1. Characteristics of the blade cascade of studied axial fan

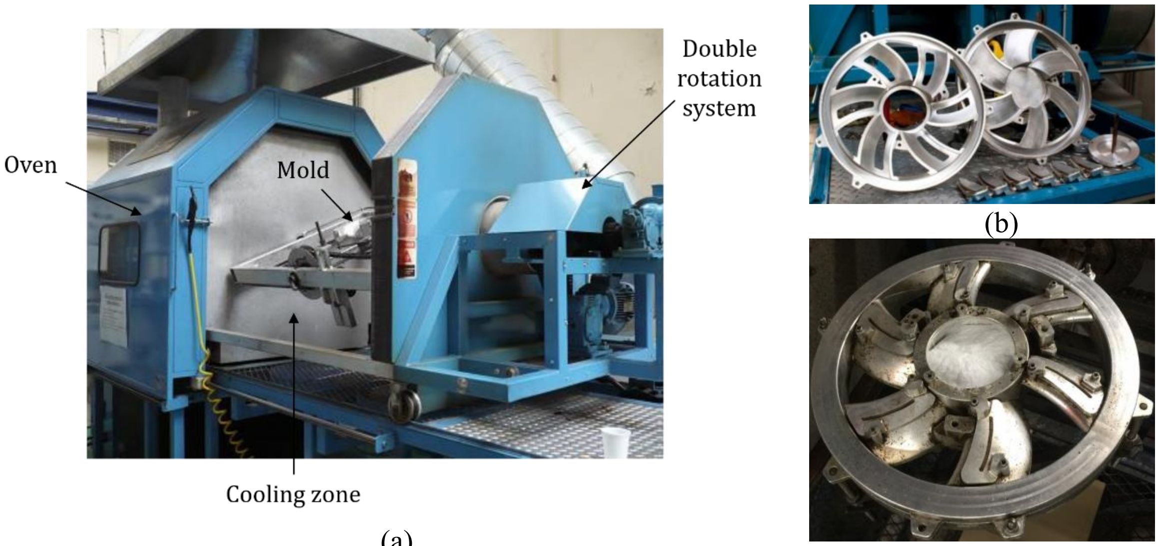
Layer	Radius (mm)	Chord (mm)	Solidity	Stagger angle (°)	Profile
Hub	65.4	66.6	0.97	53	NACA 65(07)15
Mid-span	122.2	74.0	0.58	66	NACA 65(10)13.5
Tip	179.0	81.3	0.43	70	NACA 65(11)12

1.2. Manufacturing process of rotational moulded axial fans

Currently, about 90% of the production by rotational molding is made from polyethylene (PE), which is suitable for non-technical applications (Motorway tags, toys ...) and for uses at ambient temperatures. In addition, the costs of manufacturing and materials PE are inexpensive compared to conventional molding materials. Therefore, the production of fans by rotational molding is very promising, and they enjoy a proper opportunity to develop. In the content of this study, we use polyethylene powder (LLDPE-3200) provided by C4-Polymers Company. This powder possesses a melting point of 115°C, a density of 938 kg/m^3 and a particle size of about 125-250 µm.

To produce the fans, the rotational molding machine LAB 40 of Shuttle type built by STP was used in PIMM laboratory (Figure 2). This set-up allows controlling various parameters as the temperature T_{oven}, the time employed to heat the mold Δt_{oven} and the two rotational speeds of the mold.

Two other parameters are investigated in this study: the mass m of polymer powder fed inside the mold and the cooling time of fans Δt_c after the heating step in the oven. The polymer powder filling is presented in the Figure 1b and 1c. The fill material of the mold is done in the her center and on the grooves of the blades. When it rotates, material will automatically provide to cover the border of the fan under the effect of centrifugal force. The purpose is to maintain stability and equalize the pressure inside the mold including two stages heating and cooling mold.



(a) (b) (c)

Figure 2. Photographies of the rotational molding system. (a) LAB 40 rotational rotational molding machine, (b) axial fans mold, (c) polymer powder filling.

The filled mold is then placed inside the oven. In the heating phase, the mold rotates on two axes with 3.3 rpm and 7.1 rpm. The polymer powder is a melt and the rotation of the mold according to the two axes provides a uniform distribution of material on mold walls. In a second step, the mold is placed outside the oven, in the cooling zone using blown air.

