INVESTIGATION OF MOULD MANUFACTURING CHAIN PART I: PROJECT METHODOLOGY AND FIRST RESULTS

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Abstract. The use of plastic components has been growing drastically along the recent years and proving its importance on the current market. This whole manufacturing process involves different fields of engineering and several lacks of knowledge about the whole process can be related. This paper presents an investigation about the manufacturing chain of plastic products. All manufacturing process involved in this chain were detailed. Based on these processes, a research project has been proposed in order to investigate the manufacturing of plastic products. Representative product geometry was developed as workpiece; a mould was designed and manufactured. The plastic product was injected and characterized. The present paper presents the project methodology and the preliminary results of its application.

Keywords: project development; manufacturing processes; die and mould.

1 INTRODUCTION

The use of plastic products and components has been growing exponentially in last decades. Moulds are required for manufacturing a large sort of products. The mould industry represents a key position on the whole manufacturing chain, affecting the costs, quality and lead-time of a product. Besides, in order to filling the market demand, designers have been using free form geometries in the product shape, to be more attractive for marketing. That fact increases the product manufacture complexity.

BOUJELBENE et al (2004) investigated the costs of plastic products, and concluded that 30% of these products cost is related to the mold manufacturing, 25% related to the injection process, 25% to the plastic material, 10% design and simulation, 5% mold steel and 5% related to other costs. Therefore, the mold manufacturing is the most representative item to compound the cost of a plastic product.

According to FALLBÖHMER (1996), the automotive industry is the greatest consumer of molds, following by the electronic and 60% of the mold manufacturing time can be attributed to fabricate the mold functional parts, as the cavities.

There are several inconveniencies on the mold fabrication phase as related by literature, from technological limitations of the equipments and machines (SOUZA, 2004; SOUZA et al 2006), up to lack of manufacturing process development (CHU et al 1997).

Having these considerations in mind, this paper presents a project methodology and its first results, in other to investigate this whole manufacturing process. A representative geometry for the workpiece was developed by 3D CAD software and the part was fabricated by plastic injection process. All manufacturing phases were carried out in order to inject the final part. According SOUZA et al 2006, the technological fields involved for mold manufacturing are summarized in Figure 1.

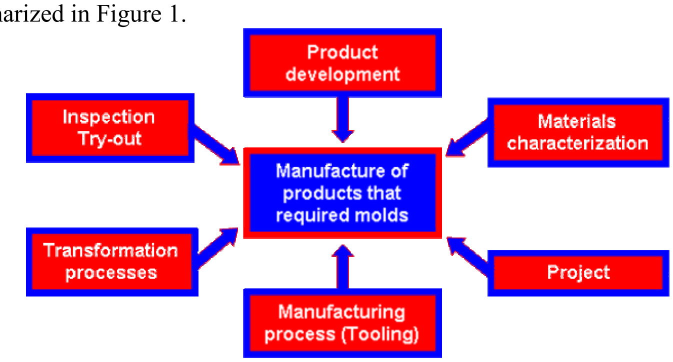


Figure 1: Technological fields in the manufacturing chain for plastic products

Based on this manufacturing chain, the current project aims to investigate these knowledge phases. It involves: part and product design, CAE simulation, NC program generation by CAM software, cavity manufacture by high speed milling, surface inspection and product injection.

The project has been developed by integrating different work levels: under and post graduate students; lectures and researchers; industrial community. Companies and its suppliers take part in this project, supporting the expenses as: cutting tools; mould restructure basis; blank still; hand polishing; CAD/CAM; plastic material. This project is also supported by the *Instituto Fabrica do Milenio-IFM*.

The six manufacturing phases presented in Figure 1 has been investigated. Following are presented the activities proposed for each project phase. The current paper aimed on the mould fabrication. The first results of this phase are further detailed on Topic 3.

2. PROJECT DESCRIPTION

This project investigates the influences of the mold fabrication on the final plastic product. The activities for each manufacturing phase are described ahead.

