ENHANCING 3D PRINTING THROUGH MATERIAL SELECTION

[1]V. Krishna Vamsi,[2]J.Lokesh,[3]K.Durga Pavan Kalyan,[4]A.Jaya Kiran Gopal,[5]K. Thanveer,
[6]Kona Ram Prasad.

[1, 2,3,4,5]Students, Department of Mechanical Engineering, N. S. Raju Institute of Technology, Affiliated to JNTUGV, AP, INDIA
[6]Assistant Professor, Department of Mechanical Engineering, N. S. Raju Institute of Technology, Affiliated to JNTUGV, AP, INDIA

Abstract

Additive manufacturing (AM) has revolutionized industries by enabling the layer-by-layer 3D printing of objects. Among the diverse materials employed in AM, polymers and their composites hold significant importance due to their wide-ranging applications in fields such as medicine, aerospace, and automotive engineering. Extensive research efforts have been dedicated to developing advanced polymer materials tailored for various AM techniques, encompassing vat photo-polymerization, material jetting, powder bed fusion, material extrusion, binder jetting, and sheet lamination. While previous reviews often focus on specific aspects, this comprehensive review offers a holistic overview of polymer material advancements in AM. The review explores notable breakthroughs in newly developed materials and their potential applications. Furthermore, it outlines the existing challenges in utilizing AM for polymer materials and identifies promising opportunities, aiming to stimulate further progress in this dynamic and transformative field.

Keywords:*Polymers,Composites,Vatphoto-polymerization,Additivemanufacturing,Powder bed fusion, Material jetting,Binder jetting,sheet lamination.*

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1. INTRODUCTION

The advent of 3D printing, also known as additive manufacturing, has truly revolutionized modern manufacturing, design, and prototyping. It has ushered in an era characterized by unprecedented freedom, enabling the creation of intricate geometries and swift iteration of prototypes. As we witness the rapid evolution of 3D printing technologies, it becomes increasingly evident that its applications span across a myriad of industries, including aerospace, medicine, architecture, and consumer goods. Yet, concealed within every triumphant 3D printing venture lies a pivotal decision, one that often wields the power to determine the quality, efficiency, and reliability of the entire process: the selection of the appropriate printing material.

In the world of 3D printing, a material is far from a passive entity; it emerges as a dynamic factor that exerts its influence at every stage of the printing journey, sculpting the properties of the final product. The choice of material extends its reach beyond the mechanical and thermal attributes of the printed object; it imparts a measure of durability, defines aesthetics, and even exerts an influence on environmental sustainability. Therefore, the act of informed material selection emerges as the linchpin in the quest to optimize 3D printing performance and bring forth the desired outcomes.

The pages of this research paper are an invitation to embark on a profound exploration—a journey that seeks to unveil the intricate interplay between material selection and the enhancement of 3D printing performance. At its core, our objective is to furnish you with a comprehensive understanding of the ways in which various materials, each endowed with unique properties and attributes, can be tactically chosen to address the specific challenges and objectives posed by 3D printing. We shall navigate the multidimensional realm of material selection, embracing considerations that span from material compatibility and printability to post-processing requirements and the harmonization of material properties with the intended application.

But we aspire to go beyond theoretical elucidation. This paper aspires to be a practical beacon, illuminating the path for practitioners, engineers, and designers. Within these pages, you will discover not only the theoretical foundations of material selection but also practical guidelines and a systematic framework that will empower you with the knowledge and tools necessary to make judicious decisions when selecting materials for 3D printing. As you leverage this framework, you shall find yourself better equipped to satisfy demanding performance criteria, curtail production costs, and minimize the wastage of materials.

Throughout this expedition, we shall draw upon a synthesis of existing research, imbued with the wisdom of real-world case studies and tangible examples. Together, these elements will bestow upon you a holistic perspective, granting you a profound insight into the profound impact that material selection wields in the domain of 3D printing. Our aspiration is that this paper shall not merely be an academic exercise but a valuable resource—a torch guiding both newcomers and experts in the field. It is our fervent hope that it shall kindle within you a deeper appreciation for the pivotal role played by material selection in the pursuit of excellence within the realm of 3D printing.

