Int J Adv Manuf Technol (2006) 29: 35–40
DOI 10.1007/s00170-005-2502-7

ORIGINAL ARTICLE

Pascal Mognol · Loic Jégou · Mickael Rivette · Benoit Furet

# High speed milling, electro discharge machining and direct metal laser sintering: A method to optimize these processes in hybrid rapid tooling

Received: 20 July 2004 / Accepted: 29 November 2004 / Published online: 21 December 2005


**Abstract** Prototype injection moulds for plastic parts must face two constraints: be designed and manufactured as quickly as possible and have a short lead time. Moreover, moulds have to evolve in the same way as the part does, to provide either a new functionality or a variant of this part. The current approach is based on a multi component tooling (hybrid rapid tooling) in order to more easily manufacture each component of the mould and to have a greater reactivity to each product evolution.

In this paper, we propose a method to manufacture the mould in multi components. This approach is based on process capability criteria (i.e. topological and geometrical criteria). An industrial example is presented. We will focus on the choice between three processes mainly used in hybrid rapid tooling: high speed machining (HSM), electro discharging machining (EDM) and direct metal laser sintering (DMLS).

**Keywords** Hybrid manufacturing · Rapid prototyping · Tool design

## 1 General context

Moulded products are increasingly present in technical systems (electronics, mobile phone and domestic appliances). For example, 11% of the weight of a car is composed of elements produced by plastic injection process [1].

At the same time, products have become more complex, with a shorter life-cycle. So, the time to market, the development and the industrialization of a manufacturing product are highly reduced [2].

P. Mognol · L. Jégou · M. Rivette · B. Furet
IRCCyN,
1 rue de la Noë, BP 92101, 44321 Nantes Cedex, France

P. Mognol (✉)
Ens Cachan – Bretagne,
Campus de kerlann, 35170 Bruz, France
E-mail: mognol@bretagne.ens-cachan.fr
Tel.: +33-29-9059327
Fax: +33-29-9059328

In the same time, different rapid production technologies are developed to quickly manufacture tooling parts [3, 4]. Some research combine high speed machining (HSM) and deposition techniques for obtaining hybrid rapid tooling [5, 6].

Direct metal laser sintering (DMLS) used in association with more traditional process (like electro discharging machining (EDM) or HSM) allow reduction of the time to obtain tools and dies.

This approach, which consists of efficient use of different processes to obtain tools, is called "rapid tooling" [7]. A tool or die can be manufactured in several parts. Each part is manufactured separately with a chosen process. After, the tooling is assembled to obtain a multi part tool called "hybrid rapid tooling" [8].

The current difficulty concerns the choice of the best process according to technical and economical criteria.

What are the possibilities and limits of different processes for obtaining hybrid rapid tooling?

What feature (accuracy, dimension) can be manufactured by a process?

How can the association of those different processes be optimized from a technical and economical point of view?

For hybrid rapid tooling, the three useful processes are HSM, EDM and DMLS [8].

The different steps to manufacture hybrid rapid tooling with EDM, HSM and DMLS can be represented like this (Fig. 1):

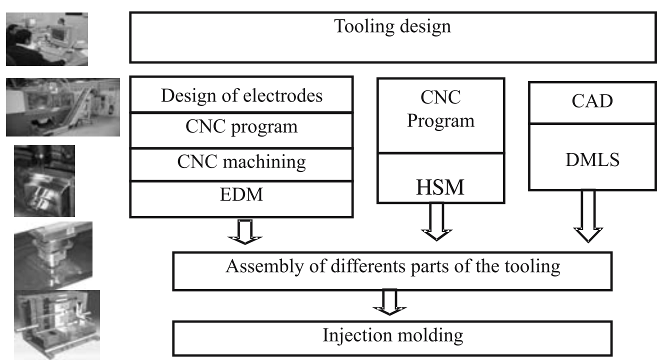



**Fig. 1.** Hybrid rapid tooling manufacturing

The European RAPTEC project has studied performances of DMLS process against EDM and HSM [9]. Tests are performed on an industrial part. The goal is to obtain a tooling, which is able to mould 1000 injected prototypes.

Results show:

- A 60% delay reduction.
- A 49.5% cost reduction.

Those results confirm the interest in manufacturing rapid tooling with HSM and DMLS, concluding that it is necessary to minimize the utilization of the EDM process.