2.1 Product development

A representative workpiece was design for this project. By exchanging knowledge with the industry's technicians, geometry of a refrigerator's eggs-receipt was chosen, in which five cavities were designed symmetrically (Figure 2).

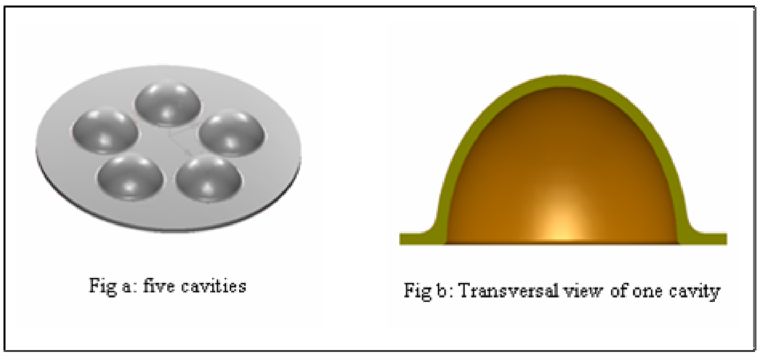


Figure 2: Workpiece geometry

Due to its symmetrical complexity, this geometry represents a possible way to investigate the manufacturing process of a plastic product. The concurrent engineering, design for manufacturing, and other project techniques (DFx) will be additionally investigated.

2.2 Material selection

The first experiment was accomplished using the VP20 steel, without coating or any heat treatment. The future steps will investigate the use of other materials, like aluminum and resins for supporting the rapid product development techniques and small fabrication bathes. Other alternatives for mould steel could be investigated, considering: machinability; roughness after milling and hand polishing easiness.

2.3 Project and mould design

Today, although 3D CAD software is worldwide spread, the mould designers commonly develop yours projects applying the ordinary 2D CAD, for drawing. In order to develop the knowledge, CAD software able to design mould in tree dimensions was applied for this project. Using the software tools, the split line; mould columns; and others components were defined. Figure 3a and Fig. 3b illustrates this task. Figure 3c illustrates the plastic flow simulation by CAE software.

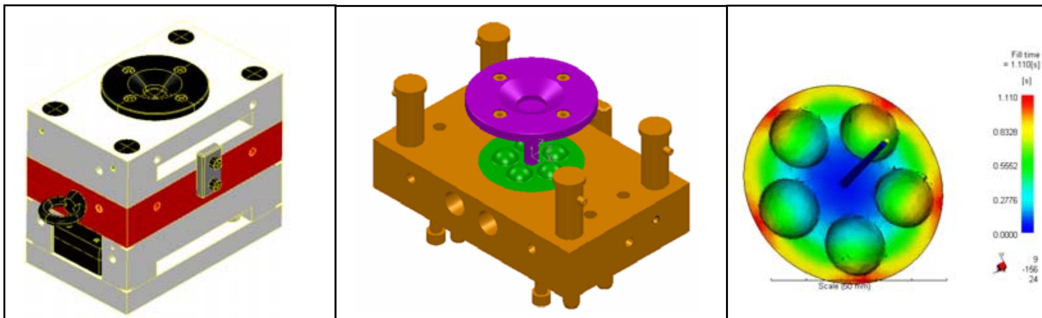


Fig a: Mould structure by a 3D CAD

Fig. b: Injection point and mainly components

Fig c: Flow simulation by CAE

Figure 3: Project mould steps

2.4 Mould fabrication

This phase of the project investigates the influence of mold fabrication in the final product. Therefore, the sequence of the fabrication process were constructed. Figure 4 shows all the sub-processes for the mould fabrication phase.