In the pages to come, we shall venture into the multifaceted world of material selection, unraveling critical considerations, revealing methodologies, and illustrating practical applications. Together, these facets shall coalesce to enhance the performance of 3D printing, unveiling new horizons and possibilities.
This introduction serves as our overture—a prelude to the symphony of knowledge and insights that awaits you in the subsequent sections. It seeks to underscore the significance of informed material selection within the context of 3D printing, and it offers a glimpse into the roadmap of what you may expect to unearth as you traverse this paper's intellectual terrain.

2. METHODS OF ADDITIVE MANUFACTURING (AM)

The classification of the additive manufacturing (AM) involves various sub divisions and categories which primarily include polymerization, solid based, power based. And secondarily extrusion, lamination process, sintering, binding, melting.

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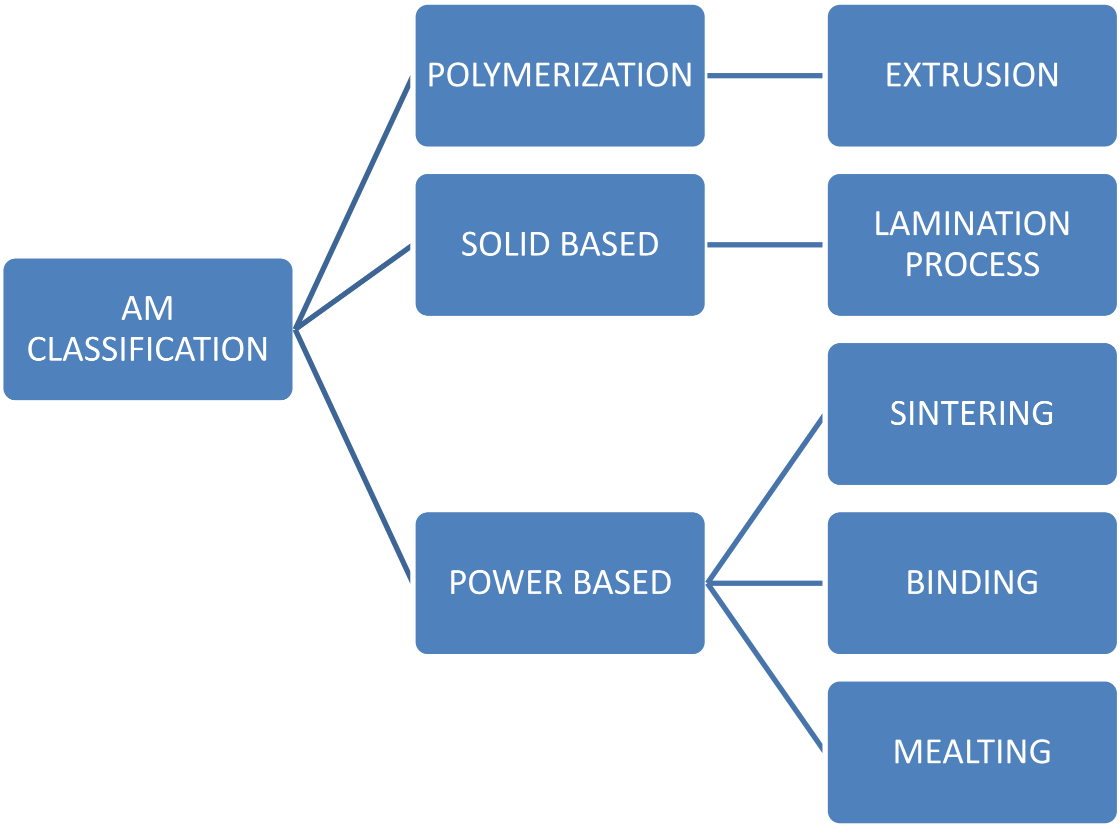


Figure 1: Classification Of (AM) (Source: Google)

2.1 FUSION DEPOSITION MODELING (FDM) METHOD

FDM builds parts by depositing a stream of hot viscous materials onto a base plate or previously deposited material. FDM is a process in which thin thermo plastic filaments or granules are melted by heating and guided by a robotic device .the material leaves the extruder in a liquid form and hardens immediately .the previously formed layers are base for the next layers is kept a temperature below the solidification point of the thermoplastic material. In this method we use polymers like PLA &ABS filaments .we will see the details in elapsed way.

