Case Study
Cyberphysical production systems using additive manufacturing

Topic:

Additive Manufacturing in automotive industry

Group 11:

Authors

Mahmoud Mostafa Hussein Hassan Elbarrawy (00822092)

Ajay Roy (00822077)

Tom Jojo Palamattam (00821354)

Krishnanunni Shaji (12103571)

Chinchu Thangam Chacko (00821387)

Nandhakumar Njundanmackal Suresh (12100505)

supervisor:

Prof. Maja Köckeis

Contents

Abstract Mahmoud (00822092)

The target of wight reduction and complex part production in industrial manufacturing is on run field of study especially in the field of automotive industry. It's known that wight of any component is inversely proportional to its cost. Not only the cost that is affected but there are other aspects as well. The Additive Manufacturing also known as 3-D printing technology is utilized by a lot of research and devilment departments in manufacturing companies to reach such goal. Due to the importance of the AM technology this research paper review additive manufacturing technology in automotive industry in details from the beginning of the technology till now. The technology levelled up from prototyping to mass production in some companies. Results shows that AM technology is spreading in wide range of manufactured components in automotive industry.

1. Introduction Mahmoud (00822092)

1.1 Brief background

In recent years, digital manufacturing technologies have shifted dramatically toward small-scale, consumer-oriented, digitally enabled production instruments. Since the mid-2000s, when several historic efforts became public, low-cost, accessible 3D printing, CNC machining, laser cutting, and robotic equipment have grown increasingly widespread in the market and have experienced fast price reductions. These projects aimed to democratize the manufacturing process and ensure that everyone in the world had equal access to products and services.

The 3D printing or additive manufacturing (AM) is evolving in rapid way. With a growth rate of 29.4 percent in 2011, it surpassed the industry's historical growth rate of 26.4 percent in a single year [1]. Many feel it will have a significant impact on the future of manufacturing and will become an integral part of our daily life. While such rapid development is now being observed, it has a history dating back over two decades. 3D printing was born in the mid-1980s from three technologies that were developed concurrently and brought to market in a short period of time. In 1987, 3D Systems created a machine that utilised the Stereolithography (SLA) technique, in which each successive layer of a model is defined and solidified by a laser within a bath of photosensitive resin. UV radiation is subsequently used to cure the semi-hardened 3D model [2].

The second breakthrough came in 1987-88, when Scott Crump created the first Fused Deposition Modelling (FDM) machine, which uses thin filaments of heated plastic that are extruded and fused in layered layers to create a 3D model. Stratasys first commercialized this technique in 1991, and it has been the company's principal technology ever since.

The third system, known as Laminated Object Modelling (LOM), was created in 1987-90 by Helisys Inc., which is now defunct. To create a 3D model, thin layers of thermo-activated binder coated material, such as paper or foil, are profile-cut and heat-bonded together [39]. While these three technologies were the most popular, several others were developed around the same time, including Selective Laser Sintering (SLS) in 1992, which uses plastic, metal, selective mask sintering (SMS) and sintered layers of powdered, each negative layer is set over powdered metal. The positive form of the layer is then exposed to IR radiation and sintered to the layer below; and 3D-Printing (3DP), developed by the Massachusetts Institute of Technology (MIT) in 1994 and commercialized in 1997, is a method of binding layers of powder together in a manner similar to SLS. but with water as the binding agent instead of a laser. Since then, Z-Corp and Object [2] have commercialized this concept as low-cost office-based devices.

When the technology of 3D printing first came out to the public it was very expensive. For example, Stratasys debuted the Dimension 3D machine in February 2002, which was the first "low-cost" desktop 3D printer, selling for little under US$30,000. Since then, a lot of technological advancements have reduced costs and increased accessibility for 3D printers to reach the general market. These are not from industry, but rather from the efforts of university researchers and amateurs whose primary goal was to democratize object-making technology. These technologies are built on Open-Source platforms and were created with the intention of being hacked, developed, and distributed by the community. The tools, known as Open-Source Hardware (OSHW), have spurred what has been dubbed the "Maker" movement, which is made up of people who are connected to the Internet and openly exchange knowledge about how to produce things. The price of non-open-source workstations has dropped considerably since low-cost OSHW devices became accessible.

1.1.1 Definition of additive manufacturing

AM is described as "The technique of combining materials to produce items from 3D model data, generally layer by layer, which is different than conventional ones" [3]. AM can produce components with extremely detailed and complicated geometries with minimal post-processing, created from customized materials with near-zero waste, and it is combatable with different kind of materials. As a result, AM is a technique that gives designers and engineers more "design freedom" and allows them to build unique items that can be mass-produced in low levels at a low cost. Traditional assemblies can be reworked into a single complicated structure that could not be made using existing manufacturing techniques, as an illustration of the design flexibility afforded. Since AM using layer by layer printing, it has no waste which huge environment benefit. Additive manufacturing technologies and methodologies are rapidly expanding in terms of application and market share, with applications in industries as diverse as automotive, medical, and aerospace, and it is projected that this rapid expansion will continue in the coming years [4].

1.1.2 Additive manufacturing in automotive Industry

The weight reduction [5] of components is one of the most important parts of the automobile industry. Advanced engineering materials and complicated geometries are used in automotive applications to save weight and increase performance. Metals and lightweight polymers can be used in AM to create components. The geometry of an item has an impact on weight and aerodynamics (and hence vehicle performance). Internal channels, concealed features, thin walls, small meshes, and complicated curved surfaces are all common in automotive parts. AM allows for the creation of exceedingly intricate structures that are nonetheless light and sturdy. It allows for a lot of design freedom, the optimization and integration of functional elements, the production of small batch sizes at low unit costs.

In the automobile business, scale models of a vehicle's shape are frequently used to start the design process. High-detail, smooth scale models of vehicle designs are created using SLA and material jetting. Accurate models make it possible to explain design intent and show off a concept's overall shape. Prototyping in automotive industry become an easy and fast. There’s an AM technology for every prototype need, from a full-size wing mirror produced rapidly using low-cost FDM to a high-detail, full-color dashboard. Full testing and validation of prototype performance is also possible with several AM engineering materials. The creation of low-cost fast tooling for injection moulding, thermoforming, and jig and fixtures is one of the areas where AM has had the biggest impact. This permits tooling to be swiftly made at a minimal cost and then utilized to make low to medium batches of components in the automobile sector. This validation lowers the risk of investing in high-cost tooling throughout the manufacturing process.

Although AM was first used for prototyping, recent advancements in AM technology and materials have enabled the fabrication of small and medium-sized final components. This can include everything from the outside to the inside, including bellows, sophisticated ducting, mounting brackets, and engine components. Bugatti, for example, stated earlier this year that it had created a completely working titanium brake caliper that was wholly 3D printed. With such advancements in end-part production, 3D printing is poised to become a critical tool in this field.

1.2 Research gap in additive manufacturing for automotive industry

While automotive original equipment manufacturers are rapidly implementing AM systems into development and production, a lack of mass production remains a barrier to widespread use. The automobile industry is primarily reliant on mass, serial production, with over 80 million cars produced in 2017. 3D printing should thus be viewed as a supplement to existing production processes, which are well-suited to bulk volumes, rather than as a replacement for low-volume, tailored end products.

Although 3D printing technology can generate bigger items, this must be done in the form of modular sections. These, in turn, must currently be put or joined together via other methods, such as welding. Large-scale additive manufacturing, on the other hand, is a key and expanding field of study, with technologies like Wire Arc Additive Manufacturing (WAAM) and Big Area Additive Manufacturing (BAAM) are currently being researched and developed to enable larger build sizes. If AM is to become more broadly adopted, additional investment in the development of AM-specific skills is required. Design for additive manufacturing, as well as AM system operation and maintenance, materials, and post-processing, are all essential talents that must be cultivated and maintained. While much has been made about the present AM skills gap, collaborations with colleges and internal training programs are one approach to ensure a qualified personnel pool capable of working with the technology's unique characteristics.

1.3 Aim of the research study

In the research case study, we review Additive Manufacturing in automotive industry from various point of views to answer substantial questions:

"Which parts of a car are additive manufactured parts, and why are these parts better than conventional manufacturing?"

2. State of the Art Ajay (00822077)

Additive Manufacturing or 3D Printing has created a revolutionary change in the manufacturing industry; therefore, companies are investing more amount of their capital in the field of additive manufacturing. Additive manufacturing finds various applications in industries such as rapid prototyping, tools, manufacturing aids, end-use parts etc. In automotive industries, additive manufacturing is widely used for manufacturing high detail visual prototypes, complex ducting, brackets, frameworks, engine components etc. This section explains more about the state of the art of additive manufacturing in the automotive industry [11].

