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Application of Polymer and Biomaterials for 3d Printing Technology: Review

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Abstract: Polymer and biomaterial 3D printing is an innovative technology that can construct any 3D entity by depositing material layer by layer with current research interpreting towards enlarged use in the medical sector. The different materials like concrete, ceramic, metals, and polymers are usually used for 3D printing. With the purpose of making 3D printing sustainable, scholars are working on the use of diverse bio-derived materials for 3D printing. Polymer and biomaterial printing is beneficial in the medical sector because it empowers the 3D printing of affordable functional parts with good properties and proficiencies. In this review, we highlight current research developments for biomaterial and polymer printing using Fused Deposition Modeling (FDM) for the medical sector. Explicitly, the composition, characteristics, and properties of bio-polymers are discussed. Further, the application of bio-polymers in the medical sector like dental implants, drug delivery systems, and safety equipment and polymers containing bio-fillers are discussed too.
Keywords: Polymer, Bio-material, 3D printing, Dental implants, Safety equipment.

I. INTRODUCTION

Additive manufacturing (AM), is transforming manufacturing technology implemented in different areas for example automotive, research, aerospace, medical, architecture, and food industries. FDM printing is an extremely necessary fabrication method because it enables the structure of designs with compound geometries and constructions that are not possible with the conventional manufacturing processes such as milling, grinding, and machining. This disadvantage of conventional manufacturing is overcome by Additive manufacturing as it fabricates extremely compound parts by adding the materials layer by layer with the least waste materials. Divergent to other conventional methods for example compression and injection molding, the 3D printing procedure does not need molds for constructing parts, which outcomes in cost and time savings. Even the AM has many advantages over conventional manufacturing processes whereas the anisotropic nature of 3D printed parts, low mechanical properties of 3D printed parts, and limited convenience of materials bound its application in various industries. For occurrence, tissue scaffold erections made-up of poly jet and stereolithography (SLA) 3D printing process can accomplish hierarchical arrangements that mimic bone, thereby providing a biological and mechanical niche to support tissue revival [1], [2]. Moreover, the choice of polymers has advantages over metal printing methods, which affect metal implantations of the body that don't degrade in the human body and leads to mechanical issues like stress shielding [3]. For safety equipment, polymer 3D printed lattice can accomplish efficient energy absorption with a quick fabrication procedure that circumvents the supply chain boundaries of high volume manufacturing [4], [5].

II. MATERIAL STRUCTURE

There are a wide range of polymers used for additive manufacturing, with proficiencies well-versed from their molecular construction, with polymers managed in diverse conducts for the individually printing process. During extrusion processes through the nozzle, thermoplastic resin is frequently used for 3D printing where they are liquefied for extrusion followed by toughening after deposition [6]. The Acrylonitrile styrene acrylate material is a substitute to Acrylonitrile butadiene styrene with better exceptional mechanical properties and heat resistance properties, while PLA is an additional common thermoplastic with biocompatibility but a lesser glass conversion temperature [7]. The properties of Acrylonitrile butadiene styrene are accommodated on the relation of its four monomers, for illustration, its mass may range from 1.5 mg/m^3 to 1.7 mg/m^3 with consequential tensile from 2.2 GPa to 2.6 GPa. For instance, ABS is a common thermoplastic that displays favorable tensile strength and better chemical resistance properties compared to polystyrene [8]. Nevertheless, when appropriately 3D printed and processed, thermoplastic resin curative processes are confirmed as safe for medical uses, dependent on the specific grouping of chemical apparatuses [9]. These contemplations for relating the chemical construction of a polymer to its working and 3D printing are vital in combination printing processes with materials to accomplish a anticipated set of polymer properties for a detailed application.