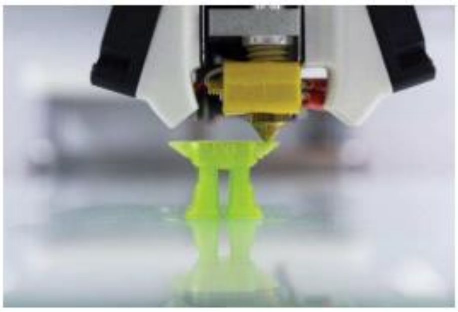


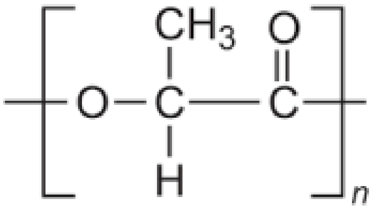
Figure 2: PLA material extruding from the nozzle (Ref.: 1)

3. MATERIALS USED FOR 3D PRINTING TECHNOLOGY IN MANUFACTURING INDUSTRY

Like any manufacturing process, 3D printing needs high quality materials that meet consistent specifications to build consistent high-quality devices. To ensure this, procedures, requirements, and agreements of material controls are established between the suppliers, purchasers, and end-users of the material. 3D printing technology is capable to produce fully functional parts in a wide range of materials including ceramic, metallic, polymers and their combinations in form of hybrid, composites or functionally graded materials (FGMs) .Metals Metal 3D printing technology gain many attentions in aerospace, automobile, medical application and manufacturing industry because the advantages existing by this process [5]

3.1 POLYLACTIC ACID (PLA)

Polylactic acid is a biodegradable and bioactive thermoplastic aliphatic polyester derived from renewable resources, such as corn starch, tapiocaroots, chips or starch, orsugarcane. In2010, PLA had the second highest consumption in the world of ant another bioplastic of the world. The name "polylactic acid" does not comply with IUPAC standard nomenclature, and is potentially ambiguous or confusing, because PLA is not a placid (polyelectrolyte), but rather a polyester.[5]



poly(2-hydroxypropanoic acid)
poly(lactic acid), PLA

Figure 3: Chemical formula of PLA (Ref.: 5)

3.2 POLYMERS

3D printing technologies are widely used for the production of polymer components from prototypes to functional structures with difficult geometries .By using fused deposition modelling (FDM), it can form a 3D printed through the deposition of successive layers of extruded thermoplastic filament, such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polypropylene (PP) or polyethylene (PE). Lately, thermoplastics filaments with higher melting temperatures such as PEEK and PMMA can already be used as materials for 3D printing technology. 3D printing polymer materials in liquid state or with low melting point are widely used in 3D printing industry due to their low cost, low weight and processing flexibility. Mostly, the materials of polymers played important role in biomaterials and medical device products often as inert materials, by contributingto the efficient functioning of the devices as well as providing mechanical support in many orthopedic implants.[6]

3.3 CERAMICS

Nowadays, 3D printing technology can produce 3D printed object by using ceramics and concrete without large pores or any cracks through optimization of the parameters and setup the good mechanical properties. Ceramic is strong, durable and fire resistant. Due to its fluid state before setting, ceramics can be applied in practically any geometry and shape and very suitable on the creation of future construction and building. According to, they said ceramics materials is useful in the dental and aerospace application.[6]

3.4 COMPOSITES

Composite materials with the exceptional versatility, low weight, and tailorable properties have been revolutionizing high-performance industries. The examples of composite materials are carbon fibers reinforced polymer composites. and glass fibers reinforced polymer composite. Carbon fiber reinforced polymers composite structures are widely used in aerospace industry because of their high specific stiffness, strength, good corrosion resistance and good fatigue performance. At the same time, glass fibers reinforced polymer composites are widely used for various applications in 3D printing application.[3]

3.5ACRYLONITRILE BUTADIENE STYRENE (ABS)

ABS is a thermoplastic which become liquefied when heating and harden when cooled down. ABS incorporated with FDM in various method to extend its uses into more areas. Thus, the objective of this is to review the FDM process in detail which includes theoretical aspect of FDM, working mechanism of FDM process, printing parameters and applications of FDM. Addition to that, this paper also reviews the theory of ABS, composites of ABS in use and researched before and their preparation techniques for FDM are also included.