The effects of relevant factors of the rotational molding process are studied here: oven temperature, time of heating and powder mass. On one hand, if the heating time or temperature is not enough, the melting and density are insufficient. This reduces the hardness of the finished piece. In another way, if the heating times or is high, the will be and the piece becomes fragile. The volume of powder equally affects the quality of propeller: as thickness or durability. Also, if we fill too much powder in the mold, it may lead to fix powder in the mold (required pinched or too confined space), then profile of the fan is uneven because of the lack of powder.

In this study we will consider these factors (mass of material, oven temperature, heating time). To distinguish each rotomolded fan, a nomenclature is adopted following the code:

$$\mathbf{PEL} - \boldsymbol{m} - \boldsymbol{T_{oven}} - \boldsymbol{\Delta t_{oven}} - \boldsymbol{\Delta t_c}$$

- Material used: **PEL** - low density polyethylene (LDPE-3200)

- Mass of material $\boldsymbol{m} = [300\ g, 400\ g, 500\ g]$

- Oven temperature $\boldsymbol{T_{oven}} = [250°C, 285°C, 330°C]$

- Heating time $\boldsymbol{\Delta t_{oven}} = [12\ min, 15\ min, 20\ min]$

- Cooling method for mold: cooling by air blowing for 20 min

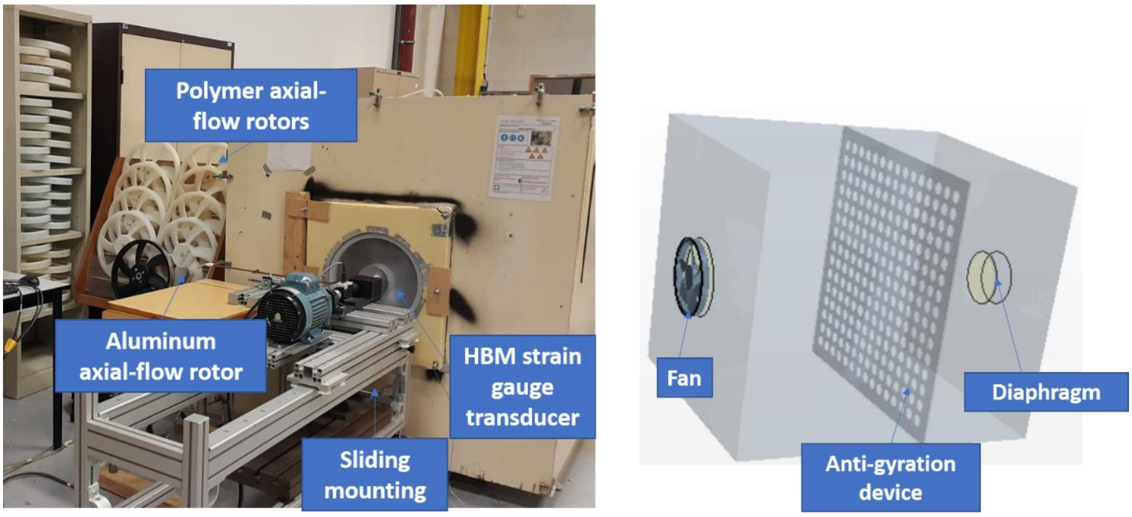
The table 2 presents the nine fans made with 500 g of polymer powder. The mass of powder used is a critical setting due to economic reasons, as the heating times and cooling. If these variables are minimum, the fans manufacture is less expensive. Oven temperature has to be higher than the melting point material but to be minimized too.

Table 2. Characteristics of considered rotomolded fans using 500 g of polymer powder with a cooling time of 20 min by air.

Fan designation	Mass m (g)	Oven temperature T_{oven} (°C)	Oven time Δt_{oven} (min)
PELD-500-250-12	500	250	12
PELD-500-250-15	500	250	15
PELD-500-250-20	500	250	20
PELD-500-285-12	500	285	12
PELD-500-285-15	500	285	15
PELD-500-285-20	500	285	20
PELD-500-330-12	500	330	12
PELD-500-330-15	500	330	15
PELD-500-330-20	500	330	20

2. Aerodynamic test bench

Aerodynamic performances of fans are measured with an air suction test bench (Figure 3) built agreeing to the ISO-5801 standard [10]. This set-up sizes 1.3 m ×1.3 m ×1.8 m. Fans are placed in the inlet section with her drive system.



(a) (b)

Figure 3. ISO-5801 aerodynamic test bench: (a) photography of the axial fan, shaft and electric motor and (b) the box.

