Direct Metal Laser Sintering Process in Engineering and Medical Applications – A Review

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Abstract:

Direct Metal Laser Sintering (DMLS) has attracted the attention of the researchers since last ten years only but has facilitated a lot of research works which include the material characterization, industrial application, and tooling in bio medicals. Many researchers worked with DMLS to characterize the new compositions of materials, to test their properties to suit different applications. The samples fabricated with the technology were used in different applications in industries and in medical fields. The process was experimented mostly in Rapid tooling and different process variables were studied. DMLS is being used to fabricate custom implants for the needy patients and to plan the surgery. The paper gives a overview of the major works produced in different areas of engineering and medical fields and identifies the future research and development.

Keywords: Direct Metal Laser Sintering, Metal powder, Rapid tooling, Additive Manufacturing

1.Introduction:

Direct Metal Laser Sintering (DMLS), sometimes called as Direct Laser Metal Sintering (DLMS) is one of the advanced rapid manufacturing system in which the metal powders are sintered using laser power, layer by layer, to fabricate a required component, how complex may be the shape. Nickel alloys , Aluminium alloys, Co-Cr alloys, Stainless Steel and Titanium alloys are some of the materials developed for laser sintering processes in engineering discipline.[1].

2.Characterization of Materials:

Direct Metal Laser Sintering Uses metal powders for preparing any product. Considering the above, many metal powders have been taken for characterization and simulated for different applications. Tungsten carbide –cobalt powders mixture has been simulated and characterized by its mechanical properties. The results obtained by the doing characterization proved better results for machining hard materials [2].By controlling the process parameters like pulsing frequency, scan speed, scan spacing for different materials density is increased [3].The properties like surface roughness, topography of the sintered surfaces are investigated by microstructure and it was observed that the surface waviness of wave length 300 µm was observed on the polished side of the sintered component [4]. By using DMLS technology Addition of Phosphorus in copper based alloys resulted in decrease of surface tension ,melt viscosity and increase in density by comparing Cu:CuSn:CuP samples weight ratio [5]

The density, microstructure, micro hardness, abrasive behaviour of Ni coated silicon carbides have been studied. There is a decrease in the volume wear rate of iron –sic composites with increase in the sic content and iron-sic composites exhibited excellent wear abrasive

resistance which are fabricated by Direct metal laser sintering technique. The increase in the silicon carbide content in iron the hardness and wear resistance has improved [7,8].
The study of microstructures, phases, compositions and mechanical properties were done on Copper alloy powder reinforced with Nickel particles and a good theoretical density was attained after sintering[9].When the study of wear performance and crack density of Silicon Carbide particulate reinforced Al based metal matrix composites were done it found that MMC specimens were susceptible for cracks due to thermal and contraction stresses. The crack density has increased above 15% of SiC and above 20% there was no enhancement of wear resistance but abrasive wear took place because of SiC particulates [10]. In Inconel718 by doing shot peening on homogenized surface residual stresses and by by aging thermal treatment lead the material to be hardened but relieved the tensile stresses developed in DMLS process[11].
The fabrication of iron nickel chromium alloy specimens by laser sintering process was when subjected to high-frequency ultrasonic peening to test their wear behaviour and micro structural characterization using SEM,AFM and Nano Scratch Testing. By comparing the results of the both the specimens there is increase in the scratch resistance and decrease in the wear rate, coefficient of friction [12].

The manufacturing of heat skins by using DMLS in electronics area given better heat transfer and good performance enhancement. The design of various lattice structures and unit cell sizes at different volume fractions were done by fabrication of AlSiMg by using DMLS.The results of low alloy high strength steel samples which are made by DMLS have same strength as of wrought materials. The finishing of AlSiMg substrate plates which are prepared by DMLS were finished easily at minimum cost and minimum time by using AFB technique. Strength and low cycle fatigue (LCF) life of Inconel 718 superalloy samples fabricated by DMLS at room temperature was investigated. The fabrication of Co-Cr-Mo samples of mechanical parts can be easily by using DMLS and can be used effectively in medical domain.[13-19]

A correlation was established well while testing of Inconel samples prepared by direct metal laser sintering and traditionally prepared Inconel while characterizing the high cycle fatigue [20].The INCONEL 718 sample prepared by using DMLS is investigated and the results of the x-ray computed tomography shows the maximum amount of the porosity developed in the last layers of the fabricated material. The results of the electron backscattered diffraction measurements gives the formation of columnar grains, it also observed that an evidence of cross grain microstructure were found in the samples undergone Hot Isostatic pressing. [21].

