International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

3D Printing Technology in Automobile Industry: A Review on Applications, Processes, Challenges and Opportunities

Ankit Jhinkwan

Department of Mechanical Engineering, (Assistant Professor) Chandigarh University, Mohali, Punjab, India
Email: *ankit.e3147[at]cumail.in*

Abstract: ***3D printing technology has gained tremendous interest in the automotive sector due to its ability to transform manufacturing processes and product development. The usage of 3D printing machines in the automotive sector, with a focus on prototyping, customization, tooling, and the manufacture of end - use parts. This paper shows how 3D printing machines have been integrated into the automotive sector, resulting in cost reductions, shorter development cycles, and novel design solutions. It concludes by examining future trends and potential problems in the implementation of 3D printing technology in the automotive sector, emphasizing the importance of ongoing research and development to realize its full potential.***

Keywords: 3D Printing, Additive Manufacturing, Automobile

1. Introduction

Additive Manufacturing also known as 3D printing is an automated method that produces scaled, three - dimensional objects straight from 3D CAD data (computer - aided design). The method relies on the layer manufacturing principle and does not need any instruments that depend on specific parts, like a milling or drilling machine. Volume elements are assembled and connected to create the components. This method was once known as rapid prototyping, and it is still used frequently today. Additive manufacturing technologies, when combined with formative production processes like casting or forging and subtractive production processes like milling or turning, constitute the third column of total production technology [1]. Additive manufacturing or 3D printing in an industrial scale has been presented as a new paradigm for manufacturing. This trend may change production systems dynamics, the organizations design, and the business models. The first form of creating layer by layer a three - dimensional object using computer - aided design (CAD) was rapid prototyping, developed in the 1980's for creating models and prototype parts. This technology was created to help the realization of what engineers have in mind. Rapid prototyping is one of the earlier additive manufacturing (AM) processes [2]. The automotive industry is rapidly evolving and changing, just like every other industry on the planet. As a result, it is not a new industry to automation.3D printing is changing this industry in a way that manufacturers are manufacturing commercial and passenger vehicles, making them more reasonable and accessible than at any other time in history. But how will the automotive industry benefit more from 3D printing technology? The answer lies in the metal additive manufacturing, or 3d metal printing technique. Since most of the parts in automobiles are manufactured by metal, it becomes extremely difficult [3]. The use of computer programmed to improve the process of creating or manufacturing goods has become widespread in today's modern society. A variety of companies have implemented 3D printing software as an example of a computer application to enhance their manufacturing and production procedures. The goal of this project is to use 3D printing software to improve the manufacturing process in the automotive industry. The research that follows will go over the problem statement's description, the research's introduction and background, and a review of publications that highlight the importance of 3D technology in the automobile sector [4]. Research must be done to identify and remove barriers that prevent the adoption of 3D printing technology, which will lead to new benefits gradually becoming apparent. Create instruments to evaluate lifetime expenses i. e., some of the crucial elements that must be achieved include AM - oriented computer - aided design (CAD) systems with more intuitive and sophisticated simulation capabilities. Mass customization—that is, producing a range of customized items so that each one can be unique while keeping a low price because of mass production—is a standout benefit of 3D printing. The extra expenses associated with tooling and mould creation for bespoke products are eliminated with 3D printing. As a result, mass producing several similar parts can be just as economical [5]. This paper gives the insight of advancement 3D Printing in Automobile sector, where due to development in electric vehicles this technology has been used. The goal of this paper is to present a thorough analysis of 3D printing techniques, covering the primary techniques used, the materials used, the state of the technology today, and applications across a range of industries. The study will also outline the gaps in the literature and the difficulties in implementing this technology.

2. Different processes used and implementation

It is relatively easy to depict this system when one solely considers the AM process. The general AM process consists of the following essential steps: ideation and CAD translation to STL, STL file transmission and manipulation on AM machine, machine setup, construction, part removal and cleanup, post - processing, and application [6]. An example of the AM generic procedure may be seen here. Additional phases in the process, such as finishing techniques, nonconventional approaches, and/or conventional methods, may be taken into consideration once the AM process produces the final product. As a result, two primary implementation options are taken into consideration to include AM into production systems: AM processes inside manufacturing systems and AM processes outside of manufacturing systems.

