INDUSTRIAL USE OF DIRECT METAL LASER SINTERING

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Abstract

The Direct Metal Laser Sintering (DMLS) process was developed a few years ago by Electrolux Rapid Development (ERD) and EOS. DMLS has now been in commercial use for more than two years at Electrolux and also at other European prototype manufacturers, and the machine itself is also available for purchase.

This paper describes the development of the process in particular the industrialization of DMLS and how it has changed the prototype mould manufacturing process at Electrolux. Issues concerning the materials used are also described, as well as the necessary post-treatment methods in prototype mould manufacturing. Several case studies, from various injection mouldings to pressure die-casting, are presented.

1. Background

Direct Metal Laser Sintering was commercially introduced in 1996. ERD received the first laboratory machine at the beginning of 1995. ERD had conducted the first laboratory tests even earlier than this, but a more professional development of DMLS as an industrial manufacturing method started when the first laboratory machine was received.

Some of the earlier research work on materials for DMLS has been reported previously in (1), however the history of the powder concept dates back to the end of the 1980's. This basic idea has been briefly described in (2), and more thoroughly in (3). Direct laser sintering of the proprietary bronze powder has been studied in one M. Sc. work (4). A more general survey of the laser sintering of steel powders is studied in one additional M. Sc. work (5).

Apart from research and development work on materials used in direct laser sintering, the major task of the research team at ERD has been to develop new applications for laser sintered inserts. This work includes everything from surface finishing to mould concepts in the manufacture of injection moulds. The research group has been particularly successful in being able to apply research and development results to in-house prototype production – one of the tasks set out for the group.

2. DMLS Charasteristics

2.1. Net-Shape Operation

The main goal of DMLS is net-shape operation. This aim was set, in fact, before rapid prototyping, because the sintering method which DMLS is based on is a net-shape furnace sintering process. There are several reasons why the net–shape process is beneficial and in some cases essential:

- It is a simple operation: no shrink factors or compensations are needed
- Accuracy
- The potential to build large parts

The first argument is perhaps somewhat outdated, because of the ease in manipulating solids in computer models, but it is still an additional operation to take shrinkage into account in mould manufacturing. In layer manufacturing processes shrinkage is often different in the x, y and z –directions and with free-formed surfaces this can create problems.

Accuracy is probably the most important reason why net-shape operation is recommended. Shrinkage almost never occurs uniformly and this is why all rapid prototyping methods that include shrinkage can meet the given tolerances only up to a certain length or thickness (6). Size limits in some rapid prototyping methods are due to this fact.

The third argument can actually be derived from the second point. If no shrinkage is associated with the process, the only limitation for the part or mould size is the size of the manufacturing machine itself. In mould manufacturing with shrinking processes, apart from meeting the tolerances it is in many cases impossible to fit the mould halves together because distortions in different regions in the parting plane are not equal. If you cannot fit the mould halves together, the mould is useless.

Accuracy of the parting plane is naturally essential in mould making. In a shrinking process it is often suggested that extra material be added to the parting planes, and then milled away so that the mould halves can be accurately fitted together. What is often forgotten, however, is that the same unpredictable amount of distortion is also taking place in the cavity of the mould, and if this is also not corrected the part is simply not usable. If both parting planes and cavities are machined, why use the free-forming method in the first place.

2.2. Material Properties

The properties of DMLS materials have been discussed in (2). One of the problems in dealing with porous materials is mechanical strength. Because DMLS is a net-shape sintering process, it inevitably produces porous material, which is naturally not as strong as fully dense material. Development of materials has been done after reporting in (2). Normal tensile strength of the material near mould surfaces is about 200 MPa. The properties of the material depend strongly on the equipment used. The main factors are laser power and the quality of the laser beam.

In practice, weaker material has to be taken into account in the mould insert design. If a designer thinks that a certain detail in a mould needs stronger material, the detail in question simply has to be taken from a CAD file and made by other means. The detail is later added in the mould as a separate insert. This kind of hybrid construction is very common in prototype mould manufacturing, and normally does not cause serious problems. It is also becoming more and more common in series mould manufacturing.

