MATERIALS & FINISHING METODS OF DMLS MANUFACTURED PARTS

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Abstract

This contribution deals about materials and finishing methods of DMLS manufactured parts. Direct Metal Laser Sintering (DMLS) is a revolutionary technology that produces metal components that are 99.99% dense, directly from 3D CAD data. With opportunity of choosing the suitable material from wide range of produces powders and with many methods of finishing the surface determines the DMLS as technology for future of prototype manufacturing.

Key words: direct metal laser sintering, DMLS, DMLS materials, surface finishing

INTRODUCTION

Manufacturing of functional prototypes and high performance artifacts using conventional methods such as machining is usually a time consuming procedure in multiple step route. The pressure to get products on market faster has created several Rapid Prototyping methods. However, potentially one of the most important areas of Rapid Manufacturing technology lies in the field of Rapid Tooling.

1. DMLS TECHNOLOGY

The DMLS technology was developed, like other RP technologies, to provide a prototyping technique to decrease the time and cost of the product cycle design. It consists of building a three dimensional object layer by partial melting a powder bed by laser radiation.

Fig. 1 depicts the schematic picture of the instrument used for laser sintering. The machine consists of a powder handling system, a continuous wave carbon dioxide laser with related optics and a process computer. In this process, the 3D CAD models of functional parts and tooling inserts are converted to triangulated surface models in the standard STL format. The process computer slices the standard STL format to thick horizontal layers, representing the part into a stack of thin slices. The data preparation step is followed by the laser sintering process. First, a steel base plate is placed on the building platform (XY table) and leveled. Then, a powder layer is spread on the base plate using a moving wiper (mechanical re-coater). The computer scans the laser beam on the powder surface. The laser energy causes the powder particles to bond together. After laser scanning, the building platform is lowered and a new powder layer is spread on top of the previous layers. The process is repeated, and by altering the shape of each scan layer, a part of arbitrary shape can be produced.

2. MATERIALS FOR DMLS

This section summarizes the currently available powder materials for DMLS. A wide variety of materials can be used, ranging from light alloys via steels to super-alloys and composites.

Aluminium AlSi10Mg

Aluminium AlSi10Mg is a typical casting alloy with good casting properties and is typically used for cast parts with thin walls and complex geometry. It offers good strength, hardness and dynamic properties and is therefore also used for parts that are subject to high loads. Parts in Aluminium AlSi10Mg are ideal for applications which require a combination of good thermal properties and low weight. They can be machined, spark-eroded, welded, micro shot-peened, polished and coated if required.

Cobalt Chrome Alloy (CC MP1)

CC MP1 is a fine powder mixture which produces parts in a cobalt-chrome-molybdenum based super-alloy. This class of super-alloy is characterized by having excellent mechanical properties (strength, hardness etc.), corrosion and temperature resistance. Such alloys are commonly used in biomedical applications such as dental and medical implants and also for high-temperature engineering applications such as in aero engines.

In718 (718 Alloy)

718 Alloy is a nickel based heat resistant alloy in fine powder form. Its composition corresponds to UNS N07718, AMS 5662, AMS 5664, W.Nr 2.4668, DIN NiCr19Fe19NbMo3. This kind of precipitation-hardening nickel-chromium alloy is characterized by having good tensile, fatigue, creep and rupture strength at temperatures up to 700^{o}C. In718 Alloy also has outstanding corrosion resistance in various corrosive

environments. This material is ideal for many high temperature applications such as gas turbine parts, instrumentation parts, power and process industry parts etc.

Maraging Steel 1.2709 (MS1)

MS1 is a pre-alloyed ultra-high strength steel in fine powder form. Its composition corresponds to US classification 18% Ni Maraging 300, European 1.2709 and German X3NiCoMoTi 18-9-5. This kind of steel is characterised by having very good mechanical properties, and being easily heat-treatable using a simple thermal age-hardening process to obtain excellent hardness and strength. Ideal for many tooling applications such as tools for injection moulding, die casting of light metal alloys, punching, extrusion, it is also good for high performance industrial and engineering parts, for example aerospace and motor racing applications.

Stainless Steel 15-5PH (SS PH1)

Stainless Steel PH1 is a pre-alloyed stainless steel in fine powder form. Its composition corresponds to US classification 15-5PH and European 1.4540 and fulfils the requirements of AMS 5659 for Mn, Mo, Ni, Si, C, Cr and Cu. This kind of steel is characterized by having very good corrosion resistance and mechanical properties, especially in the precipitation hardened state. This type of steel is widely used in metal prototypes and a variety of medical, aerospace and other engineering applications requiring high hardness, strength and corrosion resistance.