The results of the samples of stainless steel manufactured by sintering process suggest possible innovations in automotive, aerospace and bio medical implantation [22].
The performance of the metal parts manufactured by DMLS technology were tested and it was observed that the parts that are prepared with different materials has same tensile properties and fatigue strength decreases over a long period when compared with single sintered specimens [23].

3.Process parameters:

The mechanical and other properties of the components produced with DMLS vary with change in process parameters of fabrication. The required properties can be obtained by optimizing the process parameters.
The result of granule size of the powder on comapaction and microstructure in direct laser sintering process has been studied [24]. Four impartment resulting properties are: the

geometric accuracy, mechanical properties, and surface quality, process time. By doing proper selection of set of parameters the properties can be controlled [25].

An experimental study was made for validating the accuracy of the components based on the geometrical shape and percentage shrinkages .An algorithm was proposed for finding out the optimal hatch direction by considering the hatch length as function[26][27].

By changing the parameters like scan speed, laser power layer thickness the ball phenomena can be alleviated, fatigue strength can be influenced and better bonding between layers can be prepared by microstructure analysis [28, 29]

The Multi element paradigm is applied for numerous sorts of elements or dies which require fast evolution of pure mathematics and useful properties [35]. A comparision was made between DMLS and pressure die casting and it was observed that DMLS can be used for small batch productions[30]. The results established that the build direction has shown vital impact on half quality, dimensional error surface roughness, bending strength and elongation. a rise in layer thickness weakens the elements in terms of enduringness and elongation however has no impact on bending on the elements created by DMLS. Pressure tests, flow mental image tests, micro- hardness ,dimensional accuracy, surface roughness and porosity tests were conducted and unconcealed that the method gives the potential to boost the enhancement of advanced parts not solely by reducing the element weight however by rising practicality with a lot of economical fluid flow [31, 32].

Parts with varied complexities were analyzed to elucidate the relevance of planned approach. The results depicted that incontestable the quality of the TiN strengthened SS316 MMCs for industrial view point. The support stepping impact on the quality of surface for gratis kind surfaces with the method variables like direction of build, thickness of layer and variables has been studied which can considerably change the obtained quality of surface as a results of this impact validations on an illustration half representative of a bunch of aero-engine elements [33,34,35].

4.Comparison:

It has been complete that direct fabrication of metal merchandise of high density and glorious mechanical properties is feasible by victimization laser-based layer producing techniques. The experimental results disclosed that peak current is that the most potent issue on method performances [36, 37, 38].

5.Medical:

For saving the lives of the human beings bio-medical components are produced by DMLS. Example was DEKA research development produced a complete humeral mount for fully integrated prosthetic arm [39].An implant of skull of a patient has been designed and manufactured whose jaw was broken. Porous internal structures and support structures were designed to make the implant less weight but strong enough to withstand as implant and was successfully implanted to the patient with required accuracy [40].

With the help of Additive manufacturing technologies it has become easy and viable for reproducing the prosthetically guided bone of atrophic maxillary arches in minimal intervention reconstructive surgery. [41]. Laser sintered Co-Cr implant fixed 3-unit structures have achieved best fit results than the vacuum cast Co-Cr, Ni-Cr-Ti and Pd-Au when they were evaluated for vertical discrepancy [42] The early bone response to DLMS implant surface retrieved from human jaws has been evaluated with experimental DLMS implants. throughout typical dentistry, the implants were inserted within the posterior mandibular bone of 4 patients. once eight weeks the implants and therefore the encompassing tissues were removed and analyzed with SEM and histomorphometry. The results advised that the DMLS

surfaces given an in depth contact with human bone [43] .In the jaw bone development surgery, cad software has been used to prototype the pattern followed by printing using DMLS [44] .