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III. MATERIAL CAPABILITIES

Material capabilities of 3D printing materials are well-versed by their molecular constructions, and also depend on a material's dispensation during printing. Properties of 3D-printed parts are reliant on their material construction and printing method, and therefore need widespread testing of groupings of material/3D printing parameters to regulate material abilities for a given uses [10]. For occurrence, a part's mechanical retort when made up with FDM is adaptable based on the 3D printed layer width, extrusion temperature, and build angle [11], [12]. The below-given Table 1 provides the summary of restrained mechanical properties of nearly mutual polymer 3D-printed materials established as solid samples. Supplementary proceedings in the table provide background for how testing was carried out to deliver a range of mechanical properties. Material properties contain strength and stiffness associated systems of measurement that are key properties for choosing appropriate materials for mechanical uses.

Table 1 Measured part properties systematized by material

Materials	Measured Properties	Manufacturing Technique	References
Acrylonitrile butadiene styrene (ABS)	Tensile Strength: 25–35 MPa; Elastic Modulus: 1310–1520 MPa; Orientation angle of 0° to 90°	FDM	[11]
Acrylonitrile butadiene styrene (ABS)	Tensile Strength: 25–35 MPa; Layer Width: 0.06–0.12 mm; Nozzle temperature: 200–250 °C	FDM	[12]
Acrylonitrile butadiene styrene (ABS)	Tensile Strength: 32 MPa; Elastic Modulus: 1200 MPa	FDM	[13]
Polycarbonate (PC) and Biomaterial blend	Tensile Strength: 25–55 MPa; Elastic Modulus: 2100 MPa; Nozzle Temperature: 210–240 °C; Orientation angle of 0° to 90°	FDM	[12]
Polycarbonate (PC)	Tensile Strength: 27 MPa; Elastic Modulus: 1500 MPa	FDM	[13]
Polyethylene terephthalate glycol (PETG)	Tensile Strength: 46–60 MPa; Layer width: 0.04–0.1 mm	FDM	[11]
Polycarbonate (PC) and Fossil-fuel blend	Tensile Strength: 28–62 MPa; Elastic Modulus: 1300–1500 MPa; Orientations of 0° to 90°	FDM	[12]
Polylactic acid	Tensile Strength: 265 MPa; Yield Strength: 205 MPa; Elastic Modulus: 4400 MPa	FDM	[14]
Nylon	Tensile Strength: 45–50 MPa; Elastic Modulus: 1250–1350 MPa	Multi-jet fusion	[15]
Acrylic-based material	Elastic Modulus: 1750–2000 MPa; Orientations of 0° to 60°.	Polyjet	[1]
Epoxy-based material	Tensile Strength: 25–45 MPa; Elastic Modulus: 2000–2300 MPa	Stereolithography	[16]

The Table 1 shows numerous research are described for assessments of ABS materials that all established analogous, but a little different mechanical properties [11]–[13], such as tensile strength ranging from 25 MPa to 35 MPa. These variations are described for in part because of the different processing temperatures and 3D printing parameters used to fabricate the part, the little diverse scopes of monomers in ABS's construction, and the tested part's orientation angle. For occurrence, the small tensile strength quantity of 25 MPa for ABS was payable to testing in the slanting loading way associated with the higher capacities of tensile strength nearer to 35 MPa based on the orientation angle. Same changes were detected for polycarbonate based on their handing out and chemicals used to make the material [11], [13]. Single research determined that a combination of polycarbonate denoted as a biomaterial blend polycarbonate had a little high strength of 55 MPa and a little high elastic modulus of 2100 MPa than a polycarbonate mass-produced using fossil fuels with 62 MPa strength and 1500 MPa elastic modulus [12].

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IV. MATERIAL PROPERTIES

There are various material properties required by the medical sector that are reachable through 3D printing. Frequently, medical applications purpose the necessity for exact material capabilities, such as the essential for energy-absorbing material in impact resistance parts with appropriate surfaces for modeling medical anatomies, or definite material properties to mimic organic tissues. The Figure 2 shows a new study in medical polymer materials with an emphasis on mechanical capabilities for toughness [17], [18] and flexibility [19], [20], genetic capabilities for biocompatibility [1], and further capabilities such as electrical conductivity [10], [21].