Another possibility is to treat the critical regions as separate files. The detail files are then laser sintered together with the main part of the mould, but with extremely hard sintering parameters - essentially melting. As mechanical properties of the detail are then much greater than in the mould insert generally, dimensional variations in the hard sintered detail are greater and thus this approach can not be applied in cases of high volume. Combining normal direct laser sintering and melting in the detail dimension can also be preserved.

Mechanical properties can also be enhanced by infiltration. Metal infiltration is normally applied in increasing the density of sintered inserts. Unfortunately, this technique can only be used when dealing with materials that have a higher melting point, such as steel, because there are no suitable infiltrants available for bronze-based materials. There is also a risk of losing dimensional accuracy through the interactions between solid particles and the infiltrant. Mechanical properties gained after metal infiltration are comparable with the ones of the infiltrant metal itself. Normally in case of DMLS, only polymer infiltration is used, more precisely, surface infiltration because the whole volume of the insert is not filled. The purpose of surface infiltration is to enhance surface properties, not to fill all pores of the insert.

One problem associated with layer manufacturing is determining material properties. Before layer manufacturing the task was easier because everything was machined in standardized materials. In most layer technologies, the properties are different in the x, y and z -directions. In DMLS the possibility of using different parameters in predetermined three-dimensional sections of the body makes it even more difficult to characterize the properties in the conventional way.

2.3. Surface Properties

One of the biggest problems in direct laser sintering methods, and also in DMLS, is the insert surface quality of the after sintering. Direct laser sintering is quite an aggressive method, a combination of sintering and melting. The sintered material, which is partly agglomerated particles, partly solidified melt pools, cannot form a very good surface directly from laser sintering. Therefore all critical surfaces have to be finished.

A special polymer infiltration can be used to enhance surface finish. This infiltration differs from conventional methods, because only pores on and just beneath the surface are filled. The method is called surface infiltration, and it uses a mixture of suitable metal particles and liquid polymer. Because the insert is porous, capillary forces drag the liquid inside the body. Particles move with the liquid deeper inside the pores and gradually close most of the pores on the surface.

After surface infiltration there are several possibilities for finishing the surface. Some prefer hand finishing, some try to apply automated NC-based methods. The quality of finish depends on the method chosen. If the quality is expressed in R scale, values of about 0.5 R_a and about 2 R_{max} can be reached by applying present methods. These values are subject to change because surface finishing is always undergoing intensive development.

3. Industrial Use

The use of DMLS inserts, as well all other mould inserts, differs considerably from the use of the other 'conventional' rapid prototyping parts. Service bureaus dealing with rapid prototyping machines normally just deliver rp parts. As input data they get STL files. In this kind of business the value added remains low. This can also be seen in the performance of many service bureaus – they are quite vulnerable to fluctuations in demand.

3.1. Traditional Mould Industry

The plastic component industry has been strictly divided into separate fields. Some companies manufacture tools, and some mould the plastic parts. This means that the most of the industry is quite specialized, and knowledge of the entire development process is very rare.

The development of the injection mould chain can be troublesome, because the process has to be done simultaneously in several different places. If a mould maker develops a new design concept, good results cannot be achieved unless the injection moulder is deeply involved in the development. All the problems are emphasized in the production of prototype molds, because of all additional trouble associated with product development. This difficulty has been seen many times in the history of laser sintered mould inserts.

3.2. Industrial Use at ERD

At ERD the traditional way of making injection mold business was almost totally rejected years ago. This was done even before the era of rapid prototyping. ERD realized that to be effective in product development, one must be able to control the whole development chain, from component design to the manufacturing process, including all prototype-manufacturing processes.

In prototype services, all rapid prototyping and rapid tooling methods are but a small part of the prototype production process. Services provided by an rp machine should fulfill their tasks in the development process. The tasks are many and they depend naturally on the project. This inevitably leads to the fact that there is not just one right method, not even for rapid tooling.

Because ERD specializes in product development, DMLS is only one of many tools used handle a large variety of product development projects. The reason why ERD developed the DMLS was to satisfy the internal need for such a machine. The same motivation led to the development of the furnace sintering process, which DMLS is based on.

Normal DMLS project starts when a plastic component CAD-data is received. If the part is suitable for DMLS, a CAD-designer specialized in DMLS starts to design the mould. The mould design covers both the insert and the mold itself. ERD's knowledge of the strenghts and weaknesses of the DMLS process is especially important when it comes to the design of the insert.