316L Stainless Steel

3T 316L Stainless Steel is a pre-alloyed austenitic stainless steel in fine powder form. This powder meets the chemical requirements of AISI 316L, DIN 17006 X2CrNiMo17-12-2, W.Nr1.4404. This kind of steel is characterized by having height corrosion resistance and can be used over a wide temperature range down to cryogenic temperatures. This type of steel is widely used in a variety of food processing, medical, aerospace and other engineering applications requiring high strength and corrosion resistance.

Fig.2 (a) and Fig.2(b), shows micrographs at magnifications 200X and 1000X obtained with an optical microscope of 316L Stasinles Steel. It is evident that the metal powder is completely fused and constituted by molten/re-solidified zones with curved edges (approximately parabolic). The laser tracks overlap in order to produce a non-porous part. This means that each part is welded onto the layers surrounding it. The presence of pores is very limited as it is possible to see from black spots in the pictures.

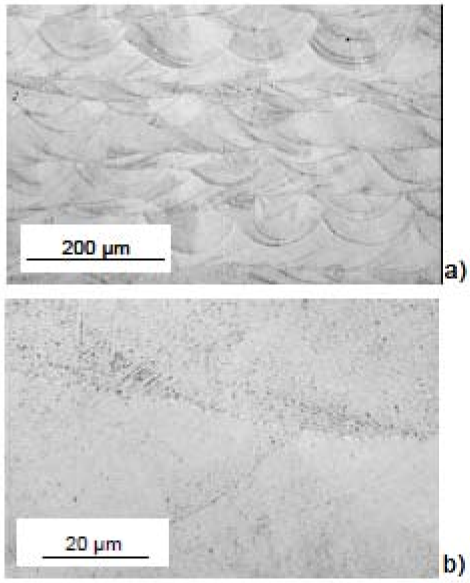


Fig. 2. 316L Stainless Steel obtained with P=100W and v=180mm/s magnification: a.) 200x, b.) 1000x

Titanium Ti64 Alloy

Titanium Ti64 is a pre-alloyed Ti6AlV4 alloy in fine powder form. This well-known light alloy is characterized by having excellent mechanical properties and corrosion resistance combined with low specific weight and biocompatibility. This material is ideal for many high-performance engineering applications, for example in aerospace and motor racing, and also for the production of biomedical implants. Unexposed powder can be re-used.

3. FINISHING OF DMLS MANUFACTURED PARTS

Parts “as built” of DMLS machines have a raw finish comparable to a fine investment cast, with a surface roughness of approximately Ra 8.75 µm, or a medium turned surface. This surface roughness can be improved all the way up to Ra 0.025 µm, qualifying as a super mirror finish. There are several processes available that can be used to achieve the desired surface roughness or finish.

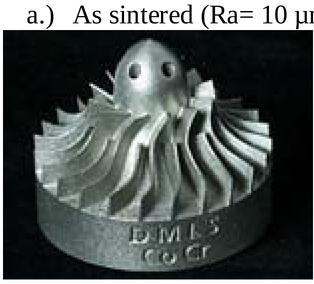
Abrasive Blast (Grit & Ceramic)

Abrasive blasting is the operation of forcibly propelling a stream of abrasive material (media) against a surface under high pressure to smooth a rough surface. Abrasive blasting services are included standard for all DMLS projects. If a “raw” DMLS part is desired, this should be noted at the time of the RFQ when addressing the desired surface roughness. Abrasive blasting with grit and ceramic media provides a satin, matte finish. This finish is largely uniform, but does not provide a 100% uniform finish.

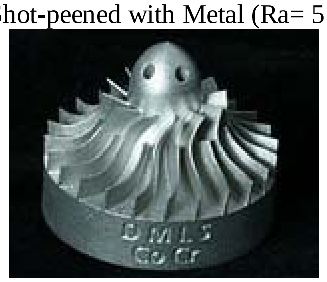
Shot Peen

Shot peening is a cold working process used to produce a compressive residual stress layer and modify mechanical properties of metals. It entails impacting a surface with shot (round metallic or ceramic particles) with force sufficient to create small indentations or dimples. It is similar to sandblasting, except that it operates by the mechanism of plasticity rather than abrasion. Peening a surface spreads it plastically, causing changes in the mechanical properties of the surface. Depending on the part geometry, part material, shot material, shot quality, shot intensity, and shot coverage, shot peening can increase fatigue life from 0–1000%. In practice, this means that less material is removed by the process, and less dust created. Fig. 3 shows the parts after sintering (3a.) and after shot peening with metal (3b.) and with metal &ceramics (3c.) with corresponding roughness. Shot peening may be used for cosmetic effect. The surface roughness resulting from the overlapping dimples causes light to scatter upon reflection. Because peening typically produces larger surface features than sand-blasting, the resulting effect is more pronounced. Detail of shot peened finished surface is shown on Fig. 4.