Fig. 1: DMLS Machine

The cutting guide (Cobalt-Chromium-Molybdenum super alloy) and bone plate (Ti-6Al-4V) were manufactured directly with DMLS. By the usage of the cutting guide in the surgery the demolition became simple and the case original mandibular profile was restored. [45] There is a enhancement in the compressive strength of the biomedical specimens by post sintering technique [46]. No significant difference between measurements for premolars and molars was found [47]. The Metal crowns and stuck partial dentures can be repaired by employing the Direct Metal optical device Sintering process by analyzing the damage. [48].

DMLS fabricated Root Analogue Implants (RAI) were placed into the extraction sockets of 15 patients. After one year the clinical and radiographic parameters were analyzed. The criterion for analysis was absence of pain, suppuration and exudation. All the implants were stable and there was no sign of infection. The good condition of peri-implant tissues were confirmed by radiographic tests [49].By using direct metal laser sintering the pins that are used in the surgery are fabricated (Fig. 3) [50].

6.Rapid Tooling:

Attempts were made to improve the surface finish of Electroless Nickel (EN) plating and semi-bright nickel electroplating without losing the dimensional accuracy using DMLS technique [51]. It was found that rapid tooling is suitable for the parts produced by beam compensation technique and accuracy of the parts was also improved [52]. The application of speedy Tooling technology to die plated for moulding in DISAmatic forged line has been investigated. It was evident that the DMLS die inserts shown anti cracking and wear resistance behavior in the production of 3750 sand moulds [53]. In DMLS technique the ejection forces on tools have been investigated and results states that choice of the layer thickness influences the forces for ejection but the amount of draft enclosed doesn't show a noticeable trend towards increasing or decreasing the force [54].The wearing of the sintered tool inserts made by DMLS is low, which indicate the improvement of the abrasive characteristics [55]. Computer aided rapid tooling process selection is developed, mapping of the process variables is done with the required application. The same way it can also be linked to mold design software for data exchange. This has been an important step towards mold lifecycle engineering [56].

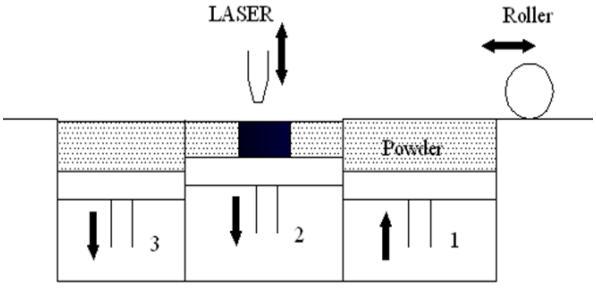

Fig. 2: Working Principle of Direct Metal Laser Sintering

The dimensional accuracy of copper based DS20 and steel based DM20 was verified. The parts were subjected to shot peening operation and better results were found in comparison with high speed milling a substrate manufacturing process [57]. Moulds with conformal cooling channels and thermally semiconducting moulds with a volumetrical conductor to embody uniform and speedy cooling of the mould by speedy tooling was developed and tested. [58].Fabrication of tools made faster by Rapid Tooling [59].

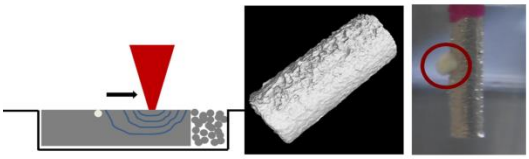

Fig. 3: DMLS Produced surgical pins

7. Conclusions:

The conclusions drawn from the study of the works produced with Direct Metal Laser Sintering in various fields like material characterization, mechanical, medical implants and dental fields are as follows.

- This process is capable of fabricating the good mechanical, geometrical components for better enhancement of system performance.
- Comparing the technology of the rapid tooling with the conventional techniques the cost is more effective for small batch production.
- DMLS shows its importance in medical field like planning surgery and for customized implant manufacturing to save the lives of the patients.
- DMLS finds its place in dentistry and maxillofacial surgeries for better results.
- Combination of both rapid tooling and conventional tooling the lead time can be reduced and cost effectiveness gain can be done.
- The results of Characterization of different materials for their metallographic and mechanical properties were found to be satisfactory with DMLS.
- The latest innovations in metal 3D printing, especially in the area of DMLS, have replaced the concepts of ‘Design for Manufacturing’ with ‘Manufacturing for Design’, as almost there are no barriers for manufacturing any component today.

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