Laser Direct Manufacturing Developments State-of-the-Art and Activities in the French Aerospace Industry

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ABSTRACT

Direct metal laser manufacturing technology is an innovative process, which allows fabricating parts directly from computer aided design data. This technology could be an alternative solution to obtain parts with excellent internal properties for low volume of production or to respond for product support in case of old aircraft. A quick overview is presented at first, then the development in the French aerospace industry. First tests or applications are shown and demonstrate the great potential of the laser direct manufacturing process for aerospace parts.

1.0 STATE OF CURRENT KNOWLEDGE ON DIRECT MANUFACTURING

To remain competitive in the aerospace market, it is important to stay at the top of advancement for the products, but also to offer new solutions for design office and manufacturing plants in order to respond quickly after modification or need, in term of lead time, price and quality of the manufacturing parts. Since 1998, DASSAULT AVIATION and others French aerospace companies (MBDA, EUROCOPTER, SNECMA Moteurs, EADS) have been creating a consortium named "Stereometal" with the objectives are to study, to develop and to demonstrate the use of Direct Manufacturing (DM) for fully dense aerospace parts without forming tooling and link directly to CAD model. Two additive processes based on metal deposition have been performed by the consortium: the first is the laser additive cladding, currently noticed Laser Forming (see figure 1) and the second one is the direct Selective metal Laser Melting (see figure 2). The main idea for the two processes is to build up metal features in layers of metal powder. For the first, the metal powder is carried on by inert gas and melted by laser beam before to be deposited. For the second, the metal powder is at first deposited and melted by laser beam or electron beam. This last process is in fact derived of the laser sintering and of the well-known stereolithography for the slicing.

If we look at the contributors for the emerging of theses innovative manufacturing processes, we observe that the laser additive cladding has been developed in USA mainly, in the 90s years successively by AeroMet Corporation (a MTS company) with the Lasform process (Laser Forming, see figure 2) and by OPTOMEC for the LENS process (Laser Engineered Net Shaping) developed by Sandia National Labs. About AeroMet Corporation, the parent company, MTS Systems Corp. decided, in October 2005, to stop the commercial activity after seven-year effort. Nevertheless, OPTOMEC is still available to supply laser additive machines in the whole world. The Selective Laser Melting technology has been developed mainly in Europe from the laser sintering without no post processing steps, as burnout or infiltration. MCP, EOS, 3D Systems, Phenix Systems, etc… are available to build and to sell Direct Manufacturing machines. Moreover, research laboratories developed their own DM machine as ILT. The table 1 presents the main characteristics of each technology. Using the two processes, the designers could cover a large amount of

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parts with different materials, different dimensions and different shapes. Preliminary results obtained from TA6V AeroMet specimens (see figure 3) proved the great interest for laser additive manufacturing process. The figure 3 indicates the static and fatigue properties. The static properties are 10% less than the AMS specification and the level of fatigue crack initiation is between current casting and forging properties. For these tests, no optimised heat treatment used after laser deposition.

So, this paper presents a project research work on laser direct manufacturing, named PROFIL, whom the aims are the understanding of this novel technologies and to demonstrate their availability for future aerospace applications.

2.0 THE PROJECT PROFIL

2.1 Context

The aims of the project PROFIL (PROjection et FrIttage Laser) and the involved partners (DASSAULT AVIATION, EADS, EUROCOPTER, MBDA, SNECMA Moteurs, Centre des Materiaux de l'Ecole des Mines de Paris, GIP-GERAILP) are to develop the 2 complementary processes for the manufacturing of parts ready to fly and without forming tooling. The objectives will be to reduce the manufacturing cost of 50% and the lead time of 70% and to simplify the supply chain. PROFIL succeeds to preliminary investigations made between 1998 and 2003 by the consortium with supporting of laboratory for the understanding and for the experimental work. The project is divided into 10 workpackges. Each of them is co-ordinated by a task leader, member of consortium. The items of workpackages are the following:

- to develop the direct manufacturing laser processes by improvement of mastery and quality of process in order to demonstrate the availability for flying parts,
- to develop the 3D numerical simulation of the Laser additive process in order to understand the metallurgical phenomena during the thermal phases of the process and to connect finally to the residual stresses. A feedback for alternative solutions or suggestions for improvement could be obtain,
- to adapt the final heat treatment for DM parts (Ti6-4, Inconel 718), after melting and cooling in order to obtain the optimised mechanical properties,
- to develop the fabrication of aerospace parts, in titanium and nickel alloys in a first time, and then others materials as aluminium alloys, tooling steels and functionally gradient materials,
- to improve the roughness of parts, in situ the DM processes or, further without finishing machining,
- to test on specimens and up-scale parts using ground testing the DM parts,
- to detect the potential defects of deposited material and to develop the Non Destructive Inspection methods to guarantee the metallurgical structure,
- to evaluate others external machines used in PROFIL,
- to adapt the design in order to respond to the constraints of these new processes,
- to perform the ROI (Return of Investment) analysis.

