

## **DMLS and Manufacturing**

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### **Abstract**

Direct Metal Laser Sintering (DMLS) has been used for manufacturing prototypes, functional metal components and prototype tools for more than 10 years. During this period the technology has advanced to a level where direct production of complex metallic parts for various applications is everyday life and manufacturing with its various challenges is its main target. The shift from prototyping to production requires changes in the technology and also in the organizations taking part in the shift.

This paper presents the latest status of the DMLS technology and materials development trends for different application areas using EOSINT M270 laser sintering machine. Commercially launched materials include presently biomedical materials like Titanium and Cobalt Chrome alloys, ultra high strength Maraging Steel alloy, Stainless Steels and other high-end engineering materials. In addition, there are many materials which have been developed for evaluation purposes, waiting for industrial applications.

### **Introduction**

The first generation DMLS technology was introduced in 1994-1995. The cooperation between EOS GmbH and Electrolux Rapid Development resulted in a novel DMLS technology and the EOSINT M250 machine. This machine was equipped with 200W CO<sub>2</sub> laser, Galvo scanners, flat field optics and suitable mechanics for taking care of powder dispensing, recoating and building platform movements [1]. This platform was used when EOS first generation materials including DirectMetal and DirectSteel families were introduced. The DirectMetal materials were bronze based metal powders with various layer thicknesses and were predominantly used for prototype tooling. This material is still widely used in tooling and part production because of its easy processing and speed. The DirectSteel family consists of two steel based powder mixtures, the first being EOS “carbon Steel” and the second, DirectSteel H20, EOS first generation production grade tool steel.

During the years it became obvious that the industry requires new and better materials to be able to fully utilise generative manufacturing methods in either replacing existing production or developing completely new ways of manufacturing. To be able to do this EOS developed EOSINT M270. It is a new machine concept based on a solid-state, dual-focus laser and redesigned mechanics enabling faster processing with higher detail resolution than the previous generation machine. Moreover, the M 270 provides a more efficient platform for current DMLS materials and especially for ongoing development of new powders and processes for a wider spectrum of future applications.

The ytterbium fibre laser used in the EOSINT M 270 has a beam quality M<sup>2</sup> of almost 1.0, which enables it to be focused to less than 100µm (0.0040 in.) beam diameter over the entire 250 mm x 250 mm build area. With 200 Watt power this corresponds to an average power intensity of up to 25 kW/mm<sup>2</sup>. This laser also has a shorter wavelength than CO<sub>2</sub> lasers, giving higher absorption in metals and therefore resulting in higher effective power and enabling higher build speeds. The variable laser focus enables a very fine focus for best possible detail resolution to be combined with fast, efficient exposure

of large areas by using a defocused, i.e. broader laser beam. Of course this can be utilised also in the optimization of processes for various materials [2].

### **DMLS and manufacturing**

It is now a widely accepted fact that generative methods, at least some of them, are real manufacturing methods. However, insufficient experience makes it difficult to make any general rules for the feasibility of the certain materials, batch sizes or part geometries. How well DMLS or any other generative method manages to compete technically or economically depends on the case. A completely new design enables the use of generative advantages which increases the success rate, whereas replacing an existing production is generally much more difficult.

One of the main advantages seen already in the early days of Rapid Prototyping was the reduction of restrictions related to manufacturing. This is of course true only if the part design is not an existing one and everything can be started from the beginning. The reality is different. So far only a limited amount of cases known to the authors have been of this kind. Most of the present manufacturing cases carried out with generative methods seem to be justified otherwise with the speed of the process chain or with features impossible for the conventional manufacturing methods.

The advantages of the generative methods depend also on the application. For example, the advantages of conformal cooling, which has been one of the most obvious new features throughout the history of the generative industry, was proven really only recently. It required further technical development of the technology, materials and design software, but above all, courage from the service providers and end users to take the necessary steps to implement the technical possibilities. The case presented later in this paper shows a very simple and good application of conformal cooling and still only scratches the surface of the advantages which will be shown in the future.