Pressure elevation Δp is measured at the wall casing with an absolute precision of $\pm 0.1\ Pa$. A pierced plate is placed inside the set-up to prevent from gyration. The air flow rate q_v is measured with respect to the ISO-5167 standard [11] and set with diaphragms of various sizes at the outlet as presented in equation (1):

$$q_v = \frac{\alpha \epsilon \pi d^2}{4}\sqrt{\frac{2\Delta p}{\rho}} \quad (1)$$

Where α and ϵ are constants, d the diaphragm diameter, Δp the static pressure and ρ the air density. Components of the drive-system allow measuring the torque C on the fan shaft with a HBM strain gauge transducer with an uncertainty equal to 0.1% of the maximum value.

A tachymeter sets the angular velocity ω with a precision of ±0.2%. The overall test bench allows to achieve a precision of ±0.8% for the static efficiency η_s, defined by the equation (2):

$$\eta_s = \frac{\Delta p q_v}{C\omega} \qquad (2)$$

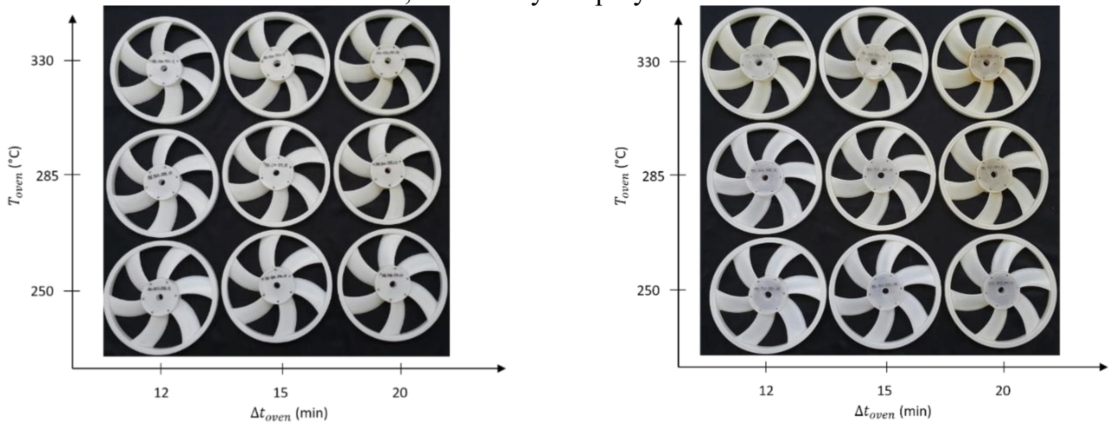
The same device is employed to represent the performances of the aluminum-fan and rotational molded fans. To perform easier comparisons results will be presented using undimensioned variables; flow ϕ and pressure ψ coefficients defined respectively by equations (3):

$$\phi = \frac{q_v}{\pi\omega R_{max}^3} \quad \text{and} \quad \psi = \frac{2\Delta p}{\rho\omega^2 R_{max}^2} \qquad (3)$$

3. Experimental results

3.1. Appearance of rotational molded fans

Two sets of 500 and 300 g fans, shown in Figure 4, are produced with the settings described in the table 2. This study focuses on aerodynamic performances, but a previous work [8] developed the analysis of thermomechanical measurement considering a similar-settings. As we can see, especially for m=300 g (Figure 4b.), the fan color is modified and turns into yellow when T_{oven} and/or Δt_{oven} increase. Therefore, the heating conditions affect the mechanical properties of fans. When the oven temperature is greater than 285°C and the time in the oven 15 min, we can observe a significant change in the fan color. This can be explained by the oxidation of the material. Oxidation leads to the loss of ductility and the increase of resistance and stiffness, and finally the polymer becomes more brittle.



(a) (b)

Figure 4. Photographies of rotational molded fans using: (a) 500 g or (b) 300 g of polymer powder and various oven temperatures (T_{oven}) and oven time (Δt_{oven}).

Conclusions of previous work lead to consider from a mechanical point of view, oven temperature of 285°C as the best. In fact, in these conditions, the pieces produced have been un-oxidized. It is observed also that a long enough heat time in the oven is crucial to manufacture a fan in entire. But if this time is elevated, the piece is submitted to oxidation and presents a risk of material oxidation. The stake of the aerodynamic analysis is to check if these settings cause a significant effect on this fans performance.

3.2. Effect of rotational molding process on aerodynamic performances

Figure 5 presents for various rotation speed and m=500 g, the static efficiency η_s following to the flow coefficient ϕ. Results show clearly that rotational molded fans provide a superior value, for each rotation speed and for a vast range of flow coefficient. At the design point (ϕ≃0.13) the efficiency value for the reference fan is equal to 42,4% at 2000 rpm and 45,4% for the rotational molded.