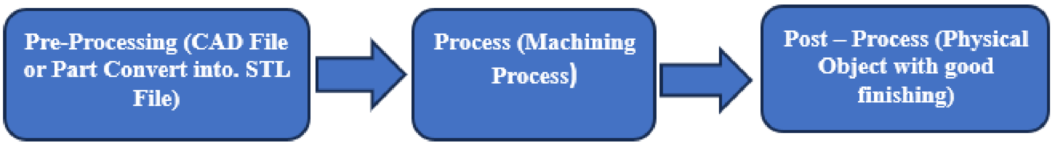

Figure: Shows 3D Printing General process

2.1 Laser Stereolithography

Polymerization is the process of selectively polymerizing a liquid resin (vinyl ether, epoxy, or acrylate) using ultraviolet light. There are several procedures that merely differ in how UV radiation is produced and how contouring is done. Only a partial solidification is the outcome of some polymerization processes. As a result, a green portion is created, which needs further care to become fully treated. After the building process, the extra treatment is applied in a unique space known as a post - curing oven [7]. The UV lamps in this chamber allow the part to cure completely and uniformly. The polymerization procedures need supports to be carried out throughout part generation. These are required to prevent deformations like twisting and warping, to stabilize and fix the part, including overhangs, and to hold separately attached elements in place. Autonomous software is used to add the supports to the 3D CAD model; once the item is finished, the supports must be manually removed. Certain kinds of supports (and materials) can be automatically cleaned with specialized cleaning equipment. A laser scanner unit is placed on top of a build space (build volume) that is filled with liquid resin (build material) to create a contour in the x - y direction (build area) [8]. This is the basic construction of a laser stereolithography machine. The moveable build platform, which can be lowered in the build direction (z - direction), is in the build space. It is a platform - built element. In addition to providing for the curing of each layer and its link to the preceding one, the laser beam simultaneously creates the contour. A laser scanner guides the laser beam's movement in accordance with the contour data of each layer. The instant the laser beam touches the resin's surface, polymerization causes an instantaneous solidification. The laser power and tracking speed of the laser beam can be used to modify the layer thickness based on the resin's reactivity and transparency. The building platform, including the partially created portion, will be lowered by the thickness of the layer once it has solidified [9]. The subsequent resin layer is then applied. We refer to this process as recoating. Owing to the resin's viscosity, recoating requires a leveling device, such as 3D Systems' Viper (if vacuum assistance is required). After that, the new layer will be cemented in accordance with its shape. Until the portion is finished, the process is repeated from bottom to top. Because the supports leave markings on the part's surface when they are removed, the build process necessitates them, which restricts the possible orientations for the part inside the building chamber. As a result, the orientation needs to be carefully considered. The components cannot be stacked on top of one another because of the supports, which lowers the build space's packing density and, consequently, productivity. The completed part is cleaned and then exposed to a UV chamber for thorough curing. This stage of the procedure, known as post - processing, is essential to the AM process. If necessary, the fully cured components can be polished, shot blasted, or varnished. Finishing is a measure that is distinct from the AM process and refers to these process steps. Type and scope are solely determined by the user's needs in terms of Epoxy and acrylic resins, both filled and unfilled, are available materials. Materials that are not filled have comparatively low strength and resistance to temperature - related deformations [10]. Microspheres or geometric grains made of glass, carbon, or aluminum in the shape of rice grains can be added to improve this poor performance. These days, this filler material often includes carbon or ceramic nanoparticles.