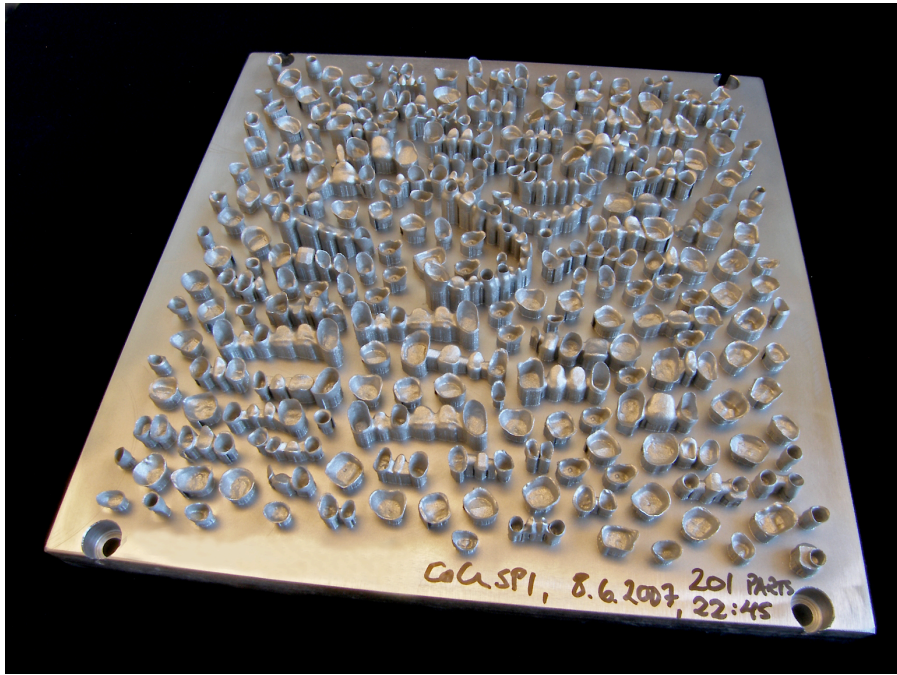
The target of more or less all the parties in the generative methods business is to enter the manufacturing world. This has led to an increasing demand of reliability and quality assurance. The industry is far away from the early days' stage when it was a sheer miracle if something usable came out of the machine but still more actions have to be taken before the standards of the 'normal' industry are fulfilled. This is a complicated task because expectations are high. It is also not fully understood that generative methods are actually part of the process industry, which means that most of the properties are created and defined in the process, inside the machine.

### **Manufacturing Materials**

After the introduction of the new platform EOSINT M270 several new materials, the second generation, have been introduced. All of them are so called production grade materials, which means that existing standards can be applied in describing the properties. Of course, because the production method is new, dedicated standards do not exist yet, but gradually they will be developed. Therefore normally cast or wrought references are used.

The first second generation material for the M270 machine was CoCrMoW biomedical alloy for dental restorations and bridges. The material is called CobaltChrome SPI. The material is to be veneered with a ceramic material, which is done at high temperature. Therefore the coefficient of thermal expansion of this material is tuned to be

suitable for this. Figure 1 shows a plateful (250x250 mm<sup>2</sup>) of dental restorations made in one job.

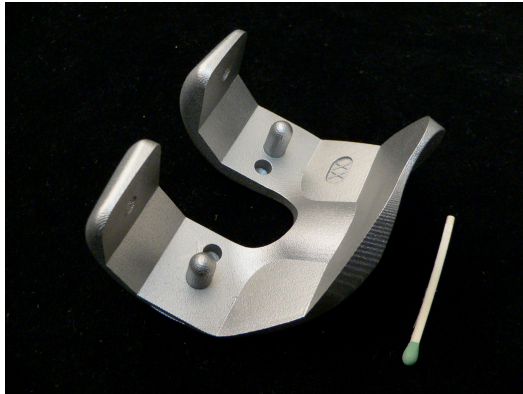


**Figure 1** 200 CobaltChrome SP1 dental restorations

The second Cobalt based superalloy is CobaltChrome MP1. This material was developed for the manufacture of biomedical implants. The properties of the alloy meet biomedical standards ASTM F75 and ISO 5832-4 of cast CoCrMo alloys and standards ASTM F1537 and ISO 5832-12 of wrought CoCrMo alloys. Figures 2 and 3 show two different implants made of CobaltChrome MP1.