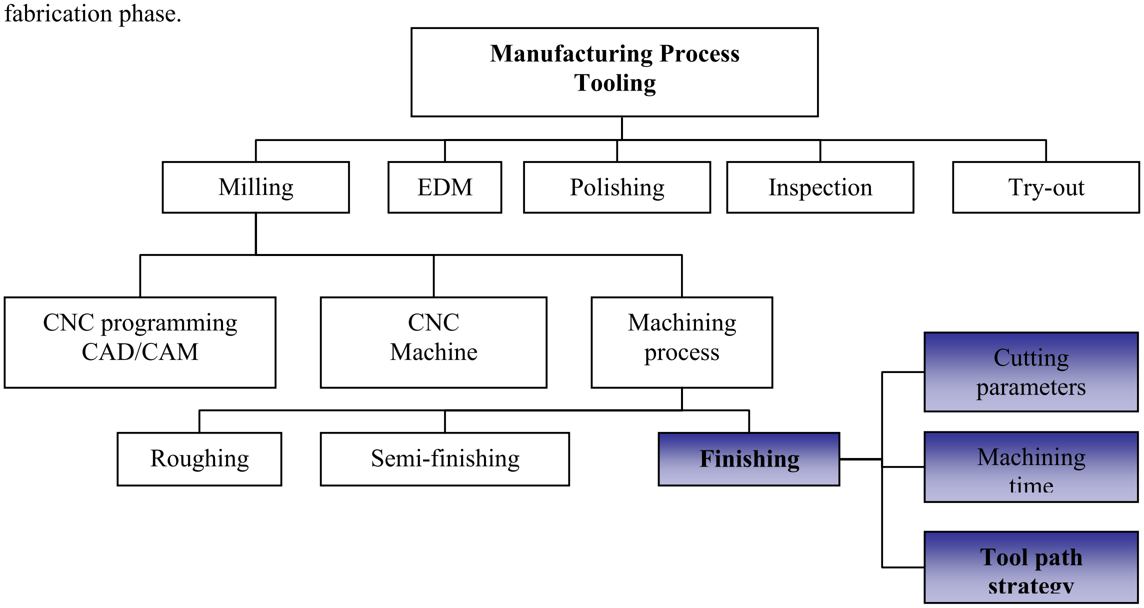


Figure 4: Mould fabrication phase

The mould cavity is mainly machined by milling operation. Usually, the mold manufacture takes long time and to get a reasonable surface quality and geometry accuracy a deep effort have to be spend. Usually the mold is not ready to go to production line after milling operation due to the difficulties to get a good surface roughness (BOUJELBENE et al 2004). Therefore the mold core has to be finished by hand operation, as polishing. Even the most able hand-finishing professional, the geometric accuracy, time and costs are compromised. According to RIGBY (1993), the hand finishing operation of mold for automotive industries spending about 38% of total labor costs and the product lead time are deeply influence by this process limitation. So, the aims of this phase investigation is to understand the relationship of the mould surface roughness requirements, milling process capacity, hand polishing, time and money consumption, and dimensional accuracy.

The first investigation of this phase, presented in the current paper, cares about milling finishing strategies of the mould cavity. Results and description of this work is presented in the Experimental Work (Topic 3).

Other experiments for this phase are planed with the aim of optimizing this whole manufacturing chain, evaluation of optimum cutting parameter set, considering the machining time, surface quality and integrity. A experimental matrix is proposed in Table 1. Different parameters will be investigated. For each parameter five magnitudes will be applied, one for each mould cavity.

Table 1: Experimental matrix used in the present investigation

Experimental Matrix	**Parameters**			
	Finishing milling strategies	**Cutting speed**	**Radial step over (ae)**	**EDM process**
Magnitude	Offset passes	100 m/min	0,001 mm	EDM condition 1
	Spiral passes	200 m/min	0,005 mm	EDM condition 2
	Parallel passes	300 m/min	0,01 mm	EDM condition 3
	Radial ascendant passes	400 m/min	0,05 mm	Electrode material 1
	Radial descendant passes	500 m/min	0,2 mm	Electrode material 2

Considering the parameters and its five magnitudes, (each magnitude correspond to each mould cavity – 5), it will be possible to identify the influences of mould fabrication processes (considering 5 machining conditions), on the final injected plastic product.