2.2 Material Jetting

Polymer printing, also known as polymer jetting, is the method of applying monomer material using print heads. To date, Stratasys has been the company that has commercialized the method. Although it may be regarded as a 3D printing process, the pieces that are produced by UV - solidifying liquid monomers indicate that it is a stereolithography or polymerization process. The devices' layout is like that of a 2D office printer. With a multiple - nozzle piezo - electric print head, the build material is transferred directly to the build platform. Two powerful UV lamps that move in tandem with the print head create a twin light curtain that works simultaneously to solidify the material. The build platform is moved in the z - direction to create more layers [11]. A layer at a time, the process is repeated. Support must be provided for the parts during printing. At the same time, a second set of nozzles prints the supports, creating them automatically. As a result, each layer has both build and supporting content. As a result, a considerable amount of material is used to create the stiff supports. Without leaving any markings on the part, the supporting material can be removed using a largely automated finishing procedure. The procedure involves the manufacturing of plastic parts using photo - sensitive monomers [12]. This makes materials with a range of hues and shore hardnesses possible.

2.3 Binder Jetting Technique

An AM technique called binder jetting involves spreading powdered material into a layer and using a binder usually a polymeric liquid to selectively connect the material into the desired layer form. An assembly of powder and binder arranged in the three - dimensional shape of the intended part geometry is produced as the print layers fuse together during the construction process. The printed part (s) may then be extracted from the layer of powder via a procedure known as "depowering, " after which the box might be heated to cure or "set" the binder if necessary [13]. The printed pieces are now deemed "green" or unfit for final usage, and they undergo a post - process like sintered or infiltrating to acquire the necessary mechanical qualities. Numerous investigations on fusion - based AM (melting and solidification, for example) on structural materials have been conducted throughout the years. Conversely, little study has been done on the application of binder jetting to the shape of comparable materials in the fields of ceramics, polymers, biomaterials, functional materials, and microfabrication. Since metal powder technology, sintering, and prototyping are the roots of binder jetting of metallic components, microstructure and density investigations have been the primary focus of published research rather than characterization of attributes like mechanical, thermal, and magnetic behavior [14]. Furthermore, binder jetting is evolving more quickly than other AM techniques. Therefore, it is essential to periodically evaluate our comprehension of the technique.

2.4 Powder Binding Process

Powder bed combination processes comprise dainty layers of exceptionally fine Powders, which are spread and firmly stuffed on a stage. The Powders in each layer are melded with a laser shaft or a fastener. The resulting layers of powder are moved on top of the past layers and Combined until the last 3D part is fabricated [15]. The powder is then taken out in a vacuum and, if essential, further handling What's more, specifying, for example, covering it is conveyed to sinter or invasion Out. Powder size, circulation and pressing, which decide the thickness of the printed part is the most significant element to the adequacy of This strategy. The laser must be utilized for powders with a low melting Sintering temperature, though a fluid fastener ought to in any case Be utilized [16]. Specific laser sintering (SLS) can be utilized for an assortment of Polymers, metals, and amalgam powders while specific laser liquefying (SLM). It must be utilized for specific metals like steel and aluminum. Laser Examining in SLS does not completely soften the powder and the raised neighborhood. Temperature on the outer layer of the grains brings about the combination of the powders [17]. At the subatomic level. Then again, the powder is completely liquefied. What is more, it melded after laser filtering in SLM, which brings about prevalent Mechanical properties. An itemized survey of various materials and applications utilizing SLM can be found. Because of utilizing a fluid folio, the strategy is alluded to as three - layered printing or 3DP. The science and rheology of the Fastener, size and state of powder particles, affidavit speed, collaboration between the powder and cover, and post - handling methods [18]. Assume a significant part in 3DP. The porosity of parts Printed by a fastener statement is, for the most part, higher contrasted with laser Sintering or dissolving, which can print thick parts. Laser power and the speed of examining is the primary boundaries influencing the sintering process. Further subtleties on various kinds of lasers and their consequences for 3D printing can be found. Fine goal and high Nature of printing are the fundamental benefits of powder bed combination, which makes it reasonable for printing complex designs. This technique is Generally utilized in different businesses for cutting edge applications. For example, Platforms for tissue designing, cross - sections, aviation, and hardware [19]. The fundamental benefit of this technique is that the powder bed is utilized as the Support, which beats hardships in eliminating supporting material. In any case, the fundamental downsides of powder bed combination, which is a sluggish Process, incorporates significant expenses and high porosity when the powder is intertwined with a folio.