2.1 Additive Manufacturing Process Chain in Automotive Industries

Additive Manufacturing entails a series of stages ranging from a virtual CAD model to a physical resulting part. Additive Manufacturing will be used in a variety of ways and to varying degrees in different goods. Smaller and basic parts may simply employ additive manufacturing for visualization of the models, but bigger and complicated parts with significant engineering content may use additive manufacturing at several stages and iterations throughout the development process. Furthermore, because of the pace with which additive manufacturing can create rough components, it is often employed in the early phases of the product development process. Parts may require careful cleaning and post-processing before they can be used at a later stage of the process [12].

2.1.1 Three-Dimensional Computer-Aided Design (CAD) Model

All additive manufacturing components must begin with a software model that accurately depicts the exterior geometry. The initial stage in the additive manufacturing process chain is to design a digital 3D model using ccomputer-aided design (CAD). It is the most frequent way of creating a digital model. This may be done with practically any professional CAD solid modelling software, but the result must be a 3D solid or surface model. Additive manufacturing is compatible with a wide range of free and professional CAD systems. In some cases, 3D scanning and reverse engineering may also be employed to create a digital model [12][8].

2.1.2 Conversion to Stereolithography (STL) File and File Manipulation

Almost all additive manufacturing machines accepts STL file format. The necessity to convert a CAD model into an STL (stereolithography) file is a significant stage in the additive manufacturing process chain that makes this process differ from traditional production techniques. STL depict the surface of the object by triangles(polygons). Physical size, water tightness and polygon count are just a few of the model limits to consider when converting a model to an STL file. A slicer application is used to import an STL file once it has been created. The STL file is loaded into this software, which then transforms it to G-code. G-code is a special programming language that can be used for numerical control (NC). G-code is used to operate automated machine tools (such as CNC machines and 3D printers) in computer-aided manufacturing (CAM). The designer may also change the build settings, such as support, layer height, and component orientation, using the slicer application [12][8].

2.1.3 Machine Setup and 3D Printing

Since 3D printing machines are made up of a lot of small, delicate pieces, proper maintenance and calibration are essential for generating accurate prints. After that, the print material is then put into the 3D printer. The raw ingredients used in additive manufacturing frequently have a short shelf life and must be handled with care. While certain techniques allow for the recycling of surplus building materials, if not replaced on a regular basis, frequent usage can cause material qualities to deteriorate. After the print has started, most additive manufacturing equipment does not need to be watched. The machine will operate automatically, with problems occurring only when the machine runs out of material or the software malfunctions [12][8].

2.1.4 Removal of Prints

It is an easy process that includes detaching the printed object from the build platform. The removal of a print from other more industrial 3D printing processes is a highly technical and complex operation that requires careful extraction of the print, while, it is still enclosed in the build substance or attached to the build plate. Complicated removal techniques, highly qualified machine operators, as well as safety equipment and regulated settings, are all required for these approaches [12][8].

2.1.5 Post Processing

Parts that have been removed from the machine may require extra cleaning before they can be used. Parts may be weak or contain supporting features that must be removed at this point. As a result, time and careful, expert physical manipulation are frequently required. Depending on the printer technology, several post-processing techniques are used. For making the 3D printed part for end-use, it may be sanded and additional post-processing procedures that include tumbling, high-pressure air cleaning, polishing, and colouring can be used [12][8].

2.1.6 Part Inspection

Here the parts manufactured through additive manufacturing are undergone expert inspection to verify the quality of printed parts, here some of the factors considered include dimensions, surface finish, tolerance etc [12][8].

2.1.7 Application

This is the final stage in the additive manufacturing process chain. The 3D printed part now may be ready to use. The parts produced are out to the packing section or the storage areas [12][8].

2.2 Literature review on Additive Manufacturing in Automotive Industries

In 1983, Chuck Hull invented the first 3D printing process called stereolithography, which the described method and apparatus for fabricating solid structures by repeatedly printing small layers of ultra-violent curable material one on top of the other. He quickly understood, however, that his approach was not confined to solids and he broadened the concept to include any substance capable of solidification or changing its physical condition. From the time of invention, 3D printing technology got widespread gradually in automotive parts and tool production. From design to the factory floor, the automobile sector is a fantastic illustration of how additive manufacturing increases efficiency and productivity. Individual part manufacturing may be a time-consuming operation for an automobile manufacturer. They can now produce components on demand using a 3D printer, conserving resources and producing less waste. Nowadays, the technology is progressively gaining in popularity and it is probable that, in the future, all vehicle manufacturers will rely on 3D printing to improve their automotive production process to a large extent [9].

2.2.1 Growth of 3D printing in the Automotive Sector

The usage of 3D printing in the automobile sector has grown dramatically over the last decade, and it is likely to continue to develop in the future years. The rise in popularity of 3D printing technology has been related to the cost savings that the technology provides to car manufacturers in the production of high-quality vehicles. The usage of 3D technology in the automobile industry has also been backed up by studies that show how it may improve a company's supply chain. According to the study, 3D printing has made it possible to create automotive and aeroplane parts more quickly and effectively, a phenomenon that has benefited the value chain [9].

Figure 1 illustrates the total market share of additive manufacturing in the automotive industry(＄millions) during 2017-2028. From this graph, it is evident that the total automotive additive manufacturing market shows a steady increasing pattern in the market of polymer and metal final parts, polymer and metal prototypes, polymer and metal tools etc. So, additive manufacturing is a promising technology in the field of the automotive industry.

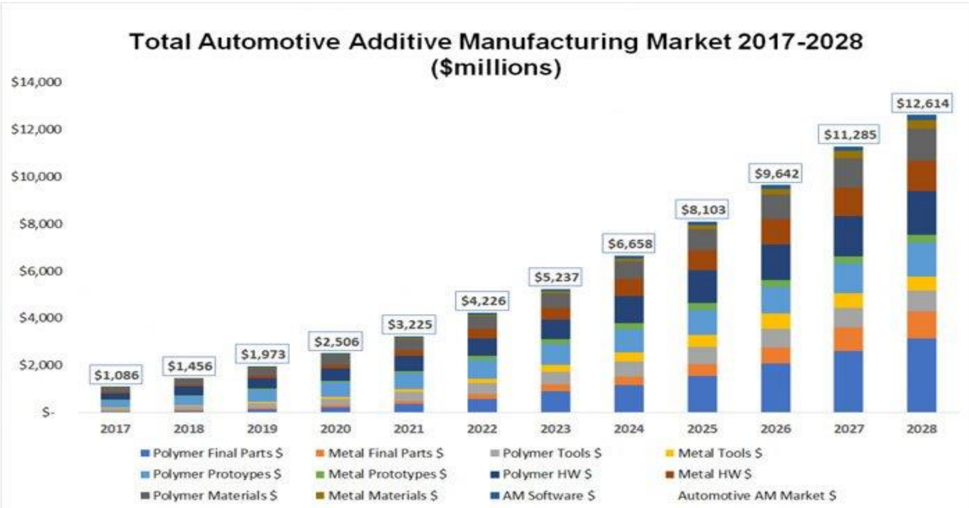

Figure 1: Automotive Additive Manufacturing Market 2017-2028 (＄millions) [10]

In 1996, Toyota received a patent for a laser light irradiation production moulding system. In 1997, they also received patents for the powder sintering process, spraying method and layered production device. Toyota has continued to explore and improve lamination technologies, and it now has 75 patents to its name. Toyota is presently using 3D printers to manufacture prototypes of interior trim and engines made of a transparent material to ensure that engine oil levels are normal and that flow is efficient. The widespread usage of 3D printers to build prototypes of vehicle body parts, on the other hand, has yet to be achieved [11].

According to most of the major automakers have already begun experimenting with 3D technology in the mass production of autos as well as the fabrication of tools and spare parts. In addition, the use of 3D printing technology in such automobile manufacturing organizations aims to improve the overall efficiency of the production processes. According to many studies, prominent automobile manufacturers such as Rolls Royce, BMW, and Bentley are already using 3D printing technology to create sturdy and lasting automotive parts. The automotive giants are investing highly in the field of additive manufacturing for improving the overall performance of the automobiles they produce. Due to the increasing demand for automobiles in most regions of the world, the automotive sector has been characterized by severe rivalry during the last decade [9][11].

2.2.2 Recent advancements by Automakers in Additive Manufacturing

While 3D printers are still commonly utilized for quick prototyping in the automotive sector, some major automakers have progressed to the next step of 3D printing technology adoption. These original equipment manufacturers (OEMs) have used 3D printing to create hand tools, fixtures, and jigs to improve manufacturing efficiency at the floor level, despite the fact that the technology is still in its early stages. Ford, one of the most experienced 3D printing users, utilizes the technology to create calibrating tools [11].

The utilization of new and innovative materials is another milestone in 3D printing. While most businesses employ silica powder, resin, and sand, just a few OEMs are pioneering the use of transparent polymers to make test pieces. As a result, they can confirm designs since the team can see what's going on within the part [11].