For each parameter, the mould will be prepared for production to get the plastic work piece. Evaluations have been making, considering the influences of each magnitude on the final product. Roughness; machining time; costs; polishing time; geometry accuracy; plastic product quality; optimization of machining process; are general variable to be investigated. Specifics additional investigation will be done according to each study.

After the full investigation of each parameter, the mould will be re-machined applying the next parameter set. It will remove material from the surface cavity. Thus, it means the plastic product will have a greater width. However, this attribute will not influence the investigation.

New parameters set will be introduced along the project development, as 5 axis milling machining, new materials for rapid tooling and others. The results of the first parameter investigated, Finishing Milling Strategies, are presented in topic 3.

2.5 Transformation process – Plastic Injection

In order to consolidate and develop the knowledge, the injection process was simulated by CAE software Moldflow. Using the 3D CAD geometry, the pressure of injection and the clamping force were obtained (Figure 5). These data were used to add the injection process.

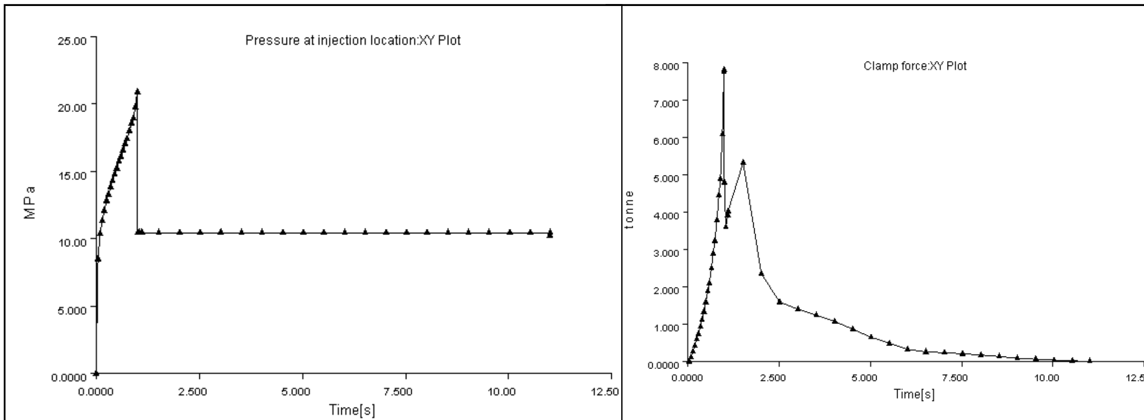


Fig a: Pressure injection estimation

Fig b: Clamping force estimation

Figure 5: Process data simulated by the CAE software

For future work, these simulated dada will be used for comparing the real injection process. This task includes the study of mould sensoring and data acquisition system. Piezo-electrical and thermo sensors will be used, and dada acquisition systems by Labview software will be developed for monitoring and controlling the plastic injection process.

Research about die-casting will be accessed for next steps. New materials will be proved, as mixing plastic and organics components.

2.6 Inspection and quality

Product quality is crucial for this industrial segment. Today, quality is manly attributed to surface roughness and dimensional accuracy. For this industry, surface roughness is a quite hard task to be done due to the free form geometries usually faced at the mould. The ordinary roughness parameters do not attend this industry requirement. This evaluation is done by workers filling. An investigation about an appropriate roughness parameter is under developing in order to understand and support this job. Another investigation about roughness correlates the surface quality after milling and polishing process. It will determine the optimal milling time to get a reasonable surface for polishing, considering cost, time and dimensional error.

About dimensional inspection of moulds the methods of evaluation is investigated applying CAD/CAI software integrated with a measuring machine coordinate. The process accuracy, considering different data acquisition equipments and the origin of the dimensional errors are accessed. Future paper will presents these results.

3 EXPERIMENTAL WORK FOR MOULD FABRICATION PHASE – PRELIMINARY RESULTS

This investigation concerns about high speed milling for finishing tool path strategy. The mainly aim is to understand different tool path option, available by the CAM software, and identify the most appropriated for the analyzed case.