2.5 Material Extrusion

In FDM technique, a nonstop fiber of a thermoplastic polymer is used to 3D print layers of materials. The fiber is warmed at the spout to arrive at a semi - fluid state and afterward expelled on the stage or on the other hand on top of recently printed layers. The thermoplastic of the polymer fiber is a fundamental property for this technique, which permits the fibers to meld during printing and afterward to cement at room temperature after printing [20]. The layer thickness, width and direction of fibers and air hole (in a similar layer or between layers) are the fundamental handling boundaries that influence the mechanical properties of printed parts. Between layer twisting was viewed as the primary driver of mechanical shortcoming. Minimal expense, fast and effortlessness of the cycle are the fundamental advantages of FDM. On the other hand, powerless mechanical properties, layer - by - layer appearance, poor surface quality and a predetermined number of thermoplastic materials are the primary downsides of FDM [21]. The advancement of fiber - built up composites utilizing FDM has reinforced the mechanical properties of 3D printed parts. In any case, fiber direction, holding between the fiber and network and void development are the primary difficulties that emerge in 3D printed composite parts.

2.6 Direct Energy Deposition

Direct energy affidavit (DED) has been utilized for assembling elite execution super - combinations. This strategy is otherwise called laser designed net molding (LENS™), laser strong framing (LSF), coordinated light creation (DLF), direct metal statement (DMD), electron shaft AM (EBAM) and wire + Bend AM (WAAM). DED utilizes a wellspring of energy (laser or electron bar) which is straightforwardly centered around a little district of the substrate and is likewise used to liquefy a feedstock material (powder or wire) at the same time [22]. The liquefied material is then stored Furthermore, melded into the softened substrate, and cemented after development of the laser bar. The contrast among DED and SLM strategies is that no powder bed is utilized in DED and the feedstock is liquefied before statement in a layer - by - layer style like FDM yet with a very higher measure of energy for dissolving metals. In this way, it can be useful for filling breaks and retrofitting made parts for which the utilization of the powder - bed technique is restricted. This technique considers both different pivot statement and various materials simultaneously. Also, DED can be joined effectively with ordinary subtractive cycles to finish machining. This procedure is usually utilized with titanium, Inconel, tempered steel, aluminum also, the related compounds for aviation applications. As a rule, DED is described by high velocities and extremely huge work envelopes (up to 6 m×1.4 m x 1.4m for business printers). Notwithstanding, it has a lower precision (0.25 mm), lower surface quality and can produce fewer perplexing parts contrasted with SLS or SLM. Subsequently, DED is usually utilized for huge parts with low intricacy and furthermore for fixing bigger parts. DED can decrease the assembling time and cost, and gives fantastic mechanical properties, controlled microstructure what is more, exact creation control [23]. This technique can be utilized for fix turbine motors and other specialty applications in different businesses such car and aviation.

