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METAL RAPID PROTOTYPING USING LASER SINTERING

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ABSTRACT

Rapid metal prototyping using laser sintering, also called Direct Metal Laser Sintering (DMLS), is a well known method for e-manufacturing, the fast, flexible & cost effective production directly from 3D CAD data. In the past 2 years the range of materials commercially available for this method has greatly increased, and with it the range of achievable part properties & applications. Driven by the increasing interest in rapid manufacturing, materials were developed and introduced for DMLS which correspond to materials commonly used in conventional manufacturing processes such as casting, forging & machining. The availability of these materials has in turn driven a rapid rise in the use of DMLS for rapid manufacturing applications.

Aim of this study is to research, analyze and obtain a dip stick knowledge of the future of manufacturing processes.

The study reports on state of the art DMLS process, materials, applications and its advantages over conventional manufacturing methods.

I. INTRODUCTION

1.1 Fading Economies of Scale:

Global markets are facing ever shortening product life cycles. At the same time, product variety is on the rise. Manufacturing methods based on economies of scale are no longer in the position to meet these challenges.

The conventional manufacturing means selling high volumes of identical products. This pre-requisite, however, can no longer be met in today's competitive environment.

Tool-based manufacturing methods are not suitable for economically fulfilling the increasing demand for customized products. Both product development and manufacturing therefore have to shift their paradigms – moving away from tool-based, static methods in favour of generative and flexible methods.

Laser-sintering adds flexibility to both product development and manufacturing. The designer no longer has to subject his creativity to the limitations of conventional methods of manufacturing. He can produce geometries that, until now, were impossible to build or only at tremendous cost. With METAL RPT, it is possible to produce inner structures just as well as undercuts. Mould draught angles are no longer necessary.

Focusing on the final product, the designer sketches out individual, three-dimensional geometries. During manufacturing, this 3D CAD model is sliced into thin layers. Metal RPT technology consequently creates layer by layer and using only powder-based materials and laser energy, the desired geometry.

1.2 History

The layer manufacturing techniques for metals have their roots in the 1971patent of Ciraud, who can be considered the precursor of the 3-d laser cladding processes and in the 1977 patent of Householder , who described the concept of SLM systems. These earlier ideas where not ready for commercialization due to the lack of powerful computers and the high price of laser systems at that time. Other important developments where made where made by the Westinghouse Electric Corp. ,in a patent application filed in 1988 by Sandia National Laboratories in the middle of 1990s . The Westing house project was further developed by Arcella at Johns Hopkins University . In 1997 Aeromet was founded. Today, Aeromet specialize in making complex parts from titanium for aeronautical applications by using the laser engineering net shaping process, in which the method of depositing the metal powder changes from 'powder-in-bed' to 'powder injection'.

II. METAL RPT PROCESS

METAL RPT was developed jointly by Rapid Product Innovations (RPI) and EOS GmbH, starting in 1994, as the first commercial rapid prototyping method to produce metal parts in a single process. With METAL RPT, metal powder (20 micron diameter), free of binder or fluxing agent, is completely melted by the scanning of a high power laser beam to build the part with properties of the original material. Eliminating the polymer binder avoids the burn-off and infiltration steps, and produces a 95% dense steel part compared to roughly 70% density with Selective Laser Sintering (SLS). An additional benefit of the METAL RPT process compared to SLS is higher detail resolution due to the use of thinner layers, enabled by a smaller powder diameter.

2.1 Metal Rapid Prototyping:

METAL RPT is a generative layer manufacturing technology and is the key technology for e-Manufacturing – the fast, flexible, and cost effective production directly from electronic data. Even highly complex three-dimensional geometries can be built efficiently and fully automatically, without requiring any tools or laborious milling path programming.

The METAL RPT process can be performed by two different methods, powder deposition and powder bed, which differ in the way each layer of powder is applied. In the powder deposition method, the metal powder is contained in a hopper that melts the powder and deposits a thin layer onto the build platform. In the powder bed method, the powder dispenser piston raises the powder supply and then a re-coater arm distributes a layer of powder onto the powder bed. A laser then sinters the layer of powder metal.