Local motors built the first 3D printed electric car in 2014 (Figure 2), using an acrylonitrile-butadlene-styrene(ABS) carbon-filter combination called "Strati" and producing it in under 44 hours. A large area additive manufacturing machine is used to produce Strati, which is made of thermoplastic. This machine is completely recyclable, and it can be sliced and recycled to make another 3D printed automobile. The mechanical and electric parts of the automobile, including the batteries, motors, and suspension, are manually assembled once it has been printed [11][8].

Figure 2: First 3D Printed Electric Car by Local Motors [12]

BMW collaborated with Stratasys, a 3D printing firm, to cut the weight of one such tool by 72 percent, significantly improving its ease of use. Technology has improved tool functioning in addition to enhancing tool handling skills. The firm has been successful in printing components with unusual forms that allow employees to reach tough regions unique to BMW automobiles. BMW also used 3D printing to produce a tool for attaching bumper supports for their cars, that includes a tube that is convoluted and bends around impediments and puts fixturing magnets precisely where they are required [8].

Formula One has been a pioneer in the use of additive manufacturing among racing organizations. Some of the teams began employing additive manufacturing components on their race vehicles in the early to mid-2000s, after initially adopting it for quick prototyping. Typically, these were nonstructural polymer powder bed fusion pieces. Formula One team used additive manufacturing models for wind tunnel testing of scale models as well as parts for full-size vehicle models, similar to the aerospace sector. Teams from other racing series, including IndyCar and NASCAR, have also included additive manufacturing in their vehicle development process [9][11].

The introduction of 3D technology into the automotive production industry has transformed the process of producing high-quality vehicles. Today, automobile manufacturers may employ 3D technology to develop and construct unique vehicle models that cater to a wide range of customer interests and preferences. Furthermore, 3D technology has enabled some automobile manufacturers to compete fairly with their competitors in the market. Furthermore, automobile makers have been able to save significant expenses and labour by employing 3D technology to produce vehicles, which would otherwise be incurred when using traditional vehicle manufacturing methods. As a result, automobile manufacturers have been able to sell their goods at somewhat lower rates, a situation that has resulted in a rise in the number of car units supplied to purchasers on the worldwide market [11][8].

These initiatives will lead to a level of skill and confidence in designing for additive processes in automobiles, which might result in significant mass reduction and a reduction in the number of materials utilized. Additive manufacturing allows designers to take their creations to a whole new level. Because undercuts, geometry, and intricate automobile parts are difficult to fabricate using traditional methods, 3D printing may make them much easier. With so many potential advantages, it's no wonder that 3D printing is finding its way into a wide range of automobile businesses and swiftly becoming an indispensable tool for innovative marketers [8].

3. Materials used in Additive Manufacturing of Automobiles

Tom (00821354)

3.1 Polymers

polymers are materials that are most commonly malleable and are made of synthetic or semi-synthetic materials. Polymers are widely used in Additive manufacturing because of their low cost, ease of manufacture, resistance to fluids, and their versatility. Below are listed some of the modern and advanced polymers used in additive manufacturing of automobile parts.

3.1.1) Silicone:

Silicone is well known for its countless mechanical properties such as high temperature and pressure resistance, great elasticity, and non-conductivity. Silicone is relatively a new material in 3-D printing mostly because of the time the technology took to mature. The Traditional Fused Deposition Modeling (FDM) process is not feasible in the case of silicone mostly because of its high viscosity [14]. FRE is a common method used in silicone 3D printing in which liquid precursors are extruded into a support bath preventing gravity flow [17]. These days hierarchical machine learning is used to optimize the printing process up to 2.5 times the speed by integration of physical models [17].

3.1.2) Thermoplastic Elastomer:

Thermoplastic Elastomers (TPE) are widely used in the rapid prototyping of automobile parts such as wheels. TPE's are a blend of rubber and plastic. The most popular TPE's are Thermoplastic polyurethane (TPU) and thermoplastic co-polyester (TPC). TPU's are used when high resistance and durability are a priority and TPC's are used when temperature resistance is important over other factors.

3.1.3) Polyester Ketones:

Polyester Ketones (PEEK) is a high-performance polymer and has high resistance to temperature and chemical wear, good flexibility, and elasticity modulus. The high wear resistance offered by PEEK is extremely useful in making components such as gears. The chemical inertness of PEEK enables it to be used around different fluids such as in the vales for battery cooling [5]. PEEK can be also reinforced with carbon fibers to provide higher stiffness and compression strength [8]. Fused Deposition Modeling and Fused Filament Fabrication processes are commonly used in the 3d-printing of PEEK.

3.1.4) Tough PLA:

Tough PLA is Polyactic acid (PLA) with some added additives which were introduced to overcome the major challenges of PLA filaments such as lower softening temperature and brittleness [16]. Not only tough PLA has comparable impact resistance with that of 3d-printed parts from ABS but also can be used with cheaper equipment. PLA materials are biodegradable and thus sustainable which means 3d-printing can be done without compromising the strength of the parts being built. Tough PLA is used in additive manufacturing of transmission system parts [16] and is also suitable in 3d-printing large structures.

3.2) Metals

Like polymers, metals are also a major material group used in additive manufacturing. Selective Laser Melting (SLM) and Direct Metal Laser Sintering are the most widely used in additive manufacturing of metals.

3.2.1) Tungsten:

Tungsten belongs to the refractory group of metals that are highly resistant to large temperatures. Tungsten 3d-printing is done with extrusion of a metal oxide ink done at room temperature, followed by thermo-chemical reduction, then followed by sintering under low pressure, and finally melt infiltration in vacuum [23] [24]. Tungsten is used when high-temperature resistance, strength, wear-resistance, and radiation shielding are valued over anything. Although tungsten assisted 3d-printing doesn't come cheap its properties make it suitable in specific and extreme areas such as racing. Bio-compatibility is another added advantage of parts made from tungsten.

3.2.2) Copper:

Copper is widely regarded for its great electrical as well as thermal conductivity. It is the same properties that prevented it from being used in 3d printing until lately the technologies became mature enough to handle copper. Copper can now make use of the design freedom additive manufacturing provides. Copper is used in the additive manufacturing of heat pipes, heat exchanges, and induction coils.

3.2.3) Titanium:

Titanium is a lightweight metal with outstanding strength and mechanical qualities, as well as good corrosion resistance and bio-compatibility. Additional heat treatments can be applied to your components to improve their mechanical qualities. Titanium can be reinforced with the help of other materials such as Graphene to form titanium matrix composites [25] which have better properties than regular tungsten. Titanium can be used in the field of motorsport

3.2.4) ScalmAlloy:

Scalmalloy is a material specifically made for 3d-printing. Its made from Scandium (SC), Magnesium (m), and Aluminium (Al) and is developed by airbus. Its major characteristics include lightweight, high corrosion resistance, high specific strength, fatigue, and toughness [26], thus making it suitable for high-performance applications. Scalmalloys are even stronger than titanium and thus can be used in heat exchangers of automobiles.

3.2.5) Graphene:

Graphene has excellent properties in mechanical, optical, and thermal areas. Based on these properties its believed Graphene could change 3d-printing forever. Although many methods such as chemical vapor deposition, assembly synthesis to create 3d Graphene, have poor efficiency and are often very expensive. The major problem is that Graphene is a 2-d object [15] since atomic bonds are in the lateral direction and thus need a binder to be used with additive manufacturing. Graphene 3d-printing is actively being developed in the area of battery technologies.

3.3 Ceramics

Ceramics are used in a variety of industries such as bio-medical, automotive, chemical and aerospace industries. The major characteristics of ceramic material include high mechanical strength, hardness, and acceptable properties in thermal, electrical, magnetical, and optical fields. Additive manufacturing enables complex geometries of ceramic structures possible which was previously impossible in traditional methods [14]. stereolithography (SLA), binder jetting, and extrusion of ceramic paste are used in the additive manufacturing of ceramic materials [21].

3.3.1) Alumina:

Alumina is usually found in powder form and is an oxide ceramic. The optimum conditions in which alumina is made are with 5 mm/s to 6 mm/s with plaster of Paris (POP) as the best option as a substrate because of better adherence [21]. The most suitable method for the additive manufacturing of alumina is vat photopolymerization which includes curing a photosensitive slurry by exposing it to UV light.

3.3.2) Zirconia:

Just like Alumina, Zirconia is also an oxide ceramic. Zirconia has a specific characteristic in which at room temperature Zirconia has a monoclinic crystal structure and Zirconia possesses a tetragonal and cubic structure. Zirconia is a hard ceramic and has high resistance towards fracture.

3.3.3) Silica:

Silica is an abundant material on the earth's surface especially in combination with other oxides such as alumina. The 3d-printing of silica can be done with the help of Digital Light Processing (DSL) which is a type of stereolithography. The 3d-printed parts of silica are found to be of high quality.