2.7 Sheet Lamination

Overlaid object producing (LOM) is one of the first industrially accessible added substance producing strategies, which depends on layer - by - layer cutting and overlay of sheets or moves of materials. Progressive layers are cut exactly utilizing a mechanical shaper or laser what is more, are then fortified together (structure then - bond) or the other way around (bond then - structure). The structure then - bond strategy is especially valuable for warm holding of ceramics and metallic materials, which additionally works with the development of inward highlights by eliminating abundance materials prior to holding. The overabundance materials after cutting are left for the help furthermore, after fruition of the interaction, can be eliminated and reused. LOM can be utilized for various materials like polymer composites, ceramics, paper, and metal - filled tapes. Post - handling for example, high - temperature treatment might be required relying upon the sort of materials and wanted properties. Ultrasonic added substance fabricating (UAM) is another subclass of LOM which joins ultrasonic metal crease welding and CNC processing in the overlay cycle. UAM is the main added substance fabricating technique that is prepared to do development of metal designs at low temperature. LOM has been utilized in different enterprises, for example, paper fabricating, foundry businesses, gadgets, and brilliant designs. Brilliant designs are grouped as designs (which can perform multiple tasks) with various sensors and processors. Dissimilar to regular strategies, UAM can indicate cavities in the construction considering the coordinated PC plan for implanted electronic gadgets, sensors, pipes, and different highlights [24]. Electronic gadgets can be imprinted in a similar overlay cycle of UAM utilizing direct compose advancements. LOM can bring about a decrease of tooling cost and assembling time, and is one of the most amazing added substance producing strategies for bigger designs. Nonetheless, LOM has mediocre surface quality (without post - handling) and its layered exactness is lower contrasted with the powder - bed strategies. Additionally, eliminating the overabundance parts of covers after arrangement of the item is tedious contrasted with the powder - bed strategies. In this manner, it is not suggested for complex shapes.

Table: Shows Automobile parts made by different processes

S. No.	3D Printing Process	Components Made
1.	Laser Stereolithography	Prototypes, Customized Parts, Air Intake Systems, Lightweight Brackets, Sensor Housings
2.	Material Jetting	Tooling and Fixtures, Interior Trim Components, Functional Prototypes
3.	Binder Jetting Technique	Engine Components, Heat Exchangers, Exhaust Manifolds, Structural Components
4.	Powder Binding Process	Lightweight Structures, Exhaust Systems, Customized Components, Functional Prototypes
5.	Material Extrusion	Jigs and Fixtures, Customized Accessories, Interior Trim Components
6.	Direct Energy Deposition	Repair and Refurbishment, Customized Tooling, Performance Enhancements
7.	Sheet Lamination	Brackets, exterior body panels, interior trim pieces, dashboard accents, and exterior accessories

3. Trending Application, Challenges, and Opportunities

Automobile manufacturers and sub - suppliers were early adopters of AM technology, when it was originated. They have pioneered the use of 3D CAD technologies from its inception. Consequently, 3D designs. There has been no barrier to the automotive industry's adoption of AM. Creating high - quality 3D data sets has never been a challenge for automakers and their suppliers. Diversification leads to a growth of prototypes, making product variations more important. Companies utilize prototypes to validate internal processes, form fit, and function. These are effective marketing tools for engaging with customers and suppliers. Customized items reduce tool costs greatly compared to direct manufacturing. Interior lamps, especially front and rear lamps, are frequently the subject of design changes and facelifts. Additive manufacturing allows for the rapid and high - quality generation of design variations, which are subsequently evaluated. The lamps incorporate transparent parts. The elements are created additively as non - transparent components. RTV is then used to cast transparent and colored pieces, as needed [25]. Even the textures of the diffusion pane can be produced using specific foils put into the silicone mold. Switches and lens frames are made independently and put into the final product using the same process. Lamp sockets and covers manufactured by additive manufacturing, like many other items, are used as spare parts for small series or as individual parts, including for racing. Special editions of cars developed from volume car productions are frequently not only equipped with more powerful engines, but also display their unique status through redesigned front and rear spoilers or side skirts, etc. [26]. Manufacturing with steel tools is not cost - effective. This tiny series' spoiler was divided into three portions (left, center, and right). Each part was created using AM (laser sintering or stereolithography), finished, and joined to a single master model with the aid of a gauge. In a subsequent RTV procedure, a small series of spoilers were created from polyurethane (PUR), varnished in the car's original color, and completed with the original cosmetic pieces (grille, logo, and trim) from the vehicle's manufacturer [27]. Volvo Cars is a worldwide automotive company that competes in the premium car segment. To continue to progress and expand as a premier vehicle manufacturer, they must find new and innovative ways to increase productivity and efficiency while also increasing the customer value of their product. As a result, AM is a technology that may improve the product development process, allowing Volvo Cars to maintain its competitive edge. Under certain conditions, additive manufacturing has emerged as a potentially disruptive technology in a variety of manufacturing sectors. Additive Manufacturing (also known as 3D Printing) is a method that involves adding material layer by layer to generate the desired shape of a product [28]. This is the most significant distinction compared to many conventional procedures, which are subtractive, meaning material is removed systematically to achieve the correct form. This provides technology with greater flexibility, free - form production, and reduced material waste [29]. To be able to adapt to this new technology, it must be economically advantageous compared to conventional manufacturing to remain profitable in an industry with generally low margins. Volvo Cars sees great value in AM and requires better guidelines and knowledge about economic analysis for end - use products fabricated by AM [30]. This thesis project will provide Volvo Cars with valuable information and guidelines regarding the economic aspects of AM.