a.) As sintered (Ra= 10 µm)



b.) Shot-peened with Metal (Ra= 5 µm)



c.) Shot-peened with Metal & Ceramics (Ra= 4 µm)

Fig. 3 Comparison the roughness of surfaces at sintered and shot-peened part

Fig. 4 Detail of shot peened finished surface, Stainless Steel PH1

Polishing

Polishing is a metal-finishing operation where articles are polished using abrasives or mops, in a multistage process. Firstly, coarse grit abrasives are applied at high speed to remove surface defects like pits, nicks, lines and scratches. Then fine grit abrasives are used to remove the residue and smooth the surface. Finally, cotton mops are used to give a mirror-like finish to the articles. Sophisticated computer-controlled machines can be used to polish intricately shaped articles, although much of this work can also be carried out by hand. This can enhance the aesthetic appearance of parts as well as preventing corrosion, particularly those being used in automotive and aerospace environments. Medical instruments can also be highly polished to maintain hygienic conditions and prevent contamination in marks in the metals.

Electrochemical Polishing

Electrochemical polishing also referred to as electro polishing, is an electrochemical process that removes material from metal parts through polishing, passivation, and deburring. It is often described as the reverse of electroplating; differing from anodizing in that the purpose of anodizing is to grow a thick, protective oxide layer on the surface of a material rather than polish. The process may be used in lieu of abrasive fine polishing in micro structural preparation, and is an inexpensive option for DMLS projects that are not tolerance dependent, creating a bright uniform finish. The extent to which electro polishing is successful depends upon the degree of preparation of the treated surfaces.

Optical Polish (Hand Finishing)

When projects have geometries in low quantities that are not tolerance dependent, the best finishing option is an optical polish. Optical polishes are extremely cost effective, and the best way to achieve a brilliant finish. Due to surface porosity of DMLS metals, 0, 0075 to 0,025 mm of surface material is removed depending upon geometry. If this option is desired, it is imperative that designers or engineers consult with GPI prior to building, as specific surfaces may need to be offset with additional material to ensure part integrity after post-processing. Optical polishing is not ideal for large batches as it lends itself to an inconsistent finish from part to part. The surface of the same part after polishing to various quality is shown on Fig. 5a, 5b, 5c.

a) Cobalt Chrome MP1, media tumbled

b) Cobalt Chrome MP1, optical polish

c) Cobalt Chrome MP1, optical polish with mirror finish

Fig. 5 Comparison of surfaces- tumbled and polished

CNC Finishing/Machining

CNC finishing permits high quality contoured milling applications to achieve tight tolerances. Detail-oriented precision can be accomplished with 3-axis, 5-axis and 6-axis CNC lathes. Conventional fixed headstock and Swiss-style CNC lathes can be utilized to support complex operations such as cross drilling and cross tapping, cross milling and slotting, C-axis milling and off-center work. Proper fixturing can yield tolerances as tight as 1 micron. Should this post processing option be desired, pre-build planning is required to add sufficient material to machined features and surfaces so that tolerances can be met.

Difference between raw material from Stainless Steel PH1 and finished part to optical finish with various methods of surface finishing is shown on Fig.6.

Fig. 6 Difference between raw material and finished part

Abrasive Flow Machining (Extrude Hone) Polishing

Abrasive flow machining (AFM), also known as extrude honing is a method of smoothing and polishing internal surfaces and producing controlled radii. A one-way or two-way flow of an abrasive media is extruded through a workpiece, smoothing and finishing rough surfaces. One-way systems flow the media through the workpiece, then it exits from the part. In two-way flow, two vertically opposed cylinders flow the abrasive media back and forth. The process is particularly useful for difficult to reach internal passages, bends, cavities, and edges. This is an inexpensive option for DMLS projects that are not tolerance dependent, and a more uniform surface roughness. The extent to which AFM is successful depends upon the degree of preparation of the treated surfaces.