It is important to notice that the DMLS process does not compete systematically with traditional manufacturing methods (HSM and EDM). In fact, HSM is a well-mastered technology, and limits with respect to the material and dimension of the mould are less important than the DMLS process.

According to the study of Syrjälä [8], the best results in manufacturing hybrid tooling have been obtained for combining the HSM and DMLS process. He uses HSM and replaces EDM by the DMLS process. This study itemizes a set of advantages and limits to the notion of hybrid rapid tooling.

The DM20 powder (with copper) from the DMLS process by EOS is suitable to manufacture tooling for the plastic injection (10 000 to 30 000 parts). DS20 (with metal) powder is also suitable for the manufacture of tooling for injection, but the strength and hardness, allows injection of about 100 000 to 300 000 parts. The resistance of DS20 (with metal) to high temperatures also permits injection under pressure, small mass production of aluminium alloys (about 1000 parts) [8, 10].

In fact, the DMLS process is technically available for the manufacture of rapid tooling. The real problem is the study of this process with an economical point of view. Our concept is based on technological criteria but the final choice is an economical one.

## 2 Concept

We propose a method to choose the best manufacturing process in order to optimize the manufacture of a "hybrid rapid tooling". This method is based on a topological analysis of the tooling and an analysis of the manufacturing possibilities of the HSM, DMLS and EDM process. So, it is possible to obtain the different components of the hybrid rapid tooling according to the envisaged process.

In the first part, our method will be described. In the second part, this method has been tested on an industrial tooling. We present the decomposition of the mould and the manufacturing of the hybrid rapid tooling.

## 3 Method

The goal of our method is to supply the design of hybrid tooling. It can be used at the same time of the design of the tooling. The method proposed, after a decomposition of the tooling into different features, is the best process to manufacture each part of the hybrid rapid tooling.

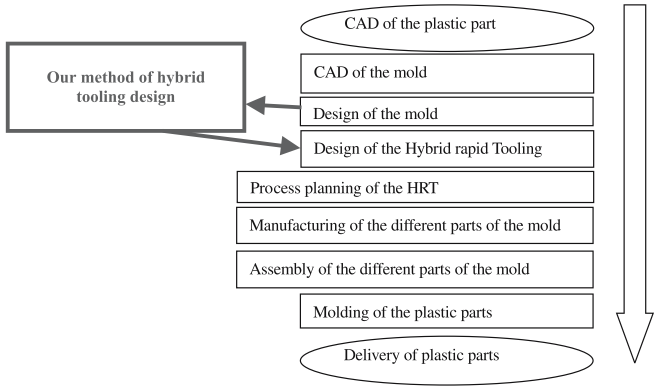


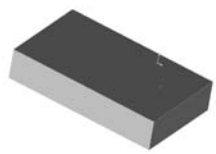
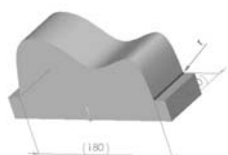
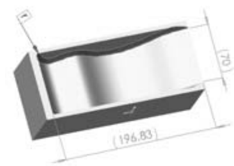
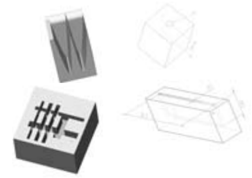

**Fig. 2.** Position of our proposed method

This method takes place since we have a numerical definition of the tooling (Fig. 2). It is based on a feature recognition. We have five features for three geometries (Table 1):

- Feature "exterior simple"
- Feature "interior simple"
- Feature "interior large complex"
- Feature "exterior large complex"
- Feature "exterior or interior little complex."

Currently, this recognition is not automated. It will be implemented in collaboration with a CAD software editor.

**Table 1.** Example of typical features

| | Exterior | Interior |
|---|---|---|
| Simple feature |  | |
| Large complex feature |  |  |
| Little complex feature |  |  |

For each "typical geometry", we propose an associate process or a couple of processes. The choice depends on the geometry and accuracy of the feature. The selection of the priority process is described as follows.

*For interiors features*

- For "simple feature" and "large complex feature", we propose to manufacture with HSM. If this process is not available, the envisaged process is EDM for finishing surfaces. We don't use DMLS.
- For "little complex feature", we propose to manufacture with HSM or DMLS. If these two processes are not available, we use EDM.