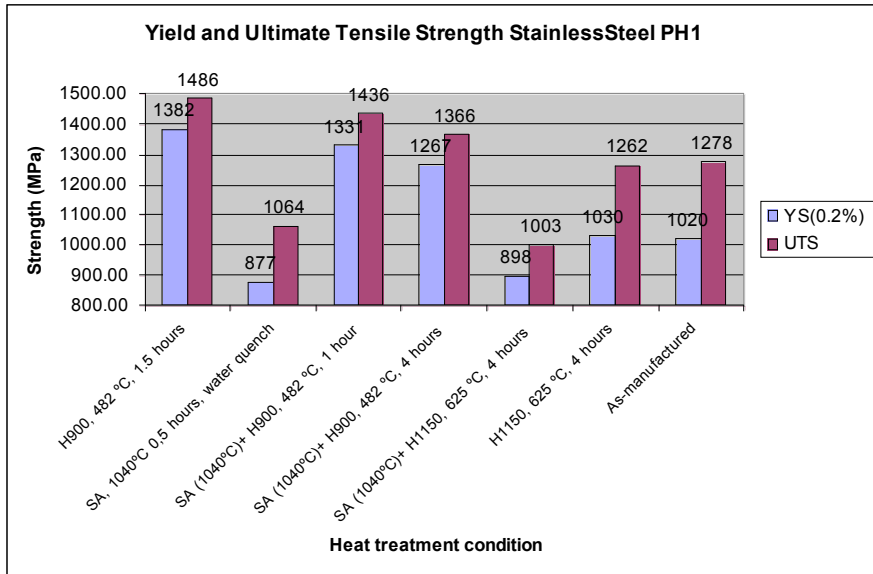
**Figure 2** CobaltChrome MP1 jaw implant



**Figure 3** CobaltChrome MP1 knee implant

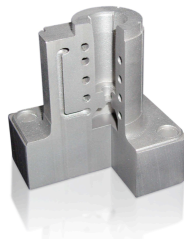
Interestingly, the MP1 material has also applications in engineering. Because of its high temperature properties it can be used for example in hot sections of engines and low volume run parts for jet engine development. In these applications the normal choice would be nickel based superalloys. The availability of similar properties combined with very fast manufacturing and increased complexity offers new possibilities to the industry.

In stainless steels there are currently two options, 17-4 and StainlessSteel PH1. The 17-4 is based on the metallurgy of conventional 17-4 PH material but the properties are more like 316L stainless, characterized mainly by the extremely high ductility. The demand for a material which has more conventional type properties was however so high that EOS developed a second stainless steel, this time fully precipitation hardenable material called StainlessSteel PH1. The properties of this material are equal or better than the properties of the conventionally manufactured 17-4 PH. One of the main advantages is that parts come out of the machine in solution annealed and quenched condition. Only precipitation hardening, H900 or similar simple heat treatment, is needed. Figure 4 shows some properties of the PH1 material in as manufactured and after different heat treatments. SA stands for solution annealed, H900 and H1150 precipitation hardening in 900 and 1150 degrees Fahrenheit, respectively.



**Figure 4** Some properties of StainlessSteel PH1 in different conditions

The company's response to series production tooling requirements is MaragingSteel MS1 material. It is an ultra high strength steel material which is also suitable for part production. The material was originally developed for aerospace part production but the unique combination of properties makes it extremely useful in generative processes. The parts come out of the machine as solution annealed and additionally they require only aging in moderate temperature. Compared to traditional tool steels the thermal treatment is really simple and produces only negligible dimensional changes. Figure 5 shows an example of MaragingSteel MS1 injection molding insert with cooling channels.



**Figure 5** MaragingSteel MS1 tool insert

The material which has the most expectations among the generative methods is Titanium. From engineering point of view it is a very attractive material but unfortunately very expensive and difficult to process, especially to meet the medical criteria. Therefore the medical companies are putting considerable amount of effort in pushing the generative methods beyond the quality requirements for the industry. The same applies of course for aerospace industry which has also started its evaluations.