4. Types Of 3d-Printing Technologies

4.1) Stereolithography (SLA):

Stereolithography works based on the solidification of photopolymer when a light source is exposed to it. [6] It is one of the oldest and still one of the most used forms of the additive manufacturing method. SLA combines photo-chemistry, computer science, and light-curing technologies. The energy required for the curing process is obtained from the light source which creates a stronger bond between molecules in the resin. Some of the commonly used light sources are gamma rays, UV, electron beam, X-rays, etc. Parts made from SLA often have a better finish than parts made from traditional manufacturing methods and also can make complex shapes and structures. The most recent development in SLA technologies includes photo-polymerization with the application of heat, light, or even water [13].

4.2) Selective Laser Sintering (SLS):

SLS is one of the oldest 3d-printing technology and now is adapted to incorporate a wide variety of materials. The materials used in SLS include metals, ceramics, wax, and polymers such as PEEK, PCL, polyurethane, and polyamide [27]. SLS requires a protected environment to work under like nitrogen gas and a temperature specific to the material it is working with. [20]. The major advantages of using SLS are, no support structure is required, large structures can be made, and can make precise parts.

4.3) Direct Metal Laser Sintering (DMLS)

Direct Metal Laser Sintering works by exposing a laser beam to thin metal powder layers which will fuse the particles together. DMLS has a wide range of material selection ranging from Scalmalloy, Stainless steel, Titanium, Nickel alloy, Aluminum to cobalt-chrome, etc. DMLS provides outstanding material properties, a short production period, superior quality of parts produced, and the possibility of highly complex designs.

4.4) Selective Deposition Lamination (SDL):

Selective Deposition Lamination is an additive manufacturing process that is similar to Laminated Object Manufacturing (LOM). The major difference between LOM and SDL is that SDL only glues the parts that are going to fabricate the object whereas LOM glues the entire sheet. Here, sheets of paper are glued together and cut to form 3-d structures. Since SDL doesn't use any expensive filaments, its very cheap to produce.

4.5) Electron Beam Melting (EBM)

Electron Beam Melting is a powder bed fusion process that utilizes a magnetically controlled electron beam as an energy source. EBM is mainly used in the additive manufacturing of metals such as Aluminum, Titanium, Stainless Steel, Cobalt Chrome, etc. [20]. EBM's are known for producing high-strength parts and are faster to print when compared to SLM.

4.6) Fused Deposition Modeling (FDM)

Fused Deposition Modeling works by extruding metal filaments through a nozzle, which is then followed by hardening of the printed structure within the bed. FDM is a widely used additive manufacturing technology mostly because of its affordability, ease of maintenance and consumables [27]. The major cons of FDM include part quality and detail.

Krishnanunni (12103571)

5. Comparison of Additive Manufacturing and Traditional Manufacturing

Unlike Additive manufacturing methods, traditional manufacturing employs subtractive manufacturing, which is the gradual removal of material from a solid block to achieve a 3D product. Majority of automobile industries still make use of traditional manufacturing techniques to a large extent. It facilitates high volume production of parts with similar design at lower costs.

5.1 Major Traditional Manufacturing Techniques

The four major Traditional manufacturing techniques commonly used are:

Computer Numerical Control(CNC) Machining:

It is computer controlled manufacturing process in which preprogrammed codes and softwares control the movement of the tool and hence the machining process. Different operations such as milling, grinding, shaping and cutting can be done very precisely with the aid of CNC machines.

The operator feeds the machine with set of instructions as of what to do. The movement of the tool, the speed of movement can all be set by the operator. The instructions are provided to the CNC machine in languages called G-Code and M-Code.

Injection Molding:

In this type of machining, molten material is injected into a mold. The part is finally achieved by cooling the molten material in the mold. Complex parts can be manufactured by injection molding, in large quantities. After the initial investment on the experimental setup, the cost of machining per part is very cheap. The more the number of parts manufactured, the more effective it is to use injection molding.

The initial investment on the design and manufacture of tools can be high. Injection molding has very low customizability. Also, Injection Molding machining have higher lead times. These are some disadvantages of injection molding.

Plastic Joining:

The process of joining semi-finished is called plastic joining. Plastic joining can be done by three ways:

1. Mechanical Fastening
2. Adhesive Bonding
3. Welding

Plastic Forming:

Plastic Forming makes use of the plasticity of material with external force of the tool and the mold to machine a work piece to the required shape.

The different techniques of plastic Forming are as follows:

1. Forging:
   Forging apparatus is used to apply pressure to work pieces and deform them into special shapes and sizes.
2. Extrusion:
   The parts with fixed cross section is machined when the work material is pushed through a die having the desired cross section.
3. Rolling:
   The work piece is passed fed into a pair of rollers providing compressive external force. When the work piece passes through the rollers there would be a reduction in the cross sectional area and increase in length of the part.

4. Stamping:
   Presses or dies are used to apply external pressure on the work pieces such as plates/strips to plastically deform or to separate them in order to get the required machined part.
5. Drawing:
   The work piece is pulled though a die of a fixed cross section and the resulting machined part would have the same cross section as that of the die.

5.2 Difference between AM and Traditional Manufacturing Techniques

According to [27] Additive manufacturing involves the layer-by-layer addition of material on top of another to achieve the three dimensional final object while Traditional manufacturing involves the removal of material from a work piece to obtain the final required part.

All types of materials can be machined with traditional manufacturing techniques while only materials with lower melting point can be used in the case of additive manufacturing method.

In additive manufacturing, the density of the material can be controlled whereas in traditional manufacturing, the density cannot be controlled and the final machined part will have the same density as that of the work piece before being machined.

Minimum material wastage occurs in additive manufacturing whereas a lot of material gets wasted in the form of chips, vapors etc. in traditional method.

Any complex parts can be machined using additive manufacturing while conventional method have limitations in the ability to create complex structures.

Additive manufacturing is preferred when customizability of the products created is a concern whereas traditional manufacturing is cheaper and quicker when the production of bulk number of similar products is involved [28].

6. Opportunities and Challenges

6.1 Opportunities of Additive Manufacturing in Automotive Industry

Production of Complex parts

Additive manufacturing allows the manufacture of complex parts that are very difficult and/or costly to manufacture with traditional manufacturing techniques [28]. Since it is a layer by layer process, the shape of the product being manufactured does not matter. The more complex a part is to manufacture, the better it would be to manufacture through additive manufacturing. Additive manufacturing technique encourages creative designs and makes realization of such designs with sustainability [29] [30].

Manufacture of lighter parts

Additive manufacturing enables the construction of light weight parts by employing lattice structures. This decreases fuel consumptions and hence increases fuel efficiency of the vehicles. The energy and expenditure to manufacture complex parts are also decreased [28] [29] [30].

Reduction in the need of assembly

Another advantage is that additive manufacturing help reduce the number of parts of a product. This eliminates the need of assembly of parts and thus saves time, cost and increased quality of the parts manufactured [28].

Enables Tool-less manufacturing

Additive manufacturing involves direct manufacturing from 3D CAD models and hence it does not have multiple stages of tooling or molds. Since no new special tooling is required for a new part design, the initial fixed costs spent on tooling is minimized. Even the first part with new design can be manufactured in a cost-effective way [28] [30].

Efficiency in Resource Requirements

Additive manufacturing facilitates in the reduction in the labor requirements and aids lower material wastage. Additive manufacturing reduces in the intermediary steps required for the completion of a product's manufacture and shortens the supply chain [28] [30].

On Demand Manufacturing and Decentralized Manufacture Unit

Parts can be manufactured as demand exists. There is no need for a centralized manufacture unit and hence logistics and transportation costs can be reduced and hence customers can get products at a reduced price. Almost 20% of additive manufacturing market deals with the production of component parts for automotive and aerospace industry. The design can be stored as digital files and can be sent to different part of their globe. The part/product can be then manufactured locally from the nearest additive manufacturing equipment [28] [27].

Multi-Material Capability and Improved Quality

Since most products are made of more than one material, the ability to manufacture with different materials in the same systems helps the manufacture of a complete product by a single additive manufacturing unit.

The quality of products of additive manufacturing were also observed to be having superior quality [27].

Facilitates rapid prototyping and easy modifications

Using additive manufacturing new designs can be created and tested out very easily with very small time and cost. This supports the introduction of creative designs. Modifications to existing designs are also very simple. There is no need to spend time and money on developing the tooling. One only need to create a new digital 3D CAD model which can be manufactured directly using the equipment. This brings great flexibility. This helps companies to be very fast in the market and product modifications can be done anytime [28] [27].

Reduction in inventory costs

Since products can be created as when required, surplus products need not be produced and hence the inventory costs associated can be minimized [27].

Production of Spare Parts

Spare parts could be made easily available to the customers at a reduced price and shorter time. The repair costs could be reduced. Even for customers who have 3D printers at their home, spare parts could be manufactured at their home itself and the company only needs to provide them the digital file. The customer and the manufacture would be directly linked by doing so [27].

Environment Benefits

Additive manufacturing technique is expected to leave a lower environmental footprint when the entire life cycle of an additive manufactured product is taken into account [27].