The duration of the total project is 4 years and has begun in December 2004.

2.2 Advancement

During the first year, the OPTOMEC 850R machine was bought and set up in the GIP-GERAILP laboratory, one of the partners of PROFIL. It was the first OPTOMEC machine in Europe and, now it was in service and ready to start the experimental work following the road map. For the Selective Laser Melting process, few greater modifications were carried on the PHENIX PM250 machine, yet set up in the same laboratory, as the introduction of hermetic chamber which is purged with argon in order to avoid contamination from oxygen and modification of laser beam system to control it.

Based of the first experimental results, few works have been done (see [1]). The objectives are to define the process window with the optimised conditions from the experimental specimens. Input parameters are defined with 2 levels of criticality. For high level of criticality, laser power (P), scanning speed (V) and powder flow speed (Dm) are considered. Output parameters are defined on the experimental specimens as the apparent height of the specimen (Happ), the apparent layer thickness (eapp), the depth of thermal affected zone (ZAT) and the process mass efficiency (Rmg). The figure 4 shows the first conclusions and the relationships between the input parameters and output parameters. For example, the increase of laser power (P) has no influence on Happ, but eapp and ZAT rise up. The figure 5 indicates the definition of optimised process window with drawing the Iso-Happ, Iso-eapp and Iso-Rmg curves. The Iso-El represents the specific energy (P/V) that combines two input parameters.

3.0 APPLICATION

At the end of 2004 year, the French navy in closed co-operation with DASSAULT AVIATION need to validate in flight operating conditions new equipments in the cockpit on the Rafale fighter. To hold them, a support must be supply by flying tests plant in a very short delivery time. Consequently, the laser direct manufacturing process using the selective laser melting was chosen for this part; based of the first results obtained previously by "Stéréometal" investigations, and of course from the required general specifications. DASSAULT AVIATION evaluated the MCP-HEK SLM Realizer, which is in possession of MBproto company, in France (see [2]). This machine has a working zone of 250x250x250 mm^3 and a 100 W Ytterbium fibre laser beam. However, the available material offered by MBproto was the stainless steel (316L). The constraint of lead time and the small size of this part had in favour of this choice. After several flights with great incidence, the first experience using a DM part was a whole success (see figure 6).

Micrography of the as-deposited material is shown in the figure 7. No heat treatment was done on this part. The observed porosity is attributed to process defect during the adding of powder layer, just before the melting operation. However, the part has filled the required mission. With adjustment, we could expect high quality.

4.0 CONCLUSIONS

Direct Manufacturing based on laser metal deposition presents a high potential for the future and could be a new fabrication route with short lead time, shape flexibility and low non recurrent cost (no mold, no die). The wide variety of materials, yet commercially available in the powder form is not a brake for the development of DM manufacturing. With the project PROFIL, the French aerospace industry want understand and to establish the knowledge of DM processes and to show the great interest of this novel technology for the future. Recent results have shown high level of promising.

Acknowledgements

Thanks for the fund support from the French Technology and Research Ministry and each partners of PROFIL project.

References

[1] Maisonneuve J., Colin C. : Fabrication directe de pièces avionnables bonne matière par projection laser du TA6V. 11ièmes assises Européennes de prototypage Rapide, October 2005

[2] Jandin G., Vacher D. : On the new parts manufacturing by direct micro-melting laser sintering process, Lisbon 2005