In another way, there is only a slight effect of the oven temperature or the heating time. Indeed, for $m = 500\ g$ a better value of efficiency is got with a higher heat temperature, $T_{oven} = 330°C$, and a longer heating time, $\Delta t_{oven} = 20\ min$. For another mass, the results are significantly different: for example, with m = 400 g at 2000 rpm, the maximum value of efficiency is 46.4% for $T_{oven} = 285°C$ C and $\Delta t_{oven} = 12\ min$ (Table 3 and Figure 6). This result confirms the conclusions of [3] for the heating temperature to be greater than or close to $285°C$.

Table 3. The optimal process of a rotational molded fan presented maximum values of static efficiency obtained for each mass of polymer powder.

Fan designation	Mass m (g)	Oven temperature T_{oven} (°C)	Oven time Δt_{oven} (min)	Rotation speed (rpm)	Coefficient flow ϕ	Static efficiency η_s
Aluminium fan	-	-	-	2000	0,13	42,4%
PELD-500-330-20	500	330	20	2000	0.13	45,4%
PELD-400-285-12	400	285	12	2000	0.13	46,4%
PELD-300-285-20	300	285	20	2000	0.13	46,9%

Figures 5 (a), (b) and (c) show the pressure coefficient of fans rotational molded with $500\ g$ of polymer powder according to flow coefficient. The reference aluminium fan presents a higher pressure coefficient ψ for the range 0.03 $\leq \phi \leq 0.15$. For higher flow coefficients, all curves are superimposed.

4. Conclusions

In this study, we have evaluated the influence of some rotational molding process settings, on the aerodynamic performance of an axial fan. Three factors were considered in the study: mass of powder, oven temperature and the heating time.

Changing the process settings varies the aeromechanical properties of the fan. For limited quantities of the polymer (300 and 400 g) the advantage of not exceeding 285 °C, during the manufacture of the fan, is highlighted. However, for more significant quantities of material like for m=500g, the optimum performance has yet been unreached at such temperatures. It is necessary to apply more elevated temperatures, 330 °C for example, without risking the oxidation. The influence of heating time seems less significant. On all the fans studied, the best efficiencies are scored for a heating time of 15 min.

A remarkable result of the study is: more superior aerodynamic efficiency is achieved with LDPE fans compared to the reference, 5% higher. So, on an industrial scale since production costs are lower, this process is more advantageous and makes it possible to achieve similar performances.

In perspective, other tests will be conducted to check : geometric dimensions, density, thickness of the fans. In addition, it is also necessary to consider factors of rotor distortion when fan rotates at high speed, imbalance of the fan, distribution of the air flow velocities… The physicochemical properties of the fan will also be analyzed to better control aerodynamic characteristics in future works.