6.2 Challenges of Additive Manufacturing in Automotive Industry

Restrictions on the size:

Only objects of size smaller than the additive manufacturing equipment casing can be manufactured with this method. Even if large printers are made to print larger objects, they need to be housed in special setup to accommodate the large size of the printer. In the automotive industry, large complex parts which have to incorporate many components have to be manufactured [27].

Cost:

Utilization of Additive manufacturing technique requires the affordability of the equipment. A lot of research and technological developments are happening to make the technology affordable to everyone. So, in the future, the cost constraint would disappear [27].

Duration of Production:

When compared to mass production utilizing conventional machining techniques, additive manufacture is slower. This is the reason why many automobiles manufactures still use traditional manufacturing methods over Additive manufacturing. When producing similar objects in bulk quality, the traditional methods are still the faster options. Methods to increase the printing speed of 3D printers must be researched to increase the practicality [27] [28].

Skill Development:

Since additive manufacturing is a new technology, it requires operators to be skilled for using the machine. Proper training for the operation, maintenance and repair of the equipment must be given [29] [28].

Limitation on Materials:

There are limitations on the materials that can be employed in the additive manufacturing technology. Material suitable to be used in 3D printers must be researched [29].

Chinchu (00821387)

7. Experts in Industry And Research

AM uses currently are limited to rapid prototyping in the automobile industry. But it is evident that some of the automakers identifies the future of additive manufacturing (AM) and they started to invest in this area, the industry and in general ,it will take some time to adapt compared to other industries like medical and aerospace. Despite this the analyst community remains excited in the automotive industry about AM's future. There is a forecast about an exponential growth occurs between 2020-2030 predicts by various organization. The global AM market from the year 2018 to 2024 is looking forward to expand at a annual growth rate (CAGR) of more than 25-30%.

7.1 AM Initiatives by the Automakers

Automakers have recently started using additive manufacturing tools and parts production, and they have created R&D departments for AM [33]. Some of the recent AM initiatives by famous automakers from news are given below.

Automakers	AM initiatives by the Automakers

Audi	• To implement AM ,Audi make partnering with EOS and SLM solution • Audi is using the Stratasys multi colour and multi material printer for a faster prototype tail light ,
BMW	• BMW invested approximately 10 million€ in a additive manufacturing specialist campus. • Since 2010 for i8 Roadster,BMW printed 1 million parts which contains window guide rail and roof bracket • BMW allows the owner of vehicle to customize a BMW MINI using 3D printing
Volkswagen	• VW opened an advanced 3D printing centre in automotive hub of Wolfsburg has edge cutting metal AM machines. They are planning for the production of 100000 units per year. • VW is establishing an AM automobile process chain with HP and GKN Powder Metallurgy. • Bugatti's brake calipers are using 3D-printed titanium.
Mercedes	• Mercedes-Benz is employing additive manufacturing to make metal parts for older truck models, eliminating the expensive and time-consuming process of casting moulds for these parts.
General Motors	• GM saved $300,000 on tools and other accessories at the Lansing Delta Township factory over the course of two years by using AM. • In the coming 5 years GM expands their recent lineup to new electric and fuel cell car model by making 3D printed components.
Ford	• Ford will incorporate the 3D printed brake parts for their Shelby Mustag GT500 • Desktop Metal, a 3D-printing business, has received a $65 million investment from Ford. • For the Lincoln Navigator and Ford Expedition SUVs, it is mainly depend upon rapid prototyping.

7.2 Need for Industry Collaboration

Collaboration and coordination across government, business, and academics can help tackle AM's difficulties more quickly and cost efficiently. There is a great need to construct teams, work on pilot projects, produce and publicize outcomes across the sector, and create a Plan-Do-Check-Act (PDCA) loop, as well as to engage the proper specialists from a broad part of the business. There are some groups for additive manufacturing like the Edison Welding Institute (EWI), a working group and Society of Manufacturing Engineers (SME) professional organizations group . However, the aerospace and medical industries account for the majority of the group's membership. While some concerns, such as part size constraints, part quality, and talent gaps, are common across industries, there are cost drivers in the automotive ecosystem, such as long cycle time and return on investment (ROI) evaluation, that offer greater challenges. CAR’s (Centre for Automotive Research) objective is to enhance the automotive industry's long-term viability, the newly formed working group will concentrate on specific AM challenges that are prevalent in the automotive and allied mobility industries. CAR intends to interact with current working groups in order to benefit from their expertise [33]. Following figure (1) shows the needs of collaboration for advance AM.

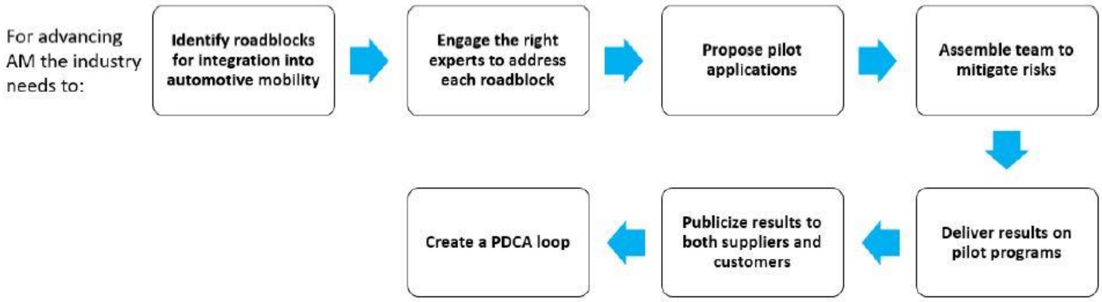

Figure 1: Need of collaboration for advancing AM

7.2.1 MOBILITY CONSORTIUM FOR ADDITIVE MANUFACTURING (MCAM)

Centre for automotive research plays an important role to bring together not only the automotive industry but also other areas like providing research support, managing projects. CAR also plays a key role in different industry events by providing results of the various project by the means of publishing and presenting projects. This event also includes the annual CAR management briefing seminar having more automotive executives [33]. The new AM working group MCAM, mainly focused on automotive additive manufacturing which was created by car have some goal and it would be as follows.

- In order to amalgamate the additive manufacturing technology into the automotive industry in a cost-effective way by providing a clear visibility and direction through identify the barriers, finding solutions of the problems, producing different prototypes.
- Ensure knowledge and technology transfer to the automotive industry from other industries.
- Take advantages from other organizations for projects like from American made ORNL (Oakridge National Laboratory), IACMI (Institute for Advanced Composites Manufacturing Innovation), LIFT (Lightweight Innovations for Tomorrow), EWI and also from the labs of universities.

- Drive the creation of material, process, and product quality standards for additive manufacturing.
- Research and share information about the effects of technical and business developments on the supply chain, such as part consolidation and decentralized production.
- Raising awareness of AM technologies and application opportunities among automakers and suppliers.

In the context of the automotive industry, CAR is an independent non-profit organization whose mission is to produce industry-driven research and foster dialogue [33]. Its unique position makes it effective as a convener and has a growing media presence. It hosts working groups focused on light weighting, power train, autonomous vehicles, and economic development. Figure (2) below shows the role of CAR in AM working group.

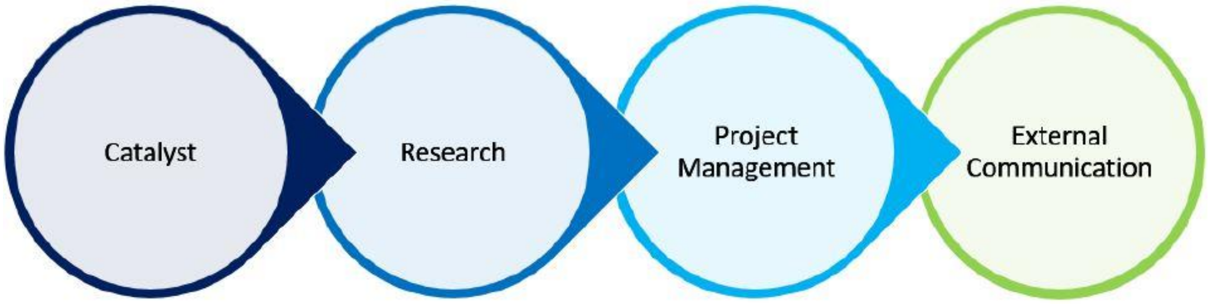

Figure 2: Role of CAR in AM

7.3 Future of AM in Automobiles

In spite of the rapid adoption of AM by the automobile industry and its widespread applications, the future of the industry is largely dependent on additive manufacturing. The following are some of the new ways that additive manufacturing will likely be employed in the near future [34].

- Seating and Interior – The dashboard and seat frame can be made using stereo lithography, polymers and laser sintering.
- Wheels, Tires and suspension - Inkjet technology, selective laser melting and Selective laser sintering can be used as alternatives of aluminium alloys and polymers to make suspension springs and tires.
- Electronics - On polymers, selective laser sintering can be used to manufacture a variety of refined elements, as well as components that must be embedded, like single-part manipulate panels or sensors.

