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ON THE PROTOTYPING OF A TWO - STROKE INTERNAL COMBUSTION ENGINE BLOCK BY INDIRECT ADDITIVE MANUFACTURING

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ABSTRACT

This paper presents the process manufacturing a two-stroke internal combustion engine block prototype, including the additive manufacturing process of the molds. For this purpose, an engine block that can be manufactured with the additive manufacturing equipment was selected. Later, silicone rubber molds will be obtained from the plastic patterns whose function is to behave like matrix to obtain replicas in wax of the motor block. Finally the appropriate casting method was selected, after experimenting with several processes the engine block was fabricated with vacuum assisted casting. The numerical simulation of the casting process for this project was a great help in predicting defects during casting. Elements such as the riser was located appropriately in the motor block to absorb the greatest amount of porosity.

KEYWORDS: silicon molds, wax patterns, vacuum casting.

INTRODUCTION

Engines are commonly used in land vehicles, marine vehicles, agricultural machinery, and power generators. Nature provides energy in such a way that it require basic transformations series before having energy in an available form to do work. Hence, men take advantage of the enormous natural reserve of energy found in some substances such as chemical or nuclear, which can be transformed into thermal energy (Ríos, Guzmán and Agudelo, 2001).

In this way, an internal combustion engine is a thermal machine. These engines drive the vast majority of the transport machinery. At present, the construction of these engines for vehicles, boats, airplanes, trains, heavy machinery, excavators and ships, as well as for small power plants, constitutes one of the largest industries in the world (Pawlak, 2014).

The cylinder block is the largest part in an engine and constitutes the basic frame of engines, contains and connects most of its components. In the engine block is where the combustion is transformed into mechanical energy. Formerly, the majority of engine blocks was made of cast iron alloys; today it can be made of aluminum, silicon and magnesium alloys (Crouse, 1993). This change provides a reduction in weight, higher corrosion resistance, lower noise and better engine cooling thus making the two-stroke engine blocks the most suitable for aluminum alloys (Calleja, 2012).

Metal casting processes are used for manufacturing of motor blocks; normally the blocks manufactured in cast iron are monoblock (one piece).

Lost Foam Casting is a reliable and efficient casting technique for the manufacture of motor blocks (Bhardwaj, 2014), this process uses a sand mold compacted around a pattern of polyurethane foam that vaporizes when the molten metal is poured into the mold (Groover, 2007). It is very advantageous technique for complex geometries with high degree of precision. Investment casting is a different technique where a wax pattern is produced and coated with a refractory ceramic material to give the shape of the mold. Hence, pieces of high geometric complexity, can be obtained. A good example is a motor block, which has internal passages for cylinders, cooling channels, blades and connection holes (Kamrani y Sferro, 2012).

METHODOLOGY

The process to be used for manufacturing the motor block will be the investment casting and vacuum assisted.

Patterns will design and fabricated through additive manufacturing. Thermoplastic extrusion equipment will be used to make the motor block pattern. See Figure 1.

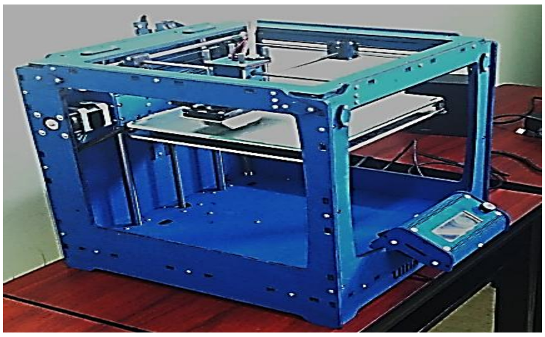

Figura 1: Thermoplastic extrusion equipment.

Due to the intricate geometry of the motor block, it will not be obtained in a single print job. The part is sectioned in five components taking into account ease of assembly and smaller number of possible divisions. Figure 2 shows the block divided in five parts and components constructed in PLA.

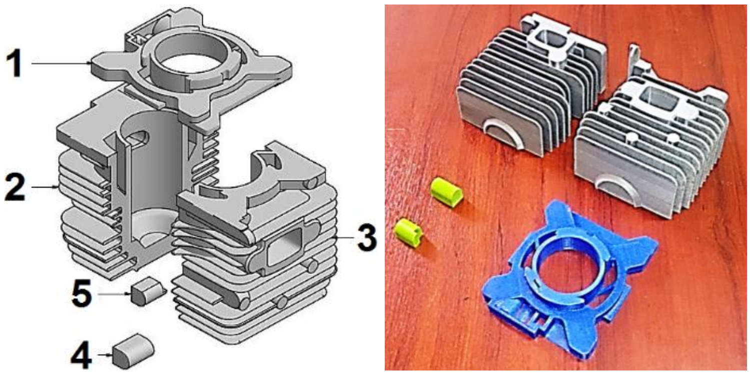

Figura 2: Thermoplastic extrusion equipment.