4. Conclusion and Future Scope

It is economically advantageous to employ AM in small series, and the results demonstrate that without any redesign, the smaller the part, the higher the total cost of the part and tools. The part volume influences both the build time and the quantity of material required. The two most important factors influencing production costs with AM are machine cost and material cost. AM can add value to both the consumer and the firm. AM's design freedom can boost client value. More complicated structures can be created and customized to a greater extent without any significant cost implications. Part integration allows for the integration of more functions into fewer components. This may also be preferable for the consumer in the case of a reduced weight, which is advantageous in many circumstances. Future scope it demonstrates that many competitors have adopted AM, not for metal manufacture of end - use components, but primarily plastic parts or metal tooling. Metal AM can be beneficial without any redesign, but if product optimization is considered, the break - even point can be raised to a value that indicates a high likelihood of low - volume production.

References

[1] V. Sreehitha, “Impact Of 3d Printing in Automotive Industries”, International Journal of Mechanical and Production Engineering, vol.5, Issue - 2, Feb.2017.

[2] Megan R. Nicholas, “How does the automotive industry benefits from 3d metal printing?”, Metal powder report, vol.74, issue 5, pp.257 - 258, September–October 2019.

[3] Yozi, “Current Status of 3D Printer Use among Automotive Suppliers: Can 3D Printed - parts Replace Cast Parts?”, IFEAMA SPSCP, vol.5, pp.69 - 82.

[4] Thomas Duda and L. Venkat Ragahvan, “3d metal printing technology” IFAC paper online 49 - 29, pp.103 - 110, 2016.

[5] Tim Caffrey’s and Terry Wohlers, “3D printing and additive manufacturing state of the industry. Annual Worldwide Progress Report”, Wohlers Associates, Inc. ISBN 978 - 0 - 9913332 - 1 - 9, Wohlers Report 2015.

[6] Andreas Gebhardt, Julia Kessler and Laura Thurn, “3D Printing Understanding Additive Manufacturing”, 2nd Edition, Hanser Publishers, Munich, 2011.

[7] N. A. Rosli, M. R. Alkahari, F. R. Ramli, S. Maidin, M. N. Sudin, s. Subramoniam, T. Furumoto, “Design and development of a low - cost 3d metal printer” Journal of Mechanical Engineering Research and Developments (JMERD), vol 41, issue 3, pp 47 - 54, 2018.

[8] Richard J. Jacksona, Adam Wojcika, Mark Miodownika, “3D printing of asphalt and its effect on mechanical properties” Materials and Design, vol.160, pp.468 - 474, 2018.

[9] Shruti Ganesh Sarvankar, Sanket Nandaram Yewale, “Additive Manufacturing in Automobile Industry” IJRAME, vol.7, Issue 4, pp.01 - 10, April 2019.

[10] Terese Wahlstrom and Johan Sahlstrom, “Additive manufacturing in production”, Master’s thesis Lund University, Lund, Sweden, 2016.

[11] K. R. Bakshi, A. V. Mulay “A Review on Selective Laser Sintering: A Rapid Prototyping Technology”, IOSR Journal of Mechanical & Civil Engineering (IOSRJMCE), 5th National Conference RDME 2016, 10 - 11th March 2016.