EOS also has different grades available, both commercially pure and Ti6Al4V. For the medical industry Ti6Al4V ELI grade is the most challenging and this can also be produced in M270 Titanium version.

Table 1 shows some main properties of five different EOS materials.

	CobaltChrome MP1	CobaltChrome SP1	StainlessSteel 17-4	StainlessSteel PH1	Ti6Al4V
<b>Description</b>	CoCrMo based alloy for biomedical implants	CoCrMoW based alloy for dental crowns and bridges	17-4 PH type stainless steel alloy for biomedical instruments	Precipitation hardenable stainless steel for biomedical instruments	Ti6Al4V alloy for implants and engineering
<b>Relative density</b>	Approx. 100 %	Approx. 100 %	Approx. 100 %	Approx. 100 %	Approx. 100 %
<b>Ultimate tensile strength (MIPF 10)</b>	1400 N/mm <sup>2</sup>	1300 N/mm <sup>2</sup>	900 N/mm <sup>2</sup>	1450 N/mm <sup>2</sup>	1180 N/mm <sup>2</sup>
<b>Yield strength (Rp 0.2 %)</b>	950 N/mm <sup>2</sup>	1020 N/mm <sup>2</sup>	500 N/mm <sup>2</sup>	1350 N/mm <sup>2</sup>	1090 N/mm <sup>2</sup>
<b>Young's modulus</b>	200 Gpa	170 Gpa	190 Gpa	190 Gpa	120 Gpa
<b>Elongation at break (A5)</b>	12 %	8 %	30 %	6 %	5 %
<b>Vickers hardness (HV1)</b>	400 – 450 HV	430 – 460 HV	250 – 320 HV	400 – 450 HV	400 – 430 HV

**Table 1** Some properties of EOS DLS materials

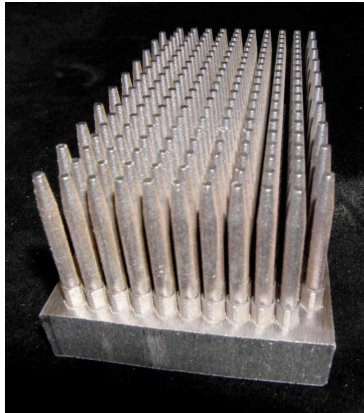
### Manufacturing Examples

Dental copings and bridges is one of the applications where direct laser processing has already proved its efficiency. There are several companies which have commercialised the production of CoCr bridges and copings using EOS or competing equipment. One of the first ones was a German company Sirona Dental Systems. Figure 6 shows a small and a larger bridge made by Sirona.



**Figure 6** CoCr bridges (Courtesy of Sirona Dental Systems)

As mentioned earlier in the paper, conformal cooling now seems to be finding its applications in tooling. Figure 6 shows a simple but effective way of cooling individual locations in tool. There are 200 MaragingSteel MS1 cooling pins built on top of M270 baseplate. They all have a very narrow cooling channel going from the bottom all the way to the top allowing very effective cooling.



**Figure 7**  
pins

MaragingSteel MS1 cooling

The same principle can be utilised in various types of hot processes in controlling temperatures. This has many effects on molding processes, for example shortened cycle times and also improved quality of the molded products, not to mention reduced need for tool service.

### **Conclusions**

Many of the generative manufacturing methods are gradually approaching the necessary quality levels required in different fields of manufacturing. The requirement levels are of course different depending on the application. In many industries, such as medical and aerospace, the requirements are based on legislation and therefore without fully fulfilling them the application doesn't exist. EOS has set clear goals to itself to be a manufacturing process provider also for the most demanding industries. The selection of materials and properties described in this paper shows the progress towards the goal.

### **References**

1. T. Syvänen, "Direct Laser Sintering of Metals – Material and Process Development", 1996, M.Sc. Thesis, Tampere University of Technology, Finland.
2. Syvänen, T., Heugel, M. & Domröse, R., "Diode Pumped Fiber Laser in Direct Metal Laser Sintering (DMLS) Process", ICALAO, San Fransisco, October 4-7th, 2004