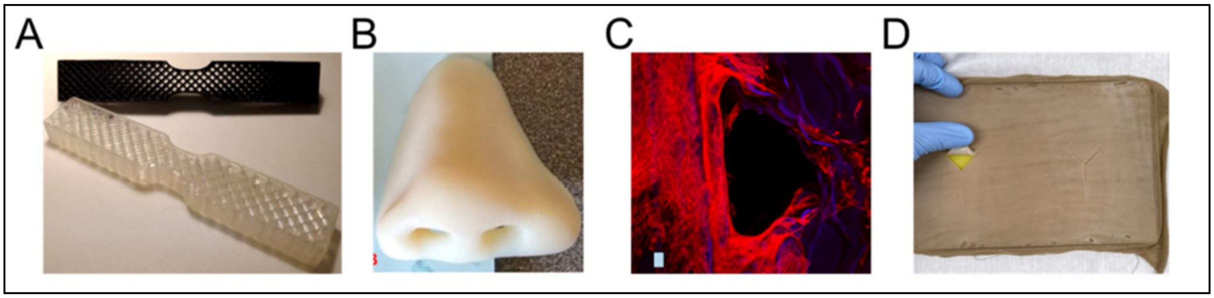

Figure 1 Properties for (A) toughness, (B) flexibility, (C) biocompatibility, (D) conductivity *[22]*

Electrical conductivity is an additional material property that is valuable for the medical sector and has been used for made-up, organic tissue analogues over the 3D printing of an organ. The technology was used to create a suture physical activity pad made-up of entrenched piezoresistive strain sensors and electrodes to measure the performance of a trainee (Figure 1D) [23]. Production steps encompassed setting nylon fabric to the bottommost of a PLA mold, then torrential and curing skin-coloured liquid, inserting electrodes into the 3D-printed organ, encapsulating sensors, adding the overweight layer, and cutting the suture pad. More polymer electric conductivity is demonstrated with thermoplastics mixture with conductive carbon fillers for 3D printing a rookie that enables turning on an LED light [21]. These additive manufacturing capabilities allow innovative types of design applications that could offer a response in different medical situations through surrounding sensors in invented designs, perhaps actuating when convinced mechanical triggers are stretched.

The Toughness material property denotes to its ability to absorb energy and buckle without fracturing, which is planned from a mixture of the material's strength and ductility. Newly, a 3D-printed tensile bar with crosshatch constructions was printed from a polyurethane material with contrasts including actually cross-linked Carbothane in pellet form and cross-linked polyurethane by 68-A hardness in molten resin form (Figure 2A) [17]. Outcomes confirmed elastomeric polyurethanes are comparatively lenient of architectures and notches, which also endorses their use in a diversity of design. A more specimen of toughness for bio-polymer was demonstrated with a methacrylic polymer 3D printed using the resin with the universal tensile strength of 42 MPa and a general elongation up to 55% before contravention [18]. The substantial was used for 3D printing the coupling for an assemblage without any before-treatment essential due to the high correctness of the printing process.

The flexible materials are erected newly that are beneficial as prosthetics, and permit the optimization of a detailed form for a person's exceptional functioning through scanning and suitable technologies (Figure 2B) [20]. The interested of patient for the research was 28 years old and had a topographical scan of their look that used 3D mapping software to print a nose shape using an FDM printer with Tango Plus flexible material. The Tango Plus material had a 24 to 26 hardness, 0.6 to 1.2 MPa strength, and 3 to 5 kg/cm resistance, while having a feel same as rubber. Flexible materials were used to print compound constructions, such as an Eiffel tower model printed with temperature stimulated flexible material printed using SLA [19]. The model twists at low temperature and as the temperature increases by 75 ◦C, the print recovers its novel form. This temperature reliant on functionality provides options for medical uses with heat-originated actuation, which could be started by body heat.