METAL RPT is a production method for creating metal parts.

It works by taking 3D geometry data such as a CAD file or scan data, which are sliced into layers by software. From this layer data, laser exposure vectors are calculated for each layer of the build process.

The dimensional accuracy achieved in case of Metal RPT process depends on the metal used for manufacturing the component.

Metal RPT process is used in cases which needs

- EDM (spark erosion)

- Five axis milling

- Multiple clamping position
- Hybrid tooling is an option.

Machining allowances provided on components manufactured by Metal RPT-

- Machining allowance of 0.1-0.5 mm to be provided on every relevant area for fitting.
- Parting surface needs to be shot peened and manual polishing.
- Shot peening system takes offset allowance of 0.05 mm.
- Polishing – 0.03mm is provided.

Minimum feature thickness that can be successfully manufactured with this technology is 0.6 mm.

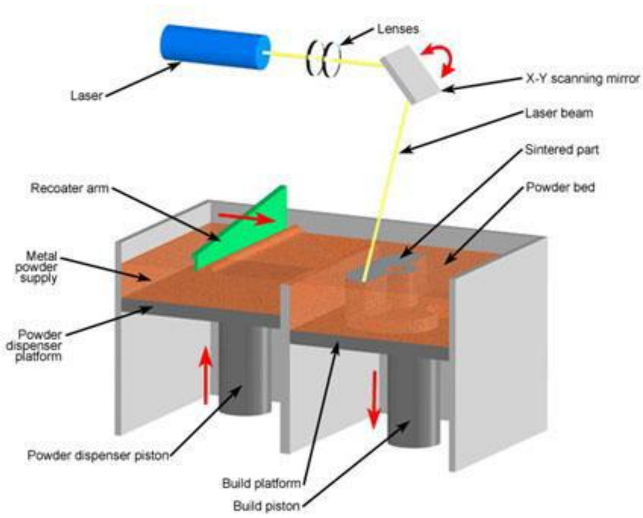


Figure-2.1. A schematic diagram of METAL RPT set-up and a part generated on METAL RPT

Figure-2.2 A Sample part generated on METAL RPT

2.2.1 Selective laser sintering

In this process a thin layer of powder is first deposited from the raised part-build area. The laser beam guided by the galvano mirrors is scanned onto the powder bed to form solidified/sintered layers. The powder in other areas remains loose and acts as a support. After the building-area drops one-layer thickness (typically 0.02-0.1 mm) another powder layer is deposited. The cycle is repeated until the 3-D part is complete. The fabrication chamber is closed and the process is performed in an inert atmosphere (nitrogen or argon) to avoid oxidation.

A mixture of powders or specially developed powders developed to allow fabrication of parts with densities typically higher than 60% are used. The densification mechanism during build up of the parts is liquid phase sintering, characterized by melting and wetting or liquid flow. In the case of single component powders, liquid phase sintering happens due to the surface melting of the particles and liquid flow. When mixed powders are used, the powder of low melting point is melted and acts as a binder. The process is called Metal Rapid Prototyping (METAL RPT). Post processing of infiltration or sintering is usually necessary to increase the final density and mechanical properties of the laser sintered parts.

Selective Laser Sintering (SLS) differs from METAL RPT as follows –

1. Steel powder used for SLS are mixed with a range of plastic material which acts as binding material during the sintering process whereas metal powder is used in pure form in case of Metal RPT process.

2. The sintered components produced by SLS need to be further heated in the furnace to increase the density of the manufactured component, whereas the component produced by Metal RPT is in its dense state after sintering.