Next, silicone rubber molds will be obtained from the PLA, their only function is to behave as a matrix so wax patterns can be created. The silicon molds are not lost in the process and can be used in a future production.

Figure 3 shows the general procedure for making mold silicone rubber, a) positioning of the master pattern inside a frame, b) pouring of the silicone rubber by gravity inside the frame and c) extraction of the master pattern.

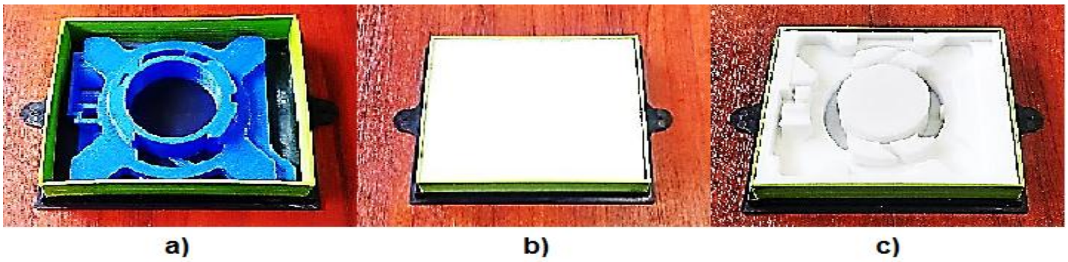

Figura 3: General procedure for making silicone rubber mold.

To predict casting defects during casting a numerical simulation has become a powerful tool (Lagad, n.d.). To simulate fluid flows, heat and mass transfer and other phenomes related to a defined system, we use Computational Fluid Dynamics (CFD), a sophisticated method that uses mathematical equations and computer algorithms (Wiley, 2012).

To perform a simulation you must

- Geometry patterning (Import the CAD in a neutral format, in this case .iges) and mesh generation (Own Software or in other softwares).
- Materials properties present.
- Interface HTC, heat transfer coefficient describes the drop temperature in the contact zone between the molten metal and the mold during solidification (Konrad, 2011).
- Border conditions.
- Execution parameters.

A mesh sensitivity analysis was done and the solutions started converging at 441262 3D elements.

The computational time of one variant was around 19 hours using four processor cores. It is, however, necessary to add to the time of the computation itself the time for preparation of the simulation and evaluation of the achieved results (Tkadlečková, 2013).

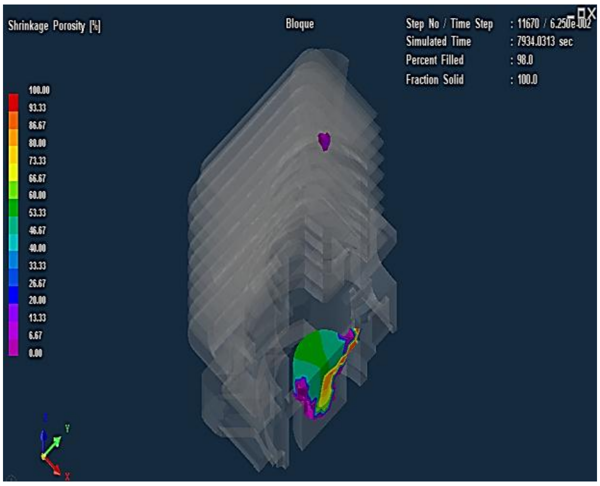

Figure 4: General porosity in the engine block.

(Figure 4) shows that when adding the riser, it absorbs the porosities that in the simulation of the block without curtain formed in the block. Thus, it can be concluded that the quality of the feed system has improved and therefore can be produced.

RESULTS AND DISCUSSION

Once the silicone rubber molds are manufactured (see Figure 5), the last operation is to manufacture the wax patterns, the wax will enter by gravity and in liquid state to the silicone rubber mold acquiring the shape of the cavity of the silicone rubber mold.

Figura 5: Silicone rubber molds to obtain wax patterns.

As shown in Figure 6 a) part 1with part 3 made from a mixture of waxes (70% paraffin and 30% beeswax), the pouring temperature of the wax was 75 [°C]. These parts made to the mentioned pouring temperature condition presents a large number of surface defects, which we will call the surface porosity.