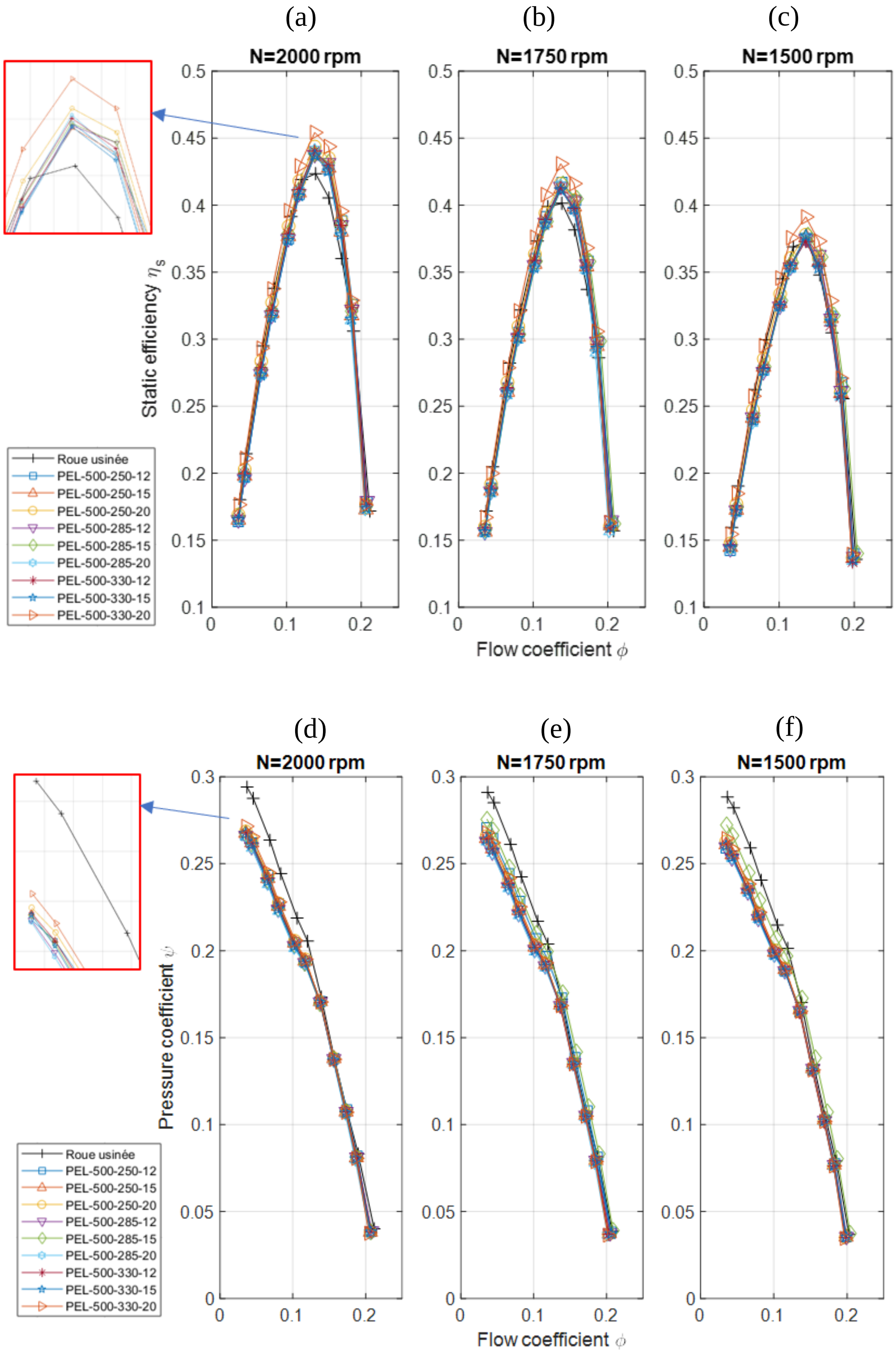


Figure 5. Comparison of the static efficiency (a,b,c) and the pressure coefficient (d,e,f) of rotational molded fans using 500 g of polymer powder and aluminium fan according to the flow coefficient.

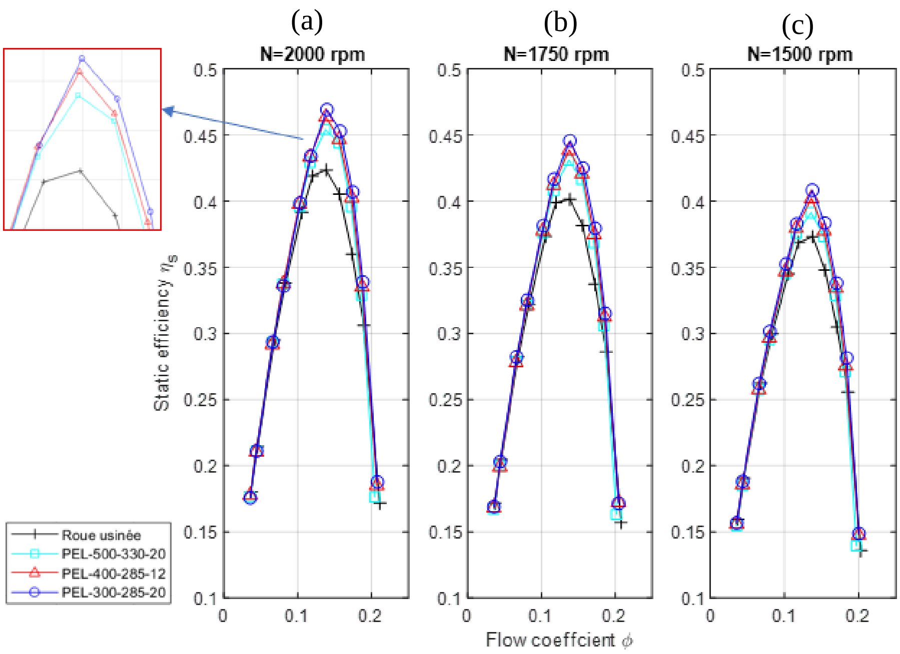


Figure 6. Comparison of the static efficiency (a,b,c) of rotational molded fans using various mass of polymer powder (300 g, 400 g and 500 g) and the reference aluminium fan according to the flow coefficient with $T_{oven} = 285, 330°C$ and $\Delta t_{oven} = 12, 20\ min$.

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