3. The power of laser beam used for SLS is half (about 100W) of that used for Metal RPT process.

2.2.2 3D laser cladding:

The 3D laser cladding process is also known as laser generating. Instead of fusing material in a powder bed, the powder is delivered in a gas jet through nozzles. The powder is usually delivered co-axially with the laser beam (perpendicular to the substrate). The powder feeder and the laser beam axis may also form an angle between them (usually from zero degree to forty five degree). Some researches showed that the maximum powder efficiency of the process is achieved when the powder arrives almost perpendicular to the substrate. The metal powder is fused in the focal zone of a high-energy laser beam and parts with complex geometries can be formed. The process occurs in closed chambers with controlled inert atmospheres. Fully dense parts with mechanical properties close (or even superior) to the conventionally processed material are usually achieved. The process is also called laser engineered net shaping (LENS).Three-axis LENS machines cannot produce complex parts with overhangs because there is no powder support during build-up. This restriction was overcome by applying five-axis machines or by depositing separate support material around the part.

This process uses very high power laser beam (500-1000 W) to melt metal powder.

Metal powders are delivered and distributed through the head either by gravity or by pressurized inert gas. Even in cases where it is not required for feeding, an inert gas shroud is typically used to shield the melt pool from atmospheric oxygen for better control of properties and to promote layer to layer adhesion by providing better surface wetting.

III. MANUFACTURING USING METAL RPT

3.1 Manufacturing sample parts

In the early stages of product development, METAL RPT can help by making design and functional prototypes available. As a result, functional testing can be initiated quickly and flexibly. At the same time, these prototypes can be used to gauge potential customer acceptance. Internal communication within and between teams can be facilitated by the availability of product models.

This results in reduced time to market and shortened reaction times to current customer demands. Gradually, the risks involved in developing new products decrease, because problems can be detected sooner and be directly addressed. Development costs are reduced, and at the same time, consumer response is accelerated.

3.2 Production of batch quantity

METAL RPT is independent of economies of scale. Tool-less production with METAL RPT makes it possible to manufacture different products, one next to the other, in one single process.

Since METAL RPT does not require lengthy lead times, one can respond to individual customer demand very quickly and cost-effectively. This makes it a viable manufacturing alternative. Even if the customer's requirements change suddenly, one can react quickly and flexibly.

The METAL RPT process allows for the simultaneous production of many different parts in one single build job. METAL RPT can be used in every phase of the product lifecycle from rapid prototyping via series manufacturing to the production of spare parts.

3.3 Manufacturing of spare parts

With METAL RPT one can also create spare parts, quickly and straightforwardly.

All one needs is 3D CAD data. It can be provided by the customer if, for example, he Scans the broken part for which he needs a replacement. This helps one to keep stocks at a minimum, as one does not need to store finished products or tooling. This reduces the costs of warehousing and administration.

IV. METAL RPT APPLICATIONS

This capability allows for more intricate part shapes. Material options that are currently offered include alloy steel, stainless steel, tool steel, aluminum, bronze, cobalt-chrome, and titanium. In addition to functional prototypes, METAL RPT is often used to produce rapid tooling, medical implants, and aerospace parts for high heat applications.

1. Tooling – Injection moulds, Die-casting dies, Rapid tooling.
2. Automotive
3. Aerospace
4. Architecture
5. Industrial Design & styling
5. Consumer goods – Interior, Lighting, Fashion, Jewellery
6. Robotics

Some of the components which could be made using METAL RPT are shown below…


Figure-4.1 A few decorative parts generated on METAL RPT


Figure-4.2 A few engineering parts generated on METAL RPT

METAL RPT is suited to every industry need viz…

• Complex, high value products

• Need to customize

• Multitude of varieties

• Ever shortening product life cycles

• Hard to anticipate customer demand

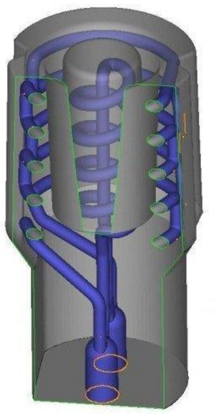
• Short response time

The design of special tools and components in all industrial sectors is often one of the most sophisticated factors in the production process. In this area especially it is necessary to be able to build customized parts quickly and flexibly. Conventional processes for producing these types of parts are, how-ever, often costly, time consuming and technically highly complex. During the laser-sintering process, integrated cooling and tempering channels can be built into the tool. This construction advantage leads to an improvement in the productivity of the tools and also in the quality of the injection-moulded parts. That in turn leads to a reduction in unit costs.