3.6 NYLON

Polyamide, commonly known as nylon, is a synthetic linear thermoplastic polyamide and it is the most widely used plastic material. Its popularity in 3D printing lies in its elasticity, lifespan, its non-sticky nature and its simplicity of upkeep. It is also a fashionable fabric for making clothing and accessories.
Nylon is great for producing complex, intricate shapes. A filament primarily used in FDM (Fused Deposition Modeling) or FFF (Fused Filament Fabrication) 3D printers. This is one of the cheapest materials on the market which at the same time possess a high level of toughness that other plastics can't keep up with.

3.7 STAINLESS STEEL

Stainless steel is printed by fusion or laser sintering. Two possible mechanical processes can be used for this product. This can be DMLS or SLM technology. Since stainless steel is all about strength and detail, it is perfect for use in baskets, bolts and key chains.

3.8 THERMOPLASTIC POLYURETHANE (TPU)

Compared to the many kinds of flexible 3D filaments, TPU filament is more rigid, making it easier to extrude and use. It's a medium strength filament material with very high durability and flexibility and can stand much higher compressive and tensile forces than its common equivalents PLA and ABS.

4. MATERIALS USED IN STEREOLITHOGRAPHY

Stereolithography, as the term itself describes, is a method of visual manufacturing in which UV rays are applied to liquid monomers, also known as photopolymer resin, to bind them together to form a polymer (they can be combined together) and then these polymers layer together The layers are solid in order to achieve the desired pattern. In a process called photopolymerization, SL uses an ultraviolet laser to curate a liquid resin into a hard plastic layer Stereolithography includes additives such as stabilizers, flexibilities, monomers/oligomers, solvents, photo-initiators, and reactive diluents, etc. Table 1 Combined groups, materials and their properties and applications.

Materials	Properties	Applications/ Industries
DC 100	Lesser shrinkage with higher accuracy.	Used for the casting of patterns for pieces of jewelry.
DC 500	Like wax in nature and can easily burn out.	For the making of precise and thinner wire patterns of jewelry which can't be easily copied using methods for molding rubber.
DL 350	Highly flexible and resistant to fatigue and chemicals etc. Similar to polypropylene.	Used to produce parts for industrial as well as general purposes.
DL 360	Strong and transparent in nature.	Produces parts for general purposes and industrial uses which require transparent properties.
AB 001	Provides good strength and stiffness and electrical characteristics.	Used for producing parts that are strong and smooth in nature.
GM 08	Highly flexible, strong and elastic, along with transparency comprises its nature.	Produces parts that don't require further finishing operations.
DM 210	Great surface qualities and including ceramic-type properties.	Used for jewelry patterns that require liquid silicone that can be extracted quite easily from rubber.

***Table 1: Materials used in stereolithography.* [4]**

Pros:

- Excellent surface finish.
- Easy production of complex parts.
- High precision.
- Great thermal durability.
- Can be used as casting patterns.

Cons:

- Slow due to limited laser exposure.
- High initial setup cost.
- Challenges with overhanging parts.
- Handling photosensitive resin can be tricky.

5. MATERIALS USED IN FUSED DEPOSITION MODELING

Other notable properties of these materials include resistance to UV radiation, durability, transparency and biocompatibility. This is a widely used AM technique that requires the use of continuous cables using heating elements as inputs. Table 2 details the characteristics and applications of several material groups and their examples.

Material class	Materials	Properties	Applications
Thermoplastic Polymer	Polylactic acid (PLA), Acrylonitrile butadiene styrene (ABS), ABSi, High Density Polyethylene (HDPE), Polyphenylsulfone(PPSF), Polycarbonates (PC), Polyethylene terephthalate glycol-modified (PETG), Ultem 9085, Polytetrafluoroethylene (PTFE), Polyether Ether Ketone (PEEK), Recycled Plastics, Acrylonitrile Styrene Acrylate (ASA), Nylon 12, etc.	Properties associated with this include toughness and strength, UV stability, good chemical resistance, and high fatigue resistance along with the high impact strength. They possess high tensile and flexural strength etc.	Because of their great thermal resistance properties, they are suitable for aerospace and aerodynamics application.
Polymer Matrix Composites	Glass Fiber Reinforced plastic (GFRP), Carbon Fiber Reinforced Polymer (CFRP).	Compatibility with toughness, ductility, yield strength, etc.	Constructional applications.
Ceramic	Alumina, Zirconia, Kaolin.	Chemical and physical	General purpose