Table 1: Main characteristics of Direct Manufacturing processes

	Laser additive deposition		Selective Laser melting
Laser process	LASFORM by AeroMet	LENS by OPTOMEC	MCP, EOS, PHENIX SYSTEM,… ARCAM (electron beam)
Size of part	2000x3000x1000 mm max		250 x 250 x250 mm max
Laser power	30 KW max	1000W	100 W
Typical characteristics of parts	Large parts, stiffened structures with deep and wide pockets		3D Complex shape, Hollow opened or closed
Deposition time	1500cm^3/hour	15cm^3/hour	
Current Material	Titanium and Nickel alloys mainly	Titanium, Nickel, Cobalt alloys, steels	steels
Materials in progress		Aluminium alloys	Titanium and nickel alloys
Emerging materials		MMC, functionally gradient materials	Aluminium alloys
Finishing operations	Total machining	Near net shape geometry so local machining	Near net shape geometry so local machining
Other application	Repairing	Repairing	

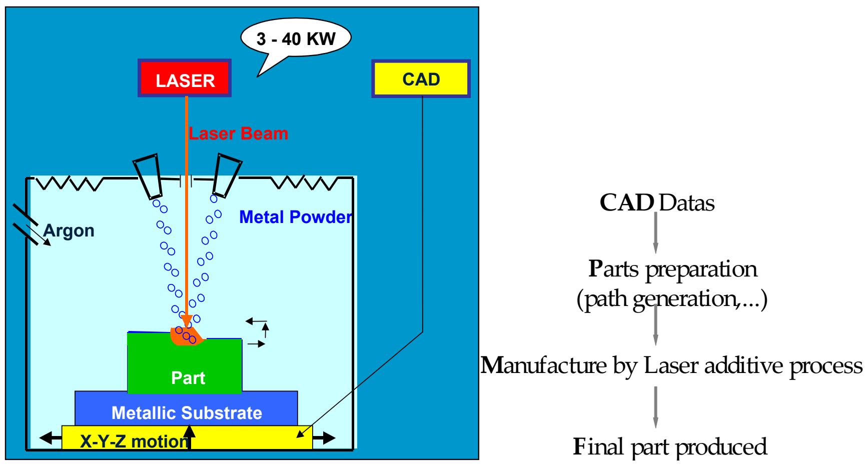


Figure 1: Principle of laser additive process

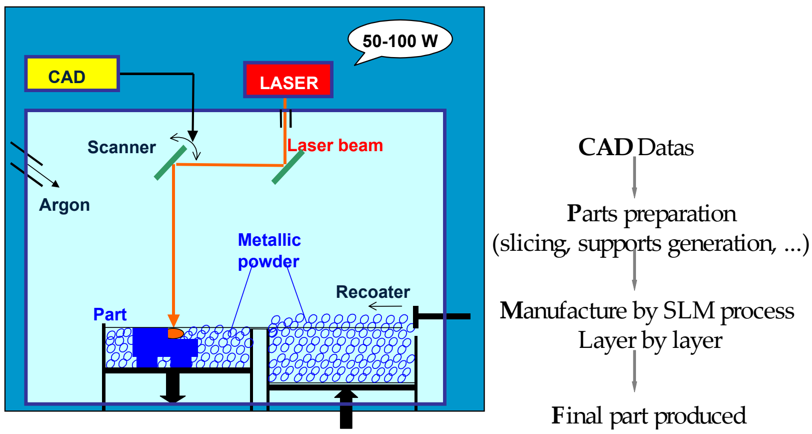
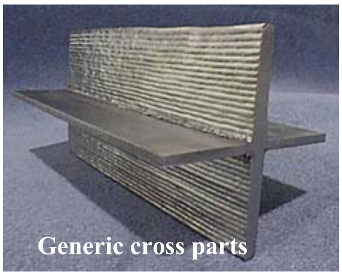
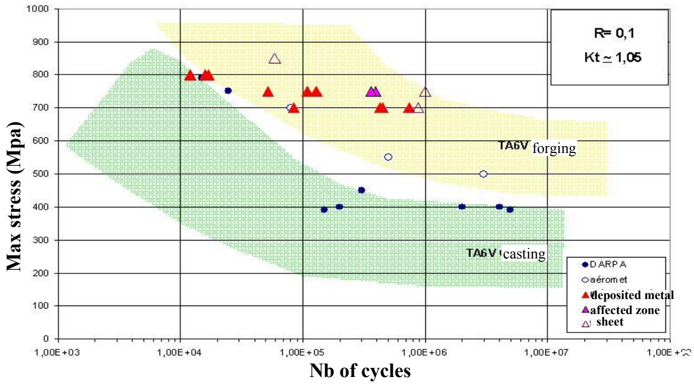
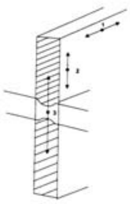


Figure 2: Principle of selective laser melting process







Specimen	YS (Mpa)		UTS (Mpa)		E%
Specif. AMS	*827*		*896*		*10*
1	748/786	-10%	843/871	-6%	10/11.5
2	761/787	-10%	843/891	-6%	9.5/13
3	726/769		861/872		8.0/9.0

Figure 3: DASSAULT AVIATION fatigue crack initiation results from AeroMet TA6V specimens and comparison with casting and forging.