- Doors and Framework – In order to produce panels such as doors, frameworks and other product, selective laser melting process is used on aluminium alloy metallic compound
- Engine components - Metals and its alloys, such as titanium and aluminium, can be used to make various useful parts of the engine and to get these processes like selective laser melting and electron beam melting can be used.
- Exterior-The production of wind breakers and bumpers uses selective laser sintering and polymers.

7.3.1 AM Materials Used in Automotive Applications

Currently, dashboards and cooling vents in some vehicles are produced using additive manufacturing [34]. A growing number of components could be produced in the future using AM thanks to new advancements in process and material technology. Figure 3 presents a non-exhaustive list of the components manufactured using AM and those that might be manufactured in the future.

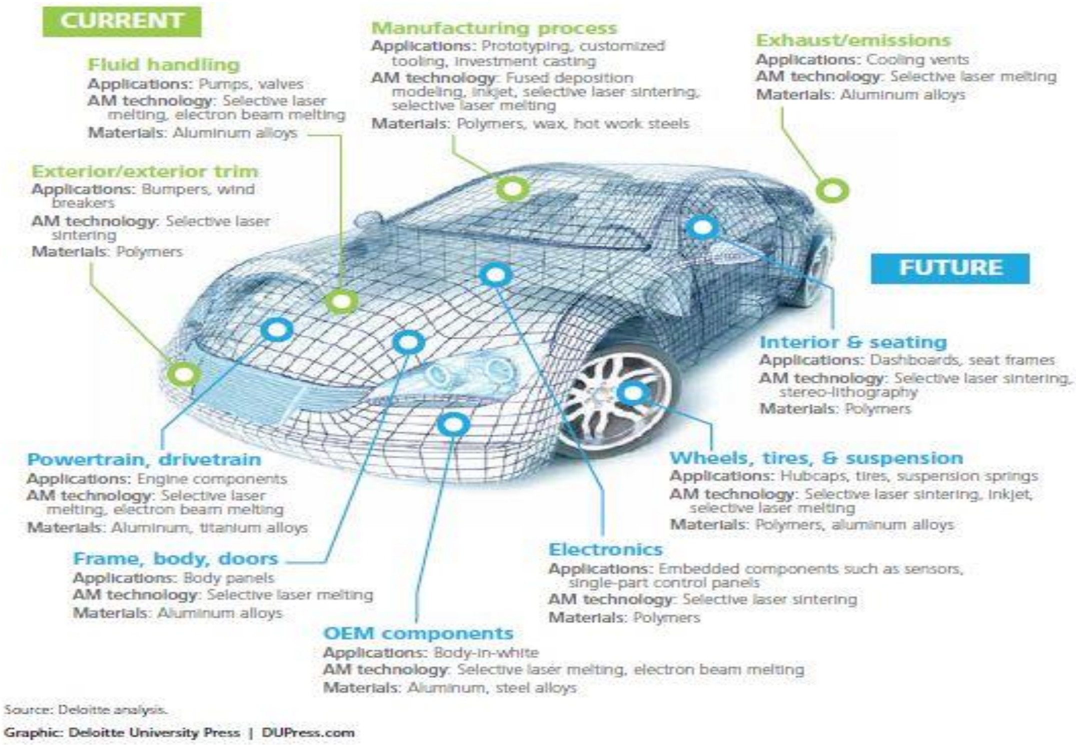

Figure 3:AM application in Automotive

Here listed a range of materials used in the automobile sector, along with their applications, in the table below.

Application	Process	Material	Material properties
Interior accessories	SLA	Resin	Customized cosmetic components
Full scale panels	Industrial SLA	Resin	Large parts with a surface finish comparable to injection molding that allow for sanding and painting
Air ducts	SLS	Nylon	Flexible ducting and bellows
Bezels	Material jetting	Photopolymer	End use custom screen bezels
Under the hood	SLS	Nylon	Heat resistant functional parts
Complex metal components	DMLS	Metal	Consolidated, lightweight, functional metal parts

7.4 Future Research of Automotive Industry

CAR organised and hosted two meetings for automotive industry participants to discuss the challenges they face when using AM. The attendees discussed ways to overcome those challenges during the meetings. In addition to machine suppliers, material suppliers, tier1 suppliers, automakers, academia, and government representatives attended the event. Whereas at the meeting various collaborative and competitive projects are going on to increasing AM's use in automotive industry. The guests were also given the opportunity to vote on the proposals in order to demonstrate their interest and support. The following below shown are the project categories and the projects list that have been recommended in each section[32].

Metal Tooling

- Get rid of machining operations for cooling lines to reduce lead times for hot stamping dies.
- The details of perishable dies should be replaced with AM.
- Build a casted base for a 3D printed die working surface.
- Online educational resources should be developed for existing AM tools.
- Eliminate machining operations for large mold runners to reduce lead times.

Plastics Tooling

- Utilize additive manufacturing to manufacture rapid, low-cost vacuum forming molds.
- By using AM, you can produce injection moulds with complex geometries and short lead times
- Using AM short run, prove out tools can be developed.

Part Production

- At comparable less cost a high volume traditionally made part can be made using AM
- AM application areas can research and publish in automotive.
- For choosing the right AM machine type suggestions are given.
- Design policy for AM will be publish and research.
- For small 3D printed parts reduce the time for post processing.

Business Models

- For high volume production formulate business techniques and models
- Providing recommendations for on-demand vehicle repair and maintenance on-location
- Analyze the AM supply chain's current status and future requirements
- Standardize and certify AM protocols

Other Projects

- Prepare database for current technology and make it available online.
- Publish case study about the past failure of using AM technology and introduce new technologies that contain the reasons of past failures
- Make recommendation for Including AM in academic curriculum of colleges and universities
- Create case studies that profile automotive companies that have used additive manufacturing and the reasons for their decision.
- Classify the AM technology based on build speed, cost and post processing time.

8. Product development and Manufacturing

8.1 Product Development

Today's automotive materials are vastly different from those utilized just a few decades ago. The new material, including other synthetic structures is being used in the car sector to help reduce vehicle weight and increase strength. Although this doesn’t like to be revolutionary, it certainly tells us a lot about how the automotive industry is quite active in innovation. Spare automotive components manufactured in 3D help supply chains run more smoothly. On-demand parts minimize or eliminate inventory. On-demand printing of automobile components might help manufacturers meet regulatory limits for how long they must keep replacement parts on hand. A considerable decrease in compliance-related automobile component inventory might save millions of dollars in manufacturing and storage expenses.

Automobile manufacturers are increasingly being asked to integrate a wide variety of motor types & energy storage technologies into vehicle chassis. Future vehicle bodywork will need to be not just lighter, but also flexible enough to handle a large number of different drive systems, some of which may be produced in small quantities. As a result, there are a rising number of vehicle variants that demand adaptive and cost-effective bodywork solutions. AM will bring up whole new possibilities in the near future.[35]

8.1.1 Concept modelling

AM allows components with complex geometrical features to be manufactured without the use of tools and directly from 3D CAD data. The Next Generation spaceframe system is an illustration the potential of additive manufacturing to transform the automotive industry. Commenting on the difficulties that the automotive industry faces in meeting sustainability targets. The redesigned bodywork structures should be lighter, stiffer, and able to withstand difficult load scenarios in the situation of a crash. [35] Despite all of the lofty weight-reduction aims, increased consumer needs, consideration of alternative drives, comfort, functionality, and networking, as well as new safety regulations from foreign legislators, are sales factors that favor heavy construction over composite structures. [36]

The essential concept of a visionary and bionic spaceframe would be, among other things, to only employ materials where they are truly required to give a function, safety, or rigidity. As a result, a simplified approach based on the maxim "less is more." Because of Additive Manufacturing and the profiling process with minimum tool use, it may be conceivable in the upcoming days to design all bodywork variations to meet the degree of loading and produce them 'on-demand.'

8.1.2 Advance prototype

All the aspects of automobile design & development cycle will be supported and satisfied by advanced prototype manufacturing. Even though traditional vehicles remain popular among customers, technology such as self-driving cars & electric vehicles are leading the charge in the automotive industry. In the never-ending competition to be the first and greatest, automakers must constantly invest in research and development in order to create better goods. With its capacity to swiftly generate functioning prototypes in only a few hours, additive manufacturing is a tremendous aid in this process, instead of the traditional turnaround times of several days or more. This allows product designers to test and iterate more often and cost-effectively, resulting in better-end products.