*For exteriors features*

- For "simple feature", the adapted process is HSM. It is possible to use EDM if the surface must have a special finishing. We don't use DMLS.
- For "large complex feature", we propose manufacturing with HSM. It is possible to use EDM if the surface must have a special finish. We don't use DMLS.
- For "little complex feature", we propose manufacturing with HSM or DMLS. If it is not possible, we use EDM.

*Other possibilities*

- For a special finishing surface (polishing, shot blasting), the choice depends on the limit of processes. It is possible, for example, to polish a surface made by DMLS.
- Only DMLS is suitable to manufacture complex drilling (mini 10 mm) for the thermical regulation of the tooling.

3.1 Organigramm of the method

A software with a Windows interface was realized using C++ language. It is based on IF/THEN rules. The technological criteria have been chosen after meeting industrial mould managers for the capability of HSM and EDM processes. For DMLS, we have testing accuracy and feature possibility in our laboratory. We have an EOS 250 Xtend machine.

Thirty criteria are implemented in the software. First results are good on little tools for plastic injection.

For example, one criterion for HSM is presented:
We take into account the geometry of the milling tool: "L" is the length of the tool and "d" is the diameter.

*If* $L/d > 7$ *then "HSM process is prohibited for finishing surface".*

3.2 Descending analysis method

For using this method, a descending analysis is proposed. There are three criteria for choosing the process which will be used for every feature.

Criterion 1: priority process
Criterion 2: possible association if $Si \cap Sj$
Criterion 3: manufacturing times

3.3 Different stages of the analysis

The third criterion called "manufacturing times" is applied when each feature has an associated process. We calculated the manufacturing time of each process and after, we can change one process into another for optimizing the global manufacturing time.

For this criterion, we have developed a method for evaluating the manufacturing time of DMLS process (Fig. 3) [11].

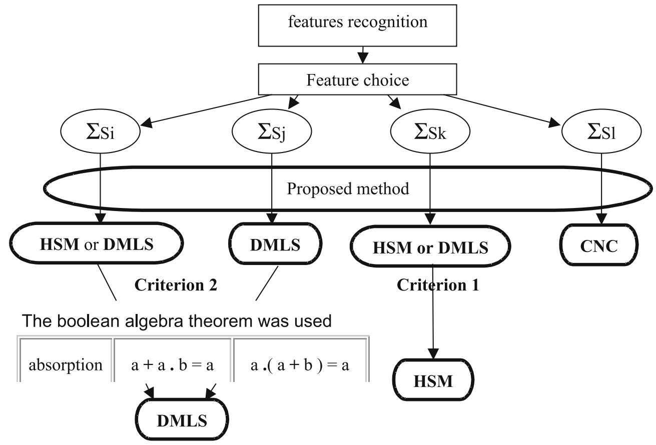



**Fig. 3.** Method

## 4 Example: mould for plastic injection part

A DMLS prototype mould for pilot production of the "ABS" link is manufactured.

The goal is to ratify the DMLS process for this application. This part has small dimensions ($50 \times 30 \times 15$ mm) and the mould has a thin form.

In the first stage, we have completely manufactured this mould with a DMLS process.

The firm is designed to inject hundreds of ABS parts. The small dimension detail (0.2 mm) must be obtained with good quality (Fig. 4).

Topologic and dimensional analysis and application of the method for the drift (Figs. 5–8).