The cavities were roughened leaving a constant amount o material, 0.2 mm for study the finishing milling operation. Each cavity was finished by a different tool path, in order to understand the influences of the machining strategy on the final product. It was observed the surface quality and the real machining time.

For finishing, only cutting parameter to be variety from the five cavities was the tool path strategy. However, after some simulation, it was concluded that the steep-over (ae) cutting parameter could not keep constant for all the cases. It is because the options of finishing milling strategies change from horizontal, vertical and also radial. Figure 6 illustrates this issue.

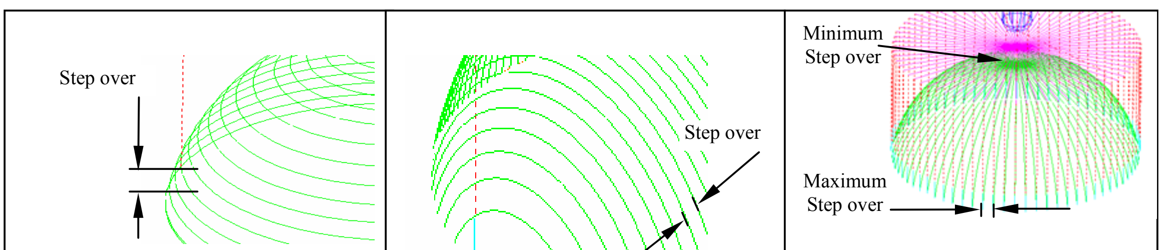


Fig a: Horizontal paths. Vertical Step over

Fig b: Vertical paths. Horizontal Step over

Fig c: Angular paths. Angular Steep over

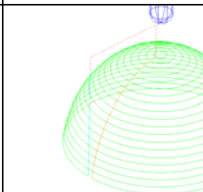
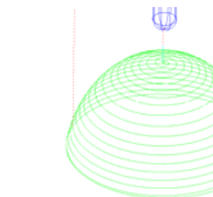
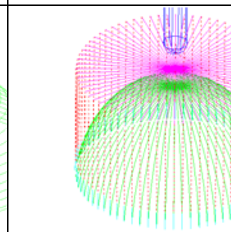
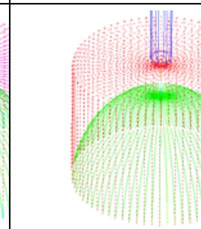
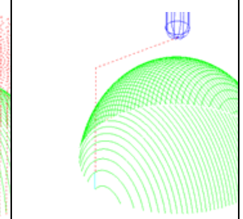
Figure 6: Differences on the steep over cutting parameters according to the tool path finishing strategy

Doe to use a parametrical domain to calculate the tool paths, the horizontal (Fig. 6a) and vertical (Fig. 6b) methods to calculate the tool paths demonstrate a better cutting contact in vertical area and horizontal areas of the workpiece, respectively. Using the angular tool path, a planar domain is projected angularly from one specific point. On the workpiece, this point was specified on its top center. The tool step over varieties from its minimum value, on the top, to its maximum value, on the bottom surface.

The CAM simulation has been shown that keeping the steep-over value constant for all the cases, the machining time will distinguish drastically. In order to make sense, this investigation aims to get the better surface quality keeping the same machining time for the five cases.

To do so, the estimation time functionality available in the CAM software was utilized. All the cavities were programmed to mill in about 6 minutes and 18 seconds. According to this constant estimated machining time, the step over value was alternated for each case. Table 2 shows the steep-over applied for each case and a detailed description of each tool path strategy.

Table 2 shows the common cutting parameters applied for finishing the five cavities

	Cavity				
	1	**2**	**3**	**4**	**5**
Tool Path	 Paths in a 3D offset of a transversal section. Starting from the floor.	 Spiral path. From the top to the floor.	 Radial path From the floor to the top.	 Radial path From the top to the floor.	 Parallels paths. One way.
Steep over	0.15 mm	0.14 mm	0.81 degree	0.81 degree	0.135 mm

It was used a 6 mm ball end mill to perform the finishing operation and a spindle frequency of 18.000 rpm. The experiments were accomplished in a HSC machine center Deckel Maho DMU 60.