The project manager makes the choice between different manufacturing methods. DMLS is suitable for moulds with extremely complex surfaces. It measures up very well with milling if large amounts of material have to be removed by this process. In cases where milling is impossible, DMLS is the best choice. If spark erosion is going to be the manufacturing method for the production mould, DMLS is an extremely competitive alternative.

The CAD designer provides the DMLS operator with a net-shape STL model. At this stage, the DMLS operator has numerous possibilities to alter the material properties at different regions of the insert. The parameters are adjusted so that strong material is produced at regions where maximum stress is expected. It is advantageous if the DMLS operator has knowledge of laser sintering materials. At ERD this is the case, because the laser sintering machines are operated by the DMLS materials development team.

The goal in the production of DMLS inserts is to be able to do it then net-shape. At present, it can be done with an overall accuracy of ±0.05 mm. This accuracy is good enough in most of the injection moulding cases. The accuracy depends both on the material and also on the machine condition - particularly on the laser power. The interaction between the laser and the material varies with the power of the laser and this variation cannot be entirely compensated for by adjusting the scan speed.

After laser sintering the insert undergoes surface infiltration, as described in chapter 2.3. The aim of surface infiltration is to make polishing easier by filling surface pores. Polishing is at the moment the most human labour-intensive process in the chain, and a lot of effort is being put into improving post-treatment methods. It seems, though, that it is extremely difficult to combine good surface quality and direct laser sintering. Some surface treatment is always needed. A completely different question is whether this task can be automated or not.

The typical turnaround time of a DMLS project from receiving the component's CAD-data to the delivery of the plastic parts is two weeks. If everything goes well, smaller components can be delivered in one week. Parts that are complicated and/or large can sometimes require three or four weeks. Figure 1 shows a typical injection mould and plastic parts, suitable for DMLS. The parting planes are complicated, and an alternative manufacturing method would probably be spark erosion, which is very time consuming. This mould was used as a small series manufacturing tool, and the number of plastic parts was in the thousands.

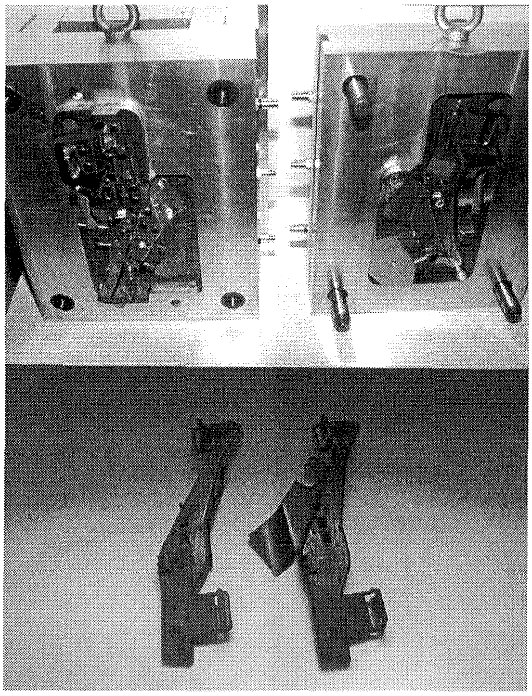

Figure 1 A Typical DMLS Mould and Plastic Parts

The maximum mould size a DMLS machine can manufacture at present is 250 x 250 x 150 mm. Larger moulds can be manufactured if the insert is divided into smaller sections the machine can handle. The injection mould is then assembled from these sections. The assembly is not very easy and it requires accurate manufacturing of the inserts. Figure 2 shows a large double injection mould. The maximum size is about one meter.