4.1 Conformal cooling channels in moulds:

The most critical and important requirement for die-casting and injection moulds is provision of proper cooling channels. By using METAL RPT for mould making, routing options for cooling channels are almost infinite. This makes it possible to create an ideal cooling channel in a well defined distance to the cavity. A conventional drilled cooling mechanism cannot achieve this due to process limitations.

Changing cross sections of the cooling channel can easily be done without splitting up the form. This allows for additional heat/cooling advantages in areas that cannot be reached by conventional methods. This ultimately helps in increasing the life of the moulds and also helps in improving the surface finish of the components moulded.



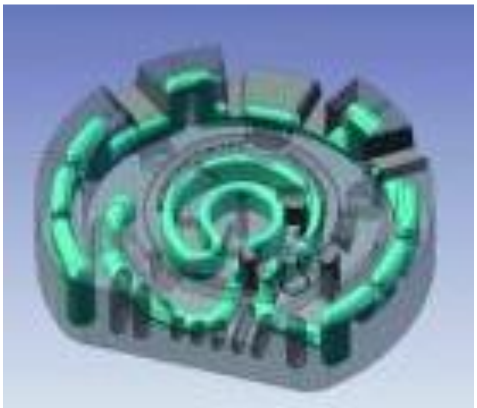


Figure-4.3 An example of moulds with Conformal cooling channels

V. APPLICATION

Stainless Steel- functional prototypes, small batch products, spares Tool Steel- injection moulds & inserts, aerospace parts, die casting dies, direct parts for engineering applications, conformal moulds with cooling channels Super Alloy Cobaltchrome-Molybdenum Steel - biomedical applications like implants e.g. spinal, knee, hip bone, toe etc., engineering applications like turbine blades, engine parts, cutting parts, thin wall parts.

Cobalt Chrome Steel- dental restorations like crowns, bridges etc. could be veneered with ceramic material

VI. ADVANTAGES

Because DMLS parts do not require tooling to make them, not only do you save on the tooling cost, but you can have as many or as few parts at a time as you want, saving on WIP inventory. You can even have small design variations for every single part and the DMLS process will treat them all in the same way. In effect, DMLS enables 'Mass Customization'. For example, each of us is very different, but we could all have individually fitted replacement joints based on a single generic design, but manufactured to suit our own sizes and shapes.

DMLS enables the formation of cavities and undercuts which, with conventional methods, can only be produced with great difficulty, if at all. Additionally, when a part needs to be tested and re-designed over and over, the lead time for receiving a traditionally tooled part can create a large bottleneck in the final production process.

VII. DISADVANTAGES

Whereas the DMLS process can make a vast range of complex forms, it cannot yet make absolutely any geometry. The melting process means that certain geometries need to be supported, causing some challenges to surface finish and requiring some post-finishing. These difficulties can be minimized by the skill of the manufacturer. There is a size limitation of about 220mm x 220mm x 200m high. If the part is particularly solid, then there can be some distortion due to residual stresses. Again, these can be minimized by a skillful operator. Overall however, the process has very many more upsides to downsides, offering enormous benefits for low volume production parts.

VIII. CONCLUSION

Layer manufacturing techniques are moving from rapid prototyping and rapid tooling to rapid manufacturing. The production of end use parts made of metals is one of the most promising applications for these techniques. Rapid manufacturing of metal parts are specially suitable for the fabrication of small number of pieces & mass customization.

Direct fabrication of metal products of high density & excellent mechanical properties is possible by using laser-based layer manufacturing techniques. The aeronautic, automotive & medical industries are the main markets.

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