Slurries and Clay		stability, heat resistance, and compatible thermal conductivity, strength and hardness.	uses along with the applications in dental field as well.
Green Ceramic/ Binder Mixture	Zirconia, Calcium phosphate.	Resistance to chemicals and corrosion, great compatibility with respect to fracture toughness, hardness, wear-resistance, and thermal resistance good frictional behavior, lower electrical and thermal conductivity and non-magnetic in nature etc.	Structures suitable for bone substitute scaffolds [19], and for making piezoelectric components.
Green Metal/ Binder Mixture	Stainless steel, Titanium, Inconel.	Providing binder viscosity, flowability, greater sintered density, leads to the homogeneous microstructure of parts. Results in strong, light and corrosion resistant properties etc.	For the manufacturing of mechanical parts used in tooling and fixtures etc.
Food pastes	Sugars and Chocolates	Flowability	Cooking

Table 2: Materials used in fused deposition modeling. [5]

Pros:

- Good surface finish.
- Lower initial cost.
- Can create complex shapes.
- Minimizes material waste.
- Offers flexibility.

Cons:

- Relatively slow.
- Quality not as high as SLA or SLS.

6. MATERIALS USED IN SELECTIVE LASER SINTERING

This method uses a laser as a power source for sintering a granular material (usually polyamide or nylon), as detailed in a three-dimensional model in which the laser itself is directed to predetermined locations in space, binding materials together make it a complex system. This is comparable to Selective laser melting (SLM) which works on the same principle but requires different mechanical conditions. This laser is used on powders with low melting or sintering temperatures, and on the other hand liquid binders are used alternatively. SLS is used with various polymers, alloys and metal powders while for some metals such as steel and aluminum, SLM is generally used Table 3 provides a comparative analysis of the components involved in in this process shows.

Laser	**Materials**	**Properties**	**Applications**
CO2/N2	Polymers including Polyamides , Polycarbonates, Polystyrene (PS), Thermoplastic Elastomer (TPE), Polyaryletherketone (PAEK)	Characterized by an ideal sintering behavior like a semi-crystalline thermoplastic , high toughness, thermal stability, etc.	Prototype making in the early design process, automobile parts, hardware, etc.
Nd:YAG	Ceramics	Great hardenability, mechanical strength, better thermal and chemical stability, and usable thermal, electrical, optical, and magnetic characteristics.	Aeronautics, biomedical, metallurgical application.
Yb-Fiber	Glasses such as fused Silica, Borosilicate Glasses.	Chemical resistance, thermal stability, etc.	Glass filters, medical and chemical field.
	Metals	Good thermal conductivity hence, used in case of selective laser melting	Varied applications in various industries.

Table 3: Materials used in selective laser sintering. [6]

Pros:

- Suitable for complex parts.
- No need for external support.
- Ideal for mass production.
- High accuracy.

Cons:

- Higher manufacturing cost.
- Requires post-processing.
- Challenging with large surfaces and tiny holes.

7. MATERIALS USED IN POWDER BED FUSION

Method Powder in fine layers of quiescent fine particles, dispersed and tightly packed on the platform PBF is a fast-manufacturing method in which heat source for example laser is used to initiate partial or complete melting between powder particles and includes | Examples of PBF methods are the SLS process, the electron beam melting (EBM) method, and the selective laser melting (SLM) method. The products, features and services included in PBF are outlined below.

Materials	Properties	Applications
Titanium (Ti)	Resistance to Corrosion and thermal expansion with great biological compatibility, along with the high strength and lower density.	Its applications are included in but not limited to design, medical, automotive, aerospace, marine industry, and jewelry industries, etc.
Stainless Steel	Increased resistance to wear and tear, corrosion, along with compatible ductility, hardness, and hardenability.	These materials have extensive application in automotive industry, maritime and medical technology, toolmaking and in varied areas of mechanical engineering.
Aluminum (Al)	Light metal with lower density and better electrical conductivity along with alloying properties and easy to process abilities.	These components are used in aerospace engineering, automotive industry, in the area of prototype construction, marked with complicated geometries.
Cobalt-Chrome	Biologically compatible, with increased hardness, corrosion resistance with comparable strength and ductility.	In the medical and dental field, and industries requiring greater thermal resistant properties for example in jet engines.
Nickel based alloys	Great weldability and hardenability along with the resistance to corrosion and outstanding mechanical strength.	Used in aerospace engineering and fields requiring thermal resistant properties also have applications in tool making.