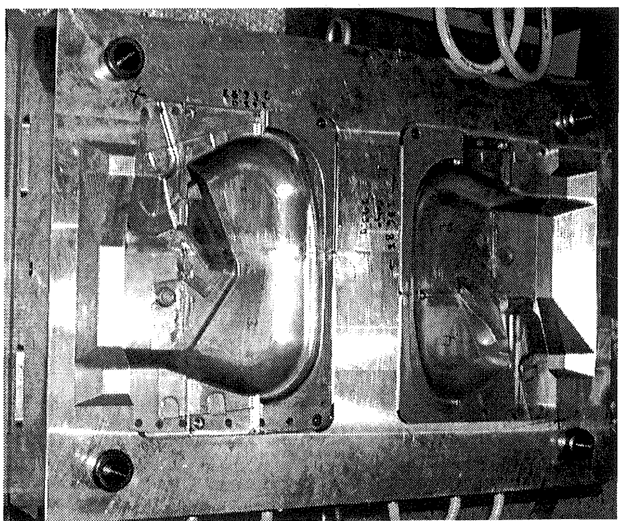

Figure 2 Large Double Injection Mould Assembled from Several Inserts

4. The Future of DMLS

The suitability of DMLS in various plastic and rubber moulding processes has been proven in many projects. The next major application field will be die-casting. First testing has been done and the results hold promise.

In materials development, the next step is stronger powder material. The goal, however, is to consistently make net-shape inserts. Good results have been achieved with steel powders. Figure 3 shows a die-casting insert made from proprietary steel powder.

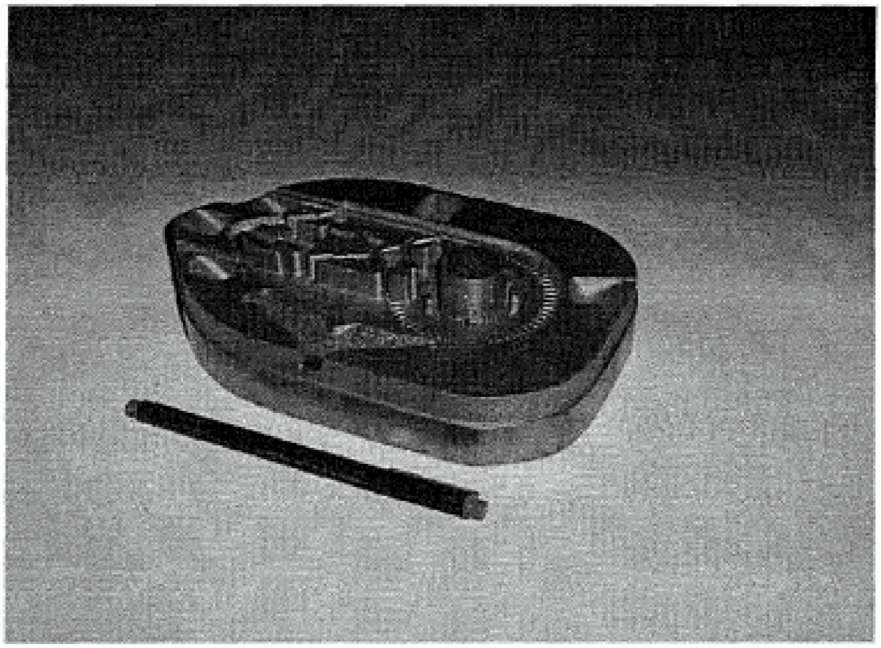

Figure 3 Die-casting Insert Made In Steel

References

1. M. Sindel, T. Pintat, M. Greul, O. Nyrhilä, C. Wilkening, "Direct Laser Sintering of Metals and Metal Melt Infiltration for Near Net Shape Fabrication of Components", Proceedings of the Solid Freeform Fabrication Symposium, The University of Texas at Austin, 1994.
2. O. Nyrhilä, "Direct Laser Sintering of Injection Moulds". Proceedings of the 5th European Conference on Rapid Prototyping and Manufacturing, University of Nottingham, June 1996.
3. O. Nyrhilä, "Pressureless Sintering of Metal Powders", M. Sc. Thesis, University of Turku, 1993.
4. T. Syvänen, "Direct Laser Sintering of Metals – Material and Process Development", M. Sc. Thesis, Tampere University of Technology, 1996.
5. J. Kotila, "Development of Steel Based Metal Powder for DMLS-Process", M. Sc. Thesis, Tampere University of Technology, 1998.
6. P. Jacobs, "The Effects of Shrinkage Variation on Rapid Tooling Accuracy". Proceedings of the Autofact '97, Detroit, Michigan 1997.