Paramètre du 1er ordre	↑ P	↑ V	↑ Dm
Happ	=	-	+
eapp	+	-	=
ZAT	+	-	-

Figure 4: Influence of each input parameters of first level (P, V, Dm) on output parameters (Happ, eapp, ZAT)

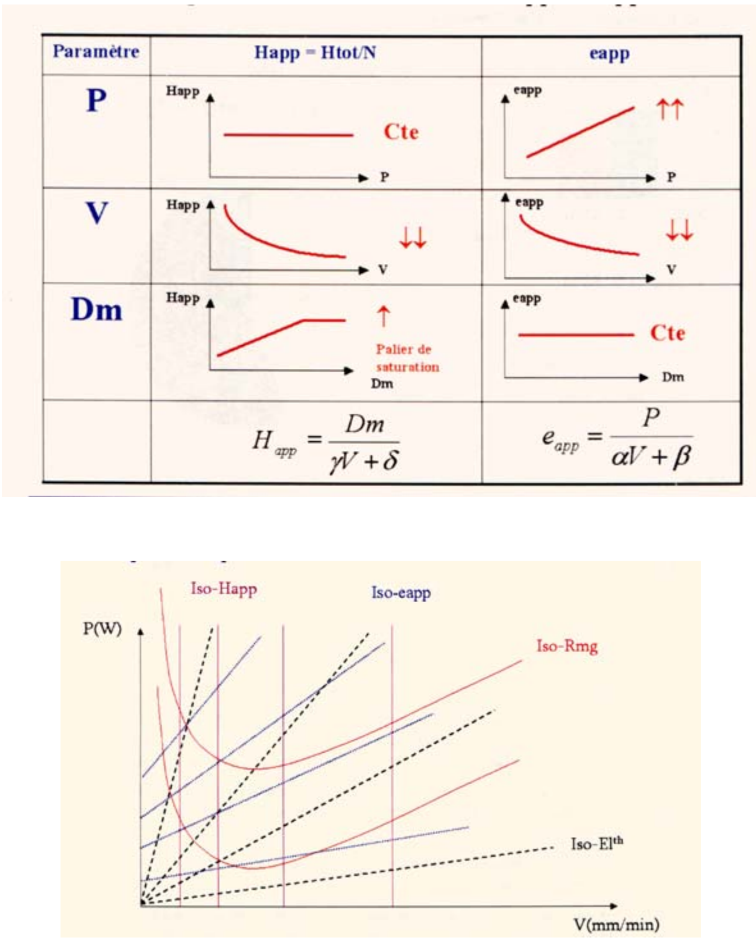


Figure 5: Definition of optimised process window from the parameters study and the determination of α, β, δ, and γ values

Figure 6: First equipment support made on DM process for Rafale flight tests.

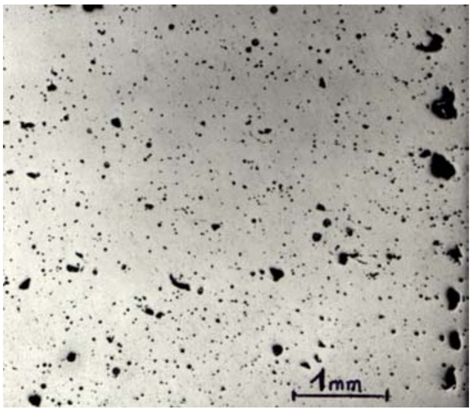


Figure 7: Micrography on 316L after deposition.

MEETING DISCUSSION – PAPER NO: 10

Author: G. Surdon

Discusser: R. Lang

Question: Elongation of the manufactured Al- component (by ILT)?

Response: ILT indicated 5% after deposition. Dassault will check soon these data on specimens plus UTS and YS.