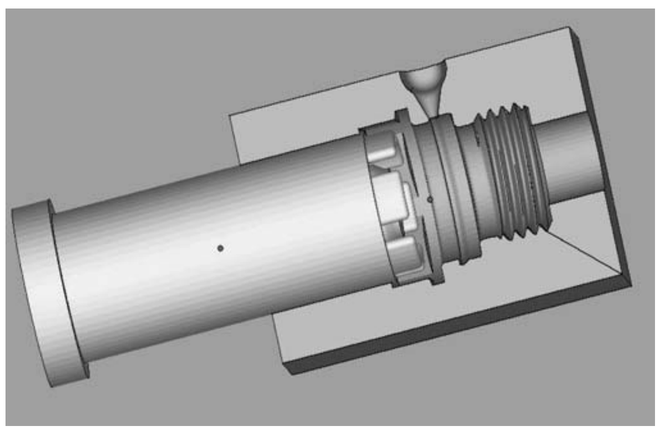


**Fig. 4.** Industrial injection mould

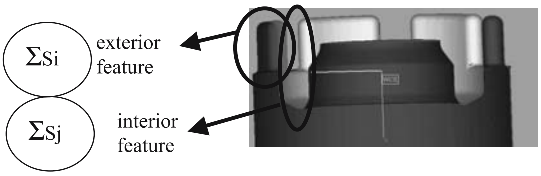



**Fig. 5.** Surfaces identification, or surfaces set, associated by geometric type

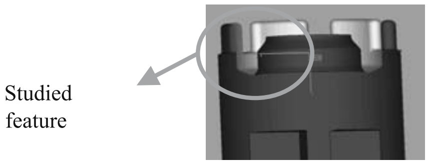



**Fig. 6.** Isolate the surface or surfaces set

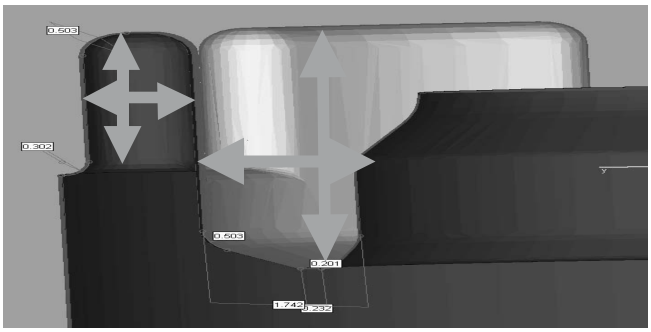



**Fig. 7.** Topological and dimensional analysis

| | *Surfaces identification* | | *Topological analysis* | *Tool specifications* | |
|---|---|---|---|---|---|
| ΣSi | Exterior feature | Little complex | l/h = 1.2 / 3.2 =0.375 and l = 1.2 and IT>0.1 | d(tool)>0.5 r = 0.3 L/h < 7 | **HSM or DMLS** |
| ΣSj | Exterior feature | little complex | l/h = 1.7 / 5.4 =0.31 and l = 1.7 and IT>0.1 | d(tool) = 0.2 r = 0.2 l/h = 6/0.2= 30 | **DMLS** |

**Fig. 8.** Application of the proposed method

4.1 Conclusion for the $\Sigma$Si and $\Sigma$Sj surfaces set:

Si$\cap$Sj, so, by association of process, according to criterion 1, we choose the DMLS process for manufacturing drift:

$(\mathbf{DMLS}+\mathbf{HSM}).\mathbf{DMLS}=\mathbf{DMLS}.$

(Figs. 9–10)

4.2 Conclusion for the $\Sigma$Si, $\Sigma$Sj, $\Sigma$Sk, $\Sigma$Sl ,$\Sigma$Sm surfaces set:

$\Sigma$Si$\cap$ $\Sigma$Sj$\cap$ $\Sigma$Sm$\cap$ $\Sigma$Sk, so, by association of process, according to criterion 1 and criterion 2, we choose the HSM process for manufacturing $\Sigma$Si, $\Sigma$Sj, $\Sigma$Sk et $\Sigma$Sm.

For $\Sigma$Sl, the result is determined, DMLS process is used.

Now a colour code can be applied on the mould before visualizing the result (Fig. 11).

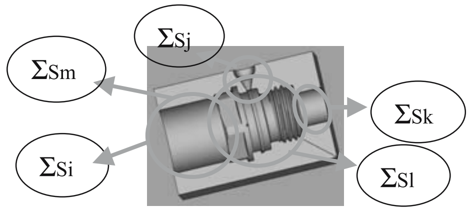



**Fig. 9.** Topologic and dimensional analysis and application of the method for the mold

| | *Surfaces identification* | | *Topological analysis* | *Tool specifications* | |
|---|---|---|---|---|---|
| ΣSi | Interior feature | Little complex | l/h = 1.01 and l = 15 and IT>0.1 | L/d(tool)=1 and h=7.5 | **HSM or DMLS** |
| ΣSj | Interior feature | Thin complex | l/h = 1,5 and l = 5 and IT>0.1 | L/d = 0.5 and h =6 | **HSM or DMLS** |
| ΣSk | Interior feature | Thin complex | l/h = 0.8 and l = 8 and IT>0.1 | L/d=1 and h=4 | **HSM or DMLS** |
| ΣSl | Interior Feature | Thin complex | l = 0.18 IT>0.1 | r = 0 d(tool)=0.18 | **DMLS** |
| ΣSm | Exterior Feature | Simple | L*l = 33.2*25 | L/d = 3 and h = 5 | **HSM** |