8.2 Manufacturing and production

8.2.1 Manufacturing Aids

The spaceframe concept blends the flexibility and lightweight construction capabilities of additive manufacturing with the efficiency of tried-and-true classical profile designs. Nodes that are topologically optimized provide the most efficient and functionally integrated lightweight construction currently available. The nodes and the profiles can be modified to new geometries and load requirements at no additional cost. This means that every single part can be developed to provide for a given amount of loading, rather than developing a single component to cope with the maximum load even if the majority of vehicle models do not require it, as was previously the case. [37] As a result, nodes and profiles are specially constructed to match what a specific vehicle model demands, resulting in a spaceframe structure with an optimized load path. It will be possible in the future to build all bodywork variations of a vehicle affordably and with the most possible flexibility by adopting processes that make minimum use of tooling.

8.2.2 Tools and Fabrication

Direct strategies in which the prototyping machine make the real inserts of the core mould and also the cavity mould, fall into one of two categories indirect approaches for prototyping master designs utilizing AM techniques in order to build a mold, and direct strategies in which the rapid prototyping machine constructs the genuine core and cavity mould inserts. Many firms use AM methods for tool production and expansion because of their market potential. However, because of their potential impact, these advancements generate a rush of demands from enterprises in sophisticated markets throughout the world. [3] Meanwhile, several institutions are working very hard to assess whether the moment is opportune to phase in both of these technologies.

8.2.3 End use parts

Tooling is widely employed in the automobile sector to aid in the production of high-quality goods. Jigs, fixtures, and other bespoke tooling equipment may be created using additive manufacturing to supplement this process. Instead of buying tooling equipment from third parties, the various factories are already employing additive manufacturing to build tooling equipment in-house. AM definitely demonstrates itself to be a cost-effective return on investment for tooling manufacture, boosting the whole production process, with a ten-day turnaround for positioning and screw assembly. As technology advances, product producers are increasingly turning to additive manufacturing (AM) to enable innovative designs and increase product performance in comparison to old approaches.[37]

End-use goods are those that are sold to customers or utilized to make a higher-level assembly that is then sold to customers. The use of AM for end-use part production along a product line, including things that have been redesigned for AM use. Instead of depending on outdated designs, these applications display innovation by rethinking product requirements. To achieve business model evolution, product development and innovation can be paired with supply chain evolution. Companies that employ additive manufacturing in the manufacturing process have the opportunity to improve the products in a variety of ways. Any tangible good sold as a product, employed as a sub-assembly, or as a component in a product is considered an end-use part. End-use parts are also utilized in the company's own activities, such as a component on its packing machine.

8.3 Additive Manufacturing for Automotive Parts

AM in the automotive sector allows for the fabrication of components without the use of tools, lowering research and production costs. Parts produced by the repeatable additive process may be fitted immediately in serial manufacturing vehicles. Additive manufacturing offers a fresh perspective on the automobile industry's present problems. It allows for design freedom while also allowing complicated but lightweight parts to be created. Automobile manufacturers may use additive manufacturing to enhance the productivity of their research and innovation, allowing them to get their vehicles to market faster. [38],[39]

8.3.1 Engine Parts

Engine production costs may be reduced with 3D printing technology while maintaining performance and dependability.

8.3.2 Cooling Systems

Custom sizes and forms are possible with additive manufacturing. Custom internal channels can change the flow of coolant for various cooling needs.

8.3.3 Battery Housings

Specialized enclosures for custom car use and racing may be simply produced.

8.3.4 Gears

Reducing the bulk of moving components is very significant since it immediately increases energy.

8.3.5 Heat Exchangers

High-end, weight optimized components for automotive sector applications are serially produced.

8.4 Additive Manufacturing drives the Future of the Automotive Industry

Over the last decade, significant advancements in additive manufacturing (AM) technology have revolutionized the possible methods in which things are conceived, produced, made, and distributed. These advancements have paved the way for fresher designs, cleaner, lighter, and safer products, quicker lead times, and reduced prices in the automobile sector. Additive manufacturing aligns with the automobile industry's demands, resulting in advancements in vehicle design. Serial production is now a reality in additive manufacturing since the technologies that fall under this point have progressed to the point where endues items can be built of both metal and plastic materials and are ready to be used in real-world situations. According to its technical trajectory, AM's future looks to be in product technology and high direct manufacturing.[40] New breakthroughs in AM technologies, as well as associated innovations in domains such as advanced materials, will enhance automobile production while also altering established manufacturing & supply chain paths.

8.4.1 Now and beyond: Where is Additive Manufacturing headed?

AM is already being used to manufacture dashboards & cooling vents in certain automobiles. With advancements in process and materials technology, as well as a wider acceptance of AM, it may see more AM-based component manufacture in the future. Some non-exhaustive list of which parts may be made in the future are Powertrain, drivetrain, Frame, body, doors, OEM components, Electronics, Wheels, tires, suspension and Interior & seating. One company's objective is to adopt additive manufacturing as the principal production method for cars as the quantity of additively created parts grows.[41]

8.4.2 AM in driving performance and growth

Most automotive companies are on path-I right now, which gives them plenty of room for improvement in their AM strategy. AM's key influence in the car industry will be along with path IV business model development in the long run.[6] This approach, however, incorporates product innovation, which is normally linked with Route III. In the future, original equipment manufacturers will most likely collaborate tightly with a smaller, more closely knit supplier base, and they will most likely provide faster refresh rates for vehicles with unique features. Original equipment manufacturers can achieve this business model by rationalizing their supplier base and strengthening their relationships. Automakers can use AM to cut the development phase of a product's life cycle in half while increasing the growth and maturity stages.[40] [41]

8.4.3 The Importance of the Role in the Global Automotive Landscape

Currently, automakers are adopting additive manufacturing in the most traditional sense for quick prototyping. It doesn’t see any substantial product changes or supply chain applications right now (with the possible exception of the luxury segment of the market). Automobile manufacturers should look at other avenues for gaining more value. As applications increase, the AM might become the main factor for future automotive operations. Original equipment manufacturers will be able to build complicated, high-performance parts for end use. AM's freeform capabilities and substantial reduction in design to complete production time. Given how car consumers are growing less willing to invest on replacement parts, aftermarket players can use AM to reduce the cost of maintenance and servicing. Companies are leading the way in the development of new process technologies and collaborating with academic institutions to produce unique materials for additive manufacturing. Rather than waiting for materials and AM process technologies to develop elsewhere and then adapting them, automakers should consider whether they can participate actively in the development of AM. This will allow to market AM as a unique selling point before the competition catches up. The automotive business is an intensive and low-margin industry. Original equipment manufacturers must rethink their business concept model in order to maintain profitability and market leadership. Part simplification and decreased assembly needs might have a direct influence on the supplier base by minimizing the size & complexity of auto chain supply. As product innovations backed by AM become more popular, original equipment manufacturers will discover that managing a leaner & tighter supply chain may help them enhance their business concept model. While it's vital to consider the benefits of AM, it's also crucial to keep track of how the legal landscape surrounding its use is changing. While traditional manufacturing processes have a stronghold in the automotive sector and will continue to do so, additive manufacturing is gaining traction.[42] While additive manufacturing will not replace traditional production techniques in the future, it will play a significant role in altering the global automotive scene.

9. CONCLUSION Mahmoud (00822092)

This research paper aimed to review the AM technology in automotive industry and why using such a technology rather than traditional techniques in the field of cars manufacturing; The conclusions from such work are:

Traditional manufacturing involves the removal of material from a work piece to produce the final work piece, but additive manufacturing uses layer-by-layer printing. The density of the material can be adjusted in additive manufacturing, however in traditional manufacturing, the density cannot be controlled, and the finished product will have the same density as the work piece before being machined.

Using additive manufacturing, any complicated item may be machined, but traditional methods have limitations in their capacity to construct complex structures. When there is a demand for a certain custom product or part additive manufacturing doesn’t face difficulties like traditional method. But traditional manufacturing is cheaper and faster when producing many comparable products.

Additive manufacturing provides for creative freedom while also enabling for the creation of intricate but lightweight pieces. Parts created by the repeatable additive process may be installed in serial production vehicles right away.

Also, the parts that the companies now use AM process to produce are a lot for example

The first electric car to be manufactured using AM was mad by local motors company. An acrylonitrile-butadiene-styrene (ABS) carbon-filter combination is used to create the car. Strati, which is constructed of thermoplastic, takes less than 44 hours to produce.

Toyota company used Am technology in manufacturing interior trim and engine with transparent substance to make oil levels in the engine normal and flow more efficient

Original equipment manufacturers (OEMs) company use additive manufacturing to make a variety of jigs, hand tools, and fittings. And Ford company uses the technology to develop calibration tools for its car manufacturing plant in Dearborn, Michigan [10].

BMW worked with 3D printing company Stratasys to reduce the weight of one such tool by seventy two percent, considerably boosting its use to increase functionality and tool handling. The company has been successful in printing components with unconventional shapes, allowing staff to reach difficult areas peculiar to BMW autos. BMW also employed 3D printing to create a tool for attaching bumper supports to their vehicles.

Formula One company was one of the first companies to use additive manufacturing in their cars. Mostly in non-structural polymer powder bed fusion components. Other racing series, such as

IndyCar and NASCAR, have also included additive manufacturing into their car development processes.