3.1 Analyzing methods

The roughness of the finishing surface was investigated as the first analyze. A Taylor Hobson appliance roughness test was applied. The parameters Ra were accessed, perpendicular to the tool paths, in intermediate region of the workpiece. The resultant values correspond to a median value of three dada acquisition. The cut-off value was selected as recommended by ISO 4288 (1998). The plastic product produced by the mold was also observed. The product surface quality was observed related to the cavity surface quality. The real surface roughness is a difficult task to obtain in this field, due to the complex surface curvature. Therefore, a digital camera was used to get the visual aspects of the surface quality.

3.2 Results

Figure 7 shows the steeps accomplished in this time for the proposed project: a) the core after milling; b) the injection machine; c) the plastic product.

		
Fig a: Milled Cavities	*Fig b: Injection Machine*	*Fig c: Plastic product*

Figure 7: Steeps of the project development

Tables 3 and 4 show the roughness parameters of the region A and B, respectively, of each cavity of the workpiece. The roughness parameters obtained on the mold surface reflects the visual aspects and are represent directly on the plastic product, as illustrated in Figure 8.

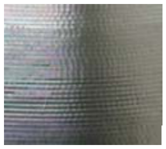
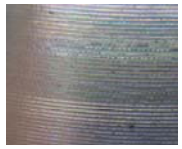
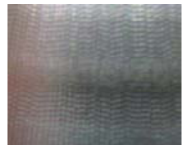
Cavity					
Amplified view					
Ra (µm)	0,9	0,88	0,99	1,45	2,51

Figure 8: Surface quality on the mold and plastic product for the five experiments

The marks left by the cutting tool due to the path strategy are clearly remarkable. The surface quality is not affected only by the cutting tool and machining parameters, but it is strongly influenced by the tool path trajectory.

Other marks on the surface were observed in some specific areas. Figure 9 shows the marks left by cutting tool due to the engagements.

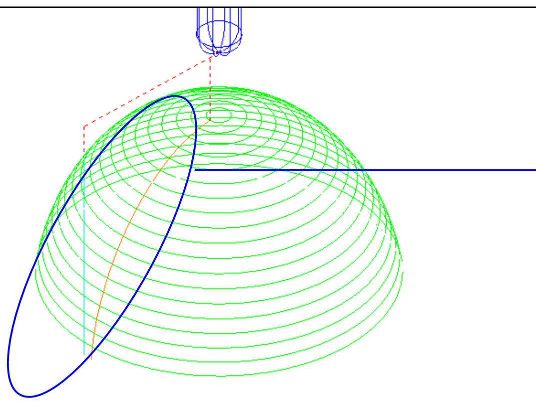
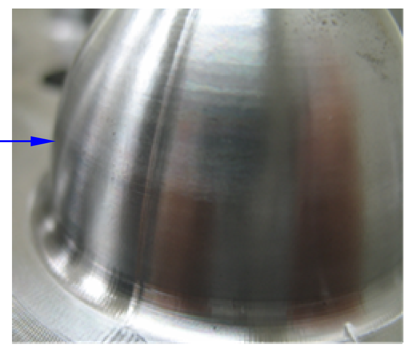
	

Fig a: Tool path movement form one to other cutting steep.	Fig b: Marks left by the tool movement form one to other cutting steep.

Figure 9: Additional marks on the mold surface

These marks can be attributed due to direction alterations of the cutting tool, when it has to change from one pass to another. These direction alterations causes un-stable tool load by the cutting force, it alternates the tool deflection ratio, damaging the machined surface.

It can explain the reason why the second strategy, spiral milling, plays the better strategy for milling these sorts of geometries. It propitiates only one engagement of the cutting tool into the material at the beginning of the cutting process and only one retract at the end. The tool keeps in a constant load during the whole cutting process. The tool moves from one pass to other by a spiral partner.