**Fig. 10.** Method

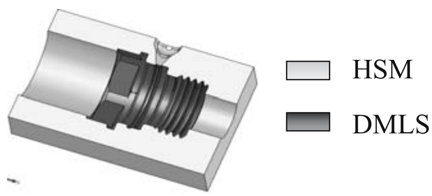



**Fig. 11.** Colour code mould

## 5 Hybrid tooling design

During the hybrid tooling design, economical (the DMLS "inserts" size must be reduced) and fitting (it's not easy to fit every form) constraints add to theoretical result. We propose this solution for the mould (Fig. 12).

The injection point is manufactured in HSM for the larger dimension and in DMLS for the thin part. It is the technical limit of HSM (Dtool = 0.5).

5.1 Winnings estimation and validation of the hybrid approach obtained by help choice process

Time and manufactured direct costs for mould were estimated in the two cases.

- *First approach: DMLS mould.*

It was the first solution before help choice process takes place.

**Table 2.** Delay

| Time | CAM for HSM | Preparation DMLS | DM LS | CAM for HSM | Preparation HSM | HSM | Shot pen | Cutting-up fitting |
|---|---|---|---|---|---|---|---|---|
| DMLS Mould | 15 min | 15 min | 7 h 45 min | | | | 10 min | 30 min |
| Habrid Mould | 15 min | 15 min | 5 h 15 min | 30 min | 15 min | 13 min | 5 min | 1 h 30 min |

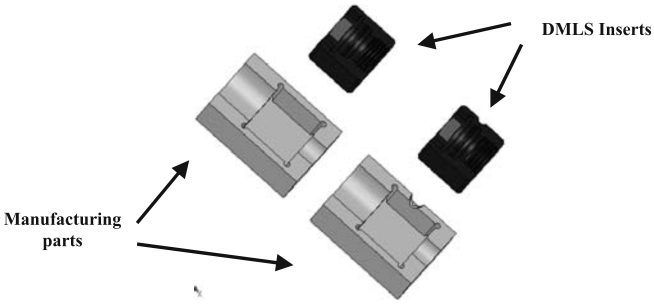



**Fig. 12.** Hybride rapid tooling

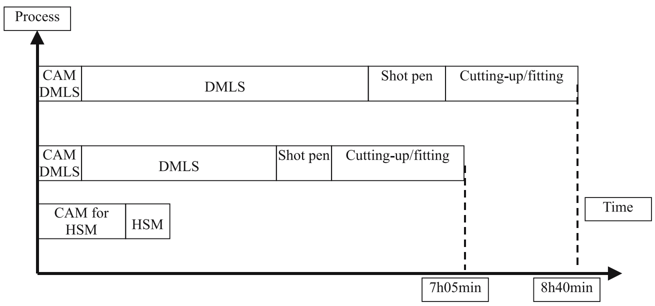



**Fig. 13.** Tooling organization of manufacturing operations hybrid mould

- *Second approach: Hybrid mould design with proposed method (Table 2).*

The delay in obtaining tooling will depend on production organization. The operation must be realized in hide time. We can see the hybrid process winning. For the DMLS mould, we obtain 8h40 for the manufacturing time. For the hybrid mould, the manufacturing time is reduced to 7h05 (Fig. 13).

## 6 Manufacturing cost

We have decreased the time for manufacturing the hybrid rapid tooling by 18%. Nevertheless, DMLS takes a long time. It is important to minimize this operation. The main solution is to design this feature the smallest as possible.

In order to calculate the cost of the manufacturing of the mould, we have used the cost per hour for the different processes (cost time is an average of our industrial partners).