The most famous materials that this companies use while utilizing additive manufacturing technology are Polymers, Silicone, Thermoplastic polyurethane (TPU), Thermoplastic co-polyester (TPC), and Resin.

Interior accessories of cars are made by SLA process with a material of customized cosmetic components. Air ducts are made by SLS process. Car Bezels are made by material jetting. Under the hood are made by the same process of air ducts.

Engine pars, cooling systems, battery housings, gears, and heat exchangers are all utilize 3D printing technology. Engine costs are reduced while performance is the same. Which led to Custom cooling system sizes. Custom internal channels can alter the flow of coolant to meet a variety of cooling requirements. Reducing the wight of gears become an easy task and that lead to a huge improvement in overall wight of cars.

10. REFERENCES

[1] M. Richardson, and B. Haylock," Designer/maker: the rise of additive manufacturing, domestic-scale production and the possible implications for the automotive industry." Computer-Aided Design & Applications PACE, 2, pp.33-48, 2012.

[2] B. Wendel, D. Rietzel, F. Kühnlein, R. Feulner, G. Hülder,: Additive processing of polymers, Ernst Macromolecular Materials and Engineering, Vol.293, 799-809, doi:10.1002/mame.200800121, 2008.

[3] A.S.T.M., Standard terminology for additive manufacturing technologies. ASTM International F2792-12a, 2012.

[4] H. Bikas, P. Stavropoulos, and G. Chryssolouris," Additive manufacturing methods and modelling approaches: a critical review." The International Journal of Advanced Manufacturing Technology, 83(1-4), pp.389-405, 2016.

[5] S.G. Sarvankar, and S.N. Yewale, "Additive manufacturing in automobile industry." Int. J. Res. Aeronaut. Mech. Eng, 7(4), pp.1-10, 2019.

[6] K. Rajaguru, T. Karthikeyan, V. Vijayan, "Additive Manufacturing-State of Art", Science Direct, 2019.

[7] S.G. Sarvankar, and S.N. Yewale, "Additive manufacturing in automobile industry", Int. J. Res. Aeronaut. Mech. Eng, 7(4), pp.1-10, 2019.

[8] I.Gibson, D.W.Rosen, B.Stucker, "Additive Manufacturing Technologies", Springer Publications, 2010.

[9] A.S. Elakkad, "3D Technology in the Automotive Industry", International Journal ofEngineering Research and Technology, Vol. 8, Issue 11, 2019.

[10] [Online], Available:https://www.3dnatives.com/en/additive-manufacturing-automotive280620184/

[11] V. Sreehitha, "Impact of 3D Printing in Automotive Industries", Int. J. of Mech. and Pro. Eng., Vol. 5, Issue-2, 2017.

[12] [Online], Available:https://www.popularmechanics.com/cars/a16726/local-motors-strati-roadster-test-drive/

[13] L. Dirk, B. Matthias, H. Axel, J. Eric, "State of Art and Emerging Trends in Additive Manufacturing: From Multi-Material processes to 3D Printed Electronics", MATEC Web of Conference 188, 2018.

[14] Z. CHEN, et al. "3D printing of ceramics: A review. Journal of the European Ceramic Society", PP 661-687, 2019.

[15] X. Wu, F. Mu, en Z. Lin, "Three-dimensional printing of graphene-based materials and the application in energy storage", Materials Today Advances, vol 11, pages 100157, 2021.

[16] S. Thapa, "3D Printing of Automobile Power Transmission System Using Tough PLA", 2020.

[17] A. Menon, B. Póczos, A. W. Feinberg, en N. R. Washburn, “Optimization of silicone 3D printing with hierarchical machine learning”, 3D Printing and Additive Manufacturing, vol 6, no 4, pp 181–189, 2019.

[18] A. Haleem en M. Javaid, “Polyether ether ketone (PEEK) and its manufacturing of customised 3D printed dentistry parts using additive manufacturing”, Clinical Epidemiology and Global Health, vol 7, no 4, pp 654–660, 2019.

[19] INEX-ADAM, Advanced Additive Manufacturing Handbook, 2018.

[20] S. Mamatha, P. Biswas, P. Ramavath, D. Das, en R. Johnson, “Effect of parameters on 3D printing of alumina ceramics and evaluation of properties of sintered parts”, Journal of Asian Ceramic Societies, pp 1–7, 2021.

[21] E. A. Gallagher, S. Lamorinière, en P. McGarry, “Multi-axial damage and failure of medical grade carbon fibre reinforced PEEK laminates: experimental testing and computational modelling”, Journal of the mechanical behavior of biomedical materials, vol 82, pp 154–167, 2018.

[22] M. Calvo, A. E. Jakus, R. N. Shah, R. Spolenak, en D. C. Dunand, “Microstructure and processing of 3D printed tungsten microlattices and infiltrated W--Cu composites”, Advanced Engineering Materials, vol 20, no 9, pages 1800354, 2018.

[23] C. Kenel, J. P. W. Sesseg, N. R. Geisendorfer, R. N. Shah, R. Spolenak, en D. C. Dunand, “3D-printed tungsten sheet-gyroids via reduction and sintering of extruded WO3-nanopowder inks”, Additive Manufacturing, pages 101613, 2020.

[24] D. Gu et al., “Carbon nanotubes enabled laser 3D printing of high-performance titanium with highly concentrated reinforcement”, IScience, vol 23, no 9, pages 101498, 2020.

[25] N. T. Aboulkhair, M. Simonelli, L. Parry, I. Ashcroft, C. Tuck, en R. Hague, “3D printing of Aluminium alloys: Additive Manufacturing of Aluminium alloys using selective laser melting”, Progress in materials science, vol 106, pages 100578, 2019.

[26] M. H. Ali, A. Abilgaziyev, en D. Adair, “4D printing: a critical review of current developments, and future prospects”, The International Journal of Advanced Manufacturing Technology, vol 105, no 1, pp 701–717, 2019.

[27] M. Attaran, "The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing," Business Horizons, 60(5), pp. 677-688, 2017.

[28] S. Ford and M. Despeisse, "Additive manufacturing and sustainability: an exploratory study of the advantages and challenges," Journal of cleaner Production 137, pp. 1573-1587, 2016.

[29] D. Böckin and A.-M. Tillman, "Environmental assessment of additive manufacturing in the automotive industry," Journal of Cleaner Production 226, pp. 977-987, 2019.

[30] M. K. Niaki, S. A. Torabi and F. Nonino, "Why manufacturers adopt additive manufacturing technologies: The role of sustainability.," ournal of cleaner production 222, pp. 381-392, 2019.

[31] S. G. Sarvankar and . S. N. Yewale, "Additive manufacturing in automobile industry," Int. J. Res. Aeronaut. Mech. Eng 7.4, pp. 1-10, 2019.

[32] 18- A. Simonazzi,J.C.Sanginés and M.Russo"The Future of the Automotive Industry", Research gate No.141,2020.

[33] 19- S .Modi., and A.Vadhavkar."Advancing Additive Manufacturing into the Mobility Industry". Center for Automotive Research, Ann Arbor, Michigan,2019.

[34] 20- B .Gangula, P.Illinda, CA.Giffi. "3D opportunity in the automotive industry". Deloitte Univ Press,2014.

[35] M. Razi Nalim, R. Vasudevan, Sameer Rahatekar, Advances in Automotive Technologies: Additive manufacturing product development and automotive applications, (21), pp.135-192,2020

[36] T.S. Srivatsan, T.S. Sudarshan, Additive Manufacturing: Innovations, Advances, Future and Applications, Future of AM in the Automotive Industry.vol.38, pp.215-360, Sept 2019

[37] T Birtchnell, J Urry,A New Industrial Future? AM and automotive Technology, Manufacturing technologies and growth in Automotive industries 18, pp.15-120, Feb 2020

[38] Jing Zhang, Yeon-Gil Jung, Additive Manufacturing Automobile industry: Materials, Processes, parts and Applications, Automotive parts and production 102, pp. 1023-1581, 2019.

[39] E. Beehler, M.Hofmann, and A. Hurst, 3D Printing in the automobile industry, "Additive manufacturing technologies and Advance development vol. 8, pp. 1–28, Mar. 2016, DOI: 10.1145/2870640

[40] M. B. Hoy, "3D printing: making things future," Future growth of the automobile industry", vol. 32, no. 1, pp. 94–99, 2018

[41] M. Yarwindran, and P. Ravivarma, The Future of Additive Manufacturing: An Exploratory Study "AM's role in boosting productivity and growth" vol. 13, no. 1, p. 201-287, 2020

[42] W. Jo, J.H. I, R.A. Harianto, J.H. So, H. Lee, H.J. Lee, M.-W. Moon, Introduction of 3DPrinting Technology in the industrial sector, J.Vis.Impair. Blind. 110 (2016)115–121.