As shown in Figure 6 b) part 1 with part 3 made from a mixture of waxes (70% paraffin and 30% beeswax), the pouring temperature of the wax was 50 [°C]. These parts manufactured at the said pouring temperature condition has less amount of surface porosity compared to the parts manufactured at a pour temperature of 75 [°C]. As conclusion we can say that as we decrease the pouring temperature for this mixture of waxes, the presence of surface porosity decreases. It should be considered that decreasing the pouring temperature decreases the flowability of the wax and therefore makes it difficult to fill the silicone mold.

Figure 6 c) clearly shows that part 1 with part 3 made with latex sap waxes has a surface finish that accurately copies the details of the silicone rubber mold and has no surface defects. The extraction of the wax pattern from the silicone rubber mold can be done 1 hour after the pouring.

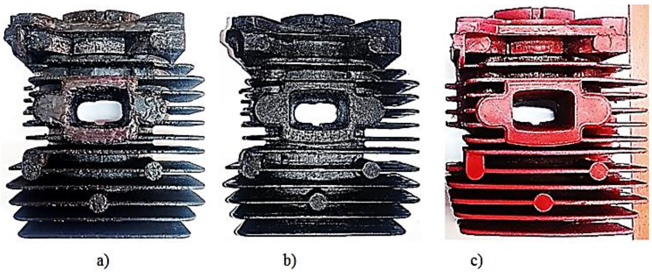
a) b) c)

Figura 6: Wax patterns fabricated from silicone rubber mold.

Patterns should be removed 1 hour after pouring, as the patterns are still hot you should square the fins, doing this will allow future assembly to be facilitated. This wax makes it possible to square the fins but in the established time, once cooled the patterns their manipulation is almost impossible, the fins are broken.

Figure 7: Wax motors block totally assembly.

The manufacture of plaster molds is made using the lost patterns manufactured, which are extracted by means of a heating regime and then the casting of the alloy in the mold will be carried out, to which the vacuum process will be added. The appropriate composition of the water/plaster mixture shall be that given by the manufacturer.

The linear shrinkage of the thermoplastic extrusion process for pieces larger than 100 mm is less than 0.5% [mm/m].

The silicone rubber mold does not generate dimensional changes.

The linear contraction of the wax that is processed from the latex sap is less than 0.5% [mm/m].

It is recommended to evacuate the vacuum chamber before filling the mold, in addition to a pressure difference between 250 and 550 mbar (7.4 to 16 inHg) to provide optimum filling of molds (Raub and Ott, 1983). For this study the pressure generated by the vacuum pump was 10 inHg.

Figure 8 shows the motor block obtained after performing the vacuum assisted casting process.

Figure 8: Metallic motor block manufactured by vacuum assisted casting.

CONCLUSIONS

With additive manufacturing, specifically thermoplastic extrusion equipment can be made complex geometry prototypes such as a two-stroke internal combustion engine block. In relatively short times, they cannot be obtained in one piece, so it must be obtained in several sections for later assembly.

The above mentioned became an advantage for the casting process used in this research.

The type of wax used to manufacture the lost patterns completely influences the manufacturing process. In this research, two types of waxes were used, one resulting from the mixture of beeswax and paraffin wax, and another wax processed from the latex sap. The beeswax and paraffin wax mixture gave a porous superficial finish in the obtained patterns, this situation was reduced reducing the injection temperature of the wax (there was less porosity). However, latex sap wax provided a fine finish free of porosity, for that reason was the wax used for this research.

With the vacuum casting process, the designers of feed systems do not have to worry about the output of gases therefore it is not necessary to design them. These gases that are formed in the casting process are evacuated directly by the vacuum system.

The simulation of the casting process using software developed specifically for metal casting processes proved to be very helpful in predicting defects in the casting of the motor block in this research. It was possible to position elements such as the riser that forms part of the feed system to absorb the greatest amount of porosity during the obtaining of the metal motor block.

It is recommended to manufacture the patterns that leave the thermoplastic extrusion equipment, with a filling density of less than 100 percent to accelerate the manufacturing process. As an example we have that for part 2 was fabricated with a fill density of 20% resulting in the manufactured section in 20 hours 14 minutes. For the same part with a 100% fill density results the manufactured section in 73 hours 15 minutes. More detailed information on additive manufacturing features can be found at (Chicaiza and Vallejo, 2016). It is recommended that prior to carrying out the casting step the flask, rubber and vacuum chamber elements are joined by presses to ensure the sealing of the vacuum system.

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