Additionally, the real time required for machining each cavity was investigated. Although the estimation done by the CAM software relays on about 6:18 minutes for all tool path strategies, it was verified in a previews work (SOUZA, COELHO 2006) that the feed rate constantly alternates when free form geometry is milled. It happens due to the linear interpolation method used to represent a free form tool path associated with the CNC/machine special characteristics. As the CAM can not simulate this issue and therefore, the estimation of the machining time becomes inaccurate. Then, the real time required for machining each cavity were accessed and compared to the estimated value for each strategy. A comparison between the real and estimated machining time value is presented in Fig. 10.

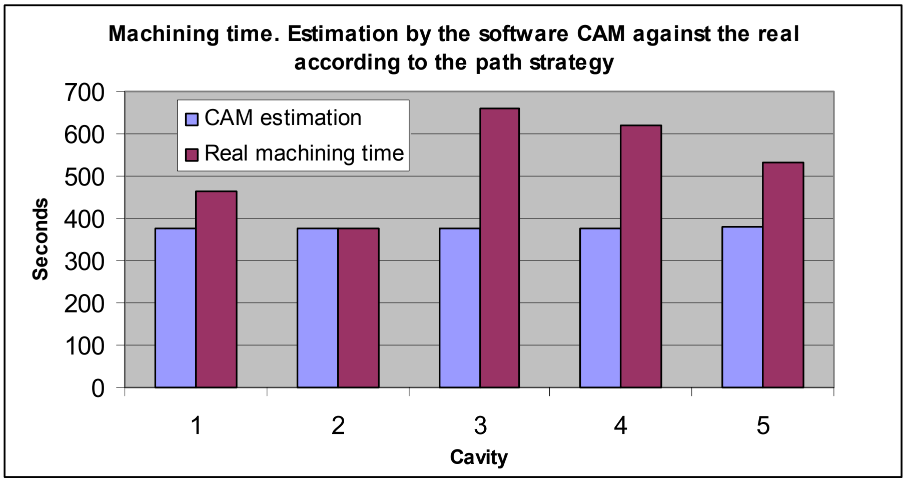


Figure 10: Comparison between the machining time estimated by the CAM and real one, related to the machining strategy.

One can note the great difference on the real machining time among the path strategies. The difference of the real and estimated machining time can reach up to 75%. It demonstrates the time required for machining can also be an important parameter to obtain an optimal machining process for mold fabrication. In this analyze, the spiral path also reaches the best result (cavity 2). The real machining time was much closed to the estimated one.

These investigations were carried out for the male part of the mold cavity. However, the female machining results were similar.

4 CONCLUSIONS

The proposed project has been demonstrating to be very useful for study the whole manufacturing chain for plastic product manufacturing. It permits the integration of all scientific/technology fields of this production chain. Beside the topics presented in this paper, this project methodology aloud several other topics, in order to improve the mentioned chain.

The difficult to measure the surface roughness of free form geometries should be related. There is a lack of equipment and roughness parameter to evaluate such kind of geometry.

The free form surface quality after milling, unlike the ordinary milling, is deeply influenced by the cutting tool trajectory. A great difference on the surface quality can be observed related to the tool path trajectory. As the current technology of CAM system can not support such kind of identification and definition, the users have to understand the behavior of the machining process, and choose correctly the path strategy according to the surface geometry, in order to get an optimal machining for molds fabrication.

Marks on surface can be observed on engages and retracts of the cutting tool from the material. The marks left by the cutting tool on the mold are directly printed on the plastic product. Selecting the right milling strategy can represent a great difference on the mold surface after milling, and can induce significant reduction on the hand finishing processes and its inconveniencies, as time consumption and geometry accuracy. Therefore, strategy selection that keeps constant the cutting tool load is also very important to get a high level of machining free form geometries.

The work shows the machining time estimated by the CAM software is very inaccurate and it can variety according to the path strategy, reach differences up to 75% on machining time. It can represent another important parameter to be considered in order to have an efficient marching process.

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