Electroplating

Electroplating is a process that uses electrical current to reduce ions of a desired material from a solution and coat a conductive object with a thin layer of the metal material. Electroplating is primarily used for depositing a layer of metal to bestow a desired property (e.g., abrasion and wear resistance, corrosion protection, lubricity, aesthetic qualities, etc.). Another application uses electroplating to build up thickness on undersized parts. Plating is also an inexpensive method of improving surface roughness, with the reduction in roughness once again hinging upon the degree to which surface are treated prior to plating. DMLS parts can also be plated in their raw state, and then finished in combination with another method.

Micro Machining Process (MMP)

Micro Machining Process (MMP) is a mechanical-physical-chemical surface treatment applied to items placed inside a treatment tank, providing highly accurate selective surface finishes. The desired surface finish is obtained by using MMP only on those areas where that particular finish is required. MMP begins with a detailed analysis of the surface state of the item to be treated, establishing the processing parameters required to meet the customer's objectives. MMP can finely distinguish and selectively apply different primary roughness, secondary roughness and waviness profiles to surfaces. This process has selective application, and is ideal for projects requiring precision tolerance finishing to a large number of parts, as well as parts with internal passages that cannot be reached by an alternate method.

CONCLUSION

Manufacturing of functional prototypes and high performance artifacts using conventional methods such as machining is usually a time consuming procedure in multiple step route. The pressure to get products on market faster has created several Rapid Prototyping methods. Utilizing the DMLS process, metal parts of the most complex geometries are built layer-by-layer (down to 20 microns) directly from 3D CAD data, automatically, without tooling. The parts have excellent mechanical properties, high detail resolution and exceptional surface quality.

Wide range of different materials covers an extensive range of applications of DMLS technologies that can produce a wide range of products for various applications. Selecting a suitable surface finishing technique can achieve the desired roughness and quality.

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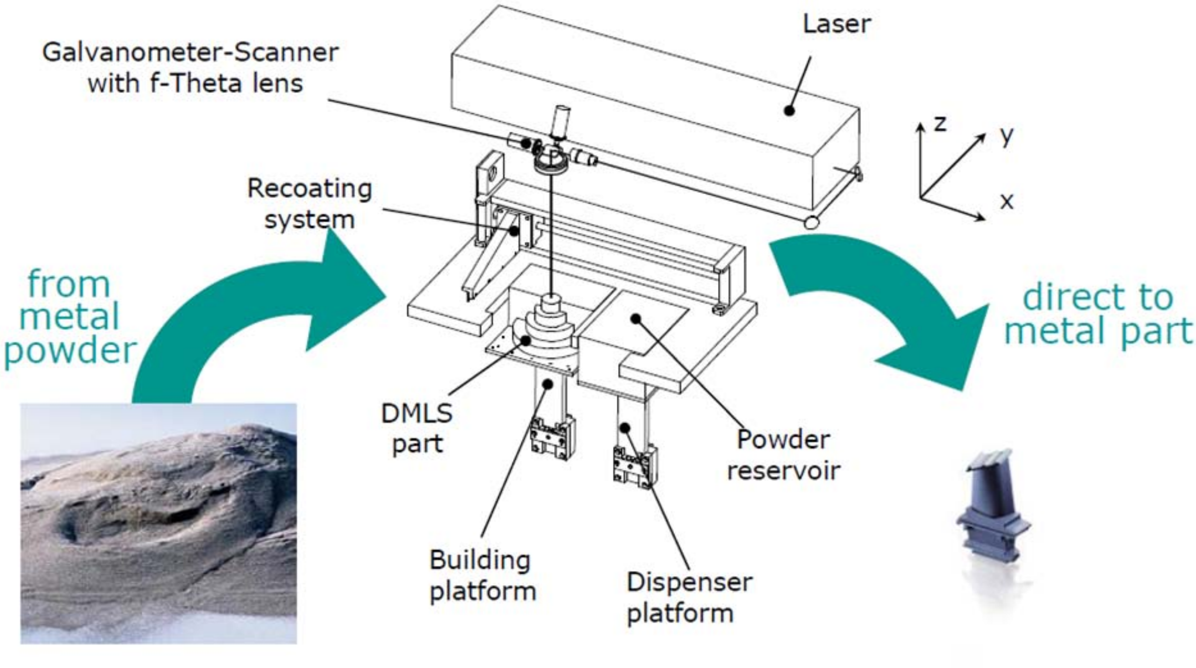

Fig.1 Schematic picture of the instrument used for laser sintering