[12] M. W. Khaing, J. Fuh, and L. Lu, “Direct Metal Laser Sintering for Rapid Tooling: Processing and Characterization of EOS Parts, ” Journal of Materials Processing Technology, 113, pp.269–272, 2001.

[13] C. D. Naiju, M. Adithan, P. Radhakrishnan, Y. Upendra Sravan, “Functional Testing of Direct Metal Laser Sintered (DMLS) Components for Automotive Application”, Advanced Materials Research, vol.383 - 390, pp.6242 - 6246, 2012.

[14] S. Dolinsek, J. Kopac: DMLS Technology – from the Prototyping to the Rapid Manufacturing, 6 th International Conference of Innovative Technologies, Piran, Slovenia, MIT 2003.

[15] Kuang - Hua Chang, “Rapid Prototyping”, Computer - aided engineering design, pp 743 - 786, 2015.

[16] Michael Zenou, Lucy Grainger, “3 - additive manufacturing of metallic materials”, Additive manufacturing, pp 53 - 103, 2018.

[17] SL sing, CF Tey, JHK Tan, S. Huang and Wai Yee Yeong, “3d printing of metals in rapid prototyping of biomaterials: technique in additive manufacturing”, rapid prototyping of biomaterials, pp 17 - 40, 2020.

[18] Chee kai Chua, Chee Hou Wong and Wai Yee Yeong, “material characterization for additive manufacturing”, standard quality control, and measurement sciences in 3d printing and additive manufacturing, pp.95 - 137, 2017.

[19] Anuradha Tidka, KR Jagtap, “Review on analysis of binder jetting process of additive manufacturing technology”, VJER, vol.1 issue 3, pp.231 - 237, September 2017.

[20] Leo Greguric, “what is binder jetting? - 3d printing simply explained” April 5, 2019 [Online]. https: //all3dp. com / 2/ what is binder jetting - 3d printing - simply - explained. [Accessed: June 5, 2019].

[21] R. F Pereira, PJ Bartoto, “recent advances in additive biomanufacturing”, comprehensive material processing, vol.10, pp.265 - 284, 2014.

[22] V. Sreehitha, “Impact Of 3d Printing in Automotive Industries”, International Journal of Mechanical and Production Engineering, Volume - 5, Issue - 2, Feb. - 2017

[23] Bandyopadhyay, A., Bose, S., & Gualtieri, T. Global Engineering and Additive Manufacturing. In A. Bandyopadhyay, & S. Bose, Additive Manufacturing. Boca Raton: Taylor & Francis Group. (2015).

[24] Kira, “Audi to use 3d printed metal parts in production cars”, [Online]. https: //3ders. org/articles/20151113 - audi - to - use - 3d - printed - metal - parts - in - production - cars. html, Nov 2015. [Accessed: Dec., 2015].

[25] Daniel Beiderbeck, Dominik Derajat and Tim Minshall, "the impact of additive manufacturing technologies on Industrial spare parts strategies", centre for technology management working paper series, March 2018.
[26] Noriko read, Wei wang, Khamis Essa and Moataz M. Attallah, "selective laser melting of AlSi10Mg alloy: process optimization and mechanical properties development", materials and design, vol.65, pp.417 - 424, January 2015.
[27] Novid Dehdari Ebrahimi, Y. Sungtaek Ju, "thermal conductivity of sintered copper sample prepared using 3d printing – compatible polymer composite filaments", additive manufacturing, vol.24, pp.479 - 485.
[28] Karolina Karolewska, Bogdan Ligaj, Mateusz Wirwicki and Grzegorz Szala, "strength analysis of Ti6Al4v titanium alloy produced by the use of additive manufacturing method under static load conditions", journal of material research and technology, not published, 2019.
[29] Jon Bruner & Faris sheikh, "Road to 3d printing: 5 ways 3d printing is changing the automotive industry".
[30] Leo Greguric, "3d printing automotive applications – the latest projects ", Feb 2019.