Table 4: Materials used in powder bed fusion [7]

Pros:

- Cost-effective.
- No need for external support.
- Wide material selection.
- Recyclable powder.

Cons:

- Often requires post-processing.
- Materials may have weaker structural properties.
- Time-consuming.

8. MATERIALS USED IN BINDER JETTING

Binder jet AM systems also known as "Powder bed and inkjet" & "drop-on-powder" printing. Examples of their content are summarized in Table 5 below.

Materials	Properties	Applications
Stainless steel	Resistant to heat and corrosion with greater tensile strength.	Used for parts of pump, drilling and mining machinery.
Ceramic beads	Highly permeable as well as better thermal properties.	Steel alloys are casted using this and can also be used for printing of cores that have to bear high met allostatic forces and subsequent stress conditions during casting.
Inconel alloy	Supplementing the product with good mechanical properties and even greater density.	Used for the manufacturing of gas turbine blades, for producing steam generators used in pressurized nuclear water reactors, seals and also in pressure vessels, these are widely applicable in the aerospace industry.
Iron	Provides better mechanical properties and is also excellent wear resistant.	Applications are in the production and repairing of automotive components, tooling, and also in machine tools, along with this they are also popular in decorative hardware.

Table 5: Materials used in binder jetting [8]

Pros:

- High resolution.
- Excellent surface finish.
- No post-processing required.
- Large-scale printing possible.
- Multiprinting capability.

Cons:

- Limited material choices.
- Lower part strength.
- Requires a substrate for printing.

9. MATERIALS USED IN LAMINATED OBJECT MANUFACTURING

Two basic methods of sheet stripping are described as follows, firstly so that this process laser cuts sheets using materials and process known as Laminated Object Manufacturing (LOM) or secondly these sheets are inserted using ultrasound and a process described as ultrasonic additive manufacturing (UAM). do. The following tables are some of the products and their characteristics and end uses.

Materials	Properties	Applications
Polymer	Good thermal conductivity, adhesive bonding.	Paper industry.
Composites	High modulus, low density, excellent resistance to fatigue, etc.	Paper industry etc.
Ceramics	Chemical and physical stability, resistance to heat, and compatible thermal conductivity, strength, and hardness.	Foundry and forging industries.
Paper	Good conductor of electricity.	Electronics industry.
Metal Rolls	Better mechanical properties.	Applicable in smart structures.

Table 6: Materials used in laminated object manufacturing [9]

Pros:

- No need for external support.
- Cost-effective.
- Quick process.
- Suitable for large parts.

Cons:

- Requires post-processing.
- Limited dimensional accuracy.
- Subpar surface finish.
- Complex parts pose challenges.

10. MATERIALS USED IN DIRECT ENERGY DEPOSITION

In one important respect, the operational concept of the DED system differs from that of PBF in that a strong and powerful laser is focused on continuous powder materials embedded in the material itself than if a preloaded metal powder is applied the following table gives a comparative analysis of 8 materials and their properties.

Materials	Properties	Applications
Titanium	Resistance to corrosion and thermal expansion with great biological compatibility, along with high strength and lower density.	Used for repairing works in the automation and aerospace industry.
Aluminum	Light metal with lower density and better electrical conductivity with alloying properties and easy to process abilities.	Filling of cracks and refitting of manufactured parts.
Stainless steel	Resistant to heat and corrosion with greater tensile strength.	Repairing of turbine engines, and other such complex applications.
Copper	Malleable, ductile, and better surface finish.	Industrial applications.
Inconel, Ceramics	Good mechanical properties and greater density.	Aerospace, biomedical applications.

Table 7: Materials used in direct energy deposition [10]

Pros:

- Allows denser part creation.
- Enhanced features with directional solidification.
- Effective for repairs and refurbishing.

Cons:

- Time-consuming.
- Lower resolution and surface finish.
- Limited material options.

11. CONCLUSION:

It was observed that the rerun column bottom stream temperature has greater effect on the linear alkylbenzene yield than the temperature variation of the top stream. At higher temperature of both streams, lower percentage yield of average wt. % of linear alkylbenzene was obtained with that of the top stream being the lowest at 87.5% as against 93.3% for the bottom stream. The highest linear alkylbenzene yield of 99.4%was recorded at bottom stream temperature of 280^{o}C and pressure of 115Kpa.

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