- C/h DMLS = 75 €
- C/h HSM = 60 €
- C/h CNC = 40 €
- C/h CAD/CAM = 20 €

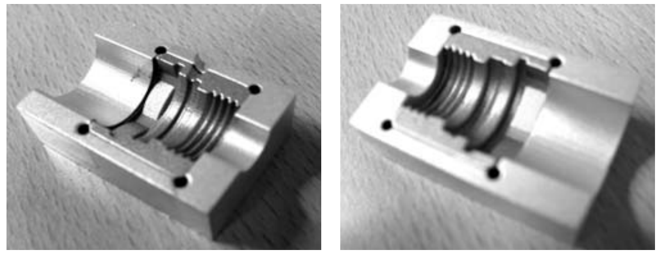


**Fig. 14.** Assembly hybrid rapid tooling

- C/h CAM for DMLS = 20 €
- C/h for assembly = 30 €

$$\begin{aligned}\mathbf{C}_{\text{total}} = {} & \textbf{Cost time}_{\text{CAD for DMLS}} \times \textbf{Time}_{\text{prepa DMLS}} \\ & + \textbf{Cost time}_{\text{DMLS}} \times \textbf{Time}_{\text{DMLS}} \\ & + \textbf{Cost time}_{\text{(shot pen/cutting-up/fitting)}} \\ & \times \textbf{Time}_{\text{(shot pen/cutting-up/fitting)}}\end{aligned}$$

The final cost, for the DMLS mould is given by the equation: Numerical application:

$$C_{\text{total}} = 20 \times 0.5 + 75 \times 7.75 + 0.67 \times 30 = 611.35\ €.$$

For the hybrid rapid tooling, the final cost is :

$$\begin{aligned}\mathbf{C}_{\text{total}} = {} & \textbf{Cost time}_{\text{CAD for DMLS}} \times \textbf{Time}_{\text{prepa DMLS}} \\ & + \textbf{Cost time}_{\text{DMLS}} \times \textbf{Time}_{\text{DMLS}} \\ & + \textbf{Cost time}_{\text{CAM for HSM}} \times \textbf{Time}_{\text{CAM for HSM}} \\ & + \textbf{Cost time}_{\text{HSM}} \times \textbf{Time}_{\text{HSM}} \\ & + \textbf{Cost time}_{\text{(shot pen/cutting-up/fitting)}} \\ & \times \textbf{Time}_{\text{(shot pen/cutting-up/fitting)}}.\end{aligned}$$

Numerical application:

$$\begin{aligned}C_{\text{total}} &= 20 \times 0.5 + 75 \times 5.75 + 0.75 \times 20 + 0.22 \times 60 + 1.58 \times 30 \\ &= 516.85\ €.\end{aligned}$$

The final cost is decreased by 15%. The hybrid rapid tooling for this application is presented figure (Fig. 14).

## 7 Conclusion

The proposed method is available for a complex tooling, but the number of features increases rapidly and the topological analysis (actually manual) becomes drudgery. The criteria utilization is efficient and gives good results on presented examples.

Currently, the DMLS process is well mastered. It is important to propose a method to efficaciously use this technology. In fact, this method allows the selection of the best process among EDM, HSM and DMLS technologies.

The final goal is to propose a software assistant used in association with CAD system during the design of hybrid rapid tooling.

Nevertheless, an important work concerning the features recognition must be implemented. The assembly of the different part of the hybrid rapid tooling must be considered and optimized.

## References


1. Sandvik Coromant (2004) Die & mould making. http://www.coromant.sandvik.com
2. Bernard A, Taillandier G (1998) Le prototypage rapide. Edition Hermes, pp 14–15
3. Knirsch J (2003) RSP Tooling – rapid production tooling. International conference on advanced research in virtual and rapid prototyping
4. Karlsen R, Reitan J (2003) Metal printing – development of a new rapid manufacturing process for metal and ceramic objects. International conference on advanced research in virtual and rapid prototyping
5. Hur J, Lee K (2002) Hybrid rapid prototyping system using machining and deposition. Comput-Aided Des 34(10):741–754
6. Zhang H, Wang G, Luo Y, Nakaga T (2001) Rapid hard tooling by plasma spraying for injection molding and sheet metal forming. Thin Solid Films 390:7–12
7. Wohlers T (2003) Rapid prototyping, tooling and manufacturing state of the industry. Wohlers reports 2003
8. Syrjälä S (2002) DMLS for injection moulding and die casting applications. Rapid product innovation Oy. Euromold, Dortmund
9. Raptec (1999) Potential RP process chains for prototype injection moulding and sheet metal forming tools. Project BE-2051. http://www.raptec.org
10. Hänninen J (2001) DMLS moves from rapid protyping to rapid manufacturing. MPR, http://www.métal-powder.net/sepfeat.htm
11. Jégou L (2003) Méthod d'aide au choix des procédés en "outillage hybride". Mémoire de DEA Ecole Centrale de Nantes