Biocompatibility is an important property for reproduced devices that cooperate with the human body, such as hearing aids, for example, non-natural joints or skin scaffolds. Dependent on the application, biocompatibility can have contradictory standards, but usually denotes to the need for the material to do not damage to the body while enabling its proposed role. For skin scaffolds, biocompatibility characteristically refers to a need for non-cytotoxicity, degradability, and elevation of tissue growth. Polyjet printing generally uses MED610 material, which is an acrylic-based material that has newly had an achievement for printing skin scaffolds of compound topologies (Figure 2C) [1].

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Organic testing was directed by measurement of cell feasibility using Saos-2 cells that lived, with no change between the 3D-printed materials and controls after 48 hours. Additional testing established development on skin scaffold surfaces; yet, the development was partial compared to other tissue engineering materials. An another method is the use of stereolithography for 3D-printed matrices using PLA that can dependably form matrix structures with microscale structures [24]. Supplementary testing is essential to regulate the assistances of 3D-printed polymers to traditional tissue engineering methods; however, polymers offer instant benefits over metals due to their capability to degrade safely in vivo.

V. MEDICAL APPLICATION

The consideration of material structure, material capabilities, and material properties enables personalized 3D printed part production, which is predominantly helpful for the medical sector. Throughout this section, we study how recent developments in polymer 3D printing are allowing new abilities in medicine as described below.

A. Dental Implants

Around 276 million people worldwide suffer from tooth injury and could get assistance from new solutions from dental implants [25]. The advent of 3D printed polymers has provided inexpensive and precise dental implants. In these treatment procedures, 3D-printed polymers, such as PLA, are made-up and fixed in an oral cavity since they are resilient against impact and are non-toxic [26]. The 3D-printed polymers as well have slight surface roughness, which is helpful meanwhile surface roughness endorses biofilm development that attracts destructive bacteria to the implant [27]. Figure 2 determines a polymer dental cast using poly jet 3D printing from a research that compared 3D printed dental casts to those made of dental stone; the 3D-printed belongings were examined with numerous printing techniques and materials [28]. Results confirmed that poly jet and SLA printing techniques providing precisions comparable to traditional dental stone implants, with alterations of means in dimensions on the x, y, and z axis being usually less than 14 µm for the finest prints. 3D-printed polymers are applied as crowns and bridges for temporary and fixed dental repair. 3D printed crowns and bridges deliver a little number of inner discrepancies while similarly providing precise occlusal fits [27]. Beforehand, metal implants were used as changeable denture components and contexts, but just, PEEK polymers have substituted metals because of their good mechanical resistance with high biocompatibility [29]. Newly, scholars and medical experts have developed and effectively implanted a patient with precise 3D-printed biopolymeric tooth [30]. The tooth was tailored to the patient and provided more benefits of being high quality and low cost.

Figure 2 Dental Implant *[28]*

B. Drug Delivery Systems

The 3D printed drug delivery system permits the production of drugs for patient requirements, unchanging drug delivery, and drug holding material production [31]. A 3D printed polycaprolactone and tricalcium phosphate engagement have verified that micro-architecture affects drug delivery efficiency [32], [33]. In vitro research validate that these drug delivery concepts are resistant in contradiction to Gram-positive and Gram-negative bacteria, although possibly delivering an advanced percentage of the incorporated drug to the body. A Drug delivery is correspondingly possible through the application of 3D prints outside of the body. Figure 3 shows a 3D-printed micro needle that drives drugs straight through the skin for circulation in the body [34]. These drug delivery methods normally remain pain free whereas endorsing well-organized transport that needs sophisticated geometric construction at a micro level permitted by 3D printing. The micro needles are made-up of a tip width between 63 and 80 µm, a pitch of 750 µm, and heights between 410 and 480 µm. The Polymeric 3D printing is too applied for producing drug delivery arrangements with multi active dose forms [35], time-custom-made tablets [36], and layer capsules [37].

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The technology is verified for tailored drug delivery systems that can regulate the release rate, drug mixture, and dosing pauses [38]. Medicating necessities vary in patients based on their biological functioning, which inspires personalization to improve patient retorts. The 3D printed polymeric micro and nano capsules endure steady in the fluid suspension and organic fluids that recover drug efficacy [39], thus inspiring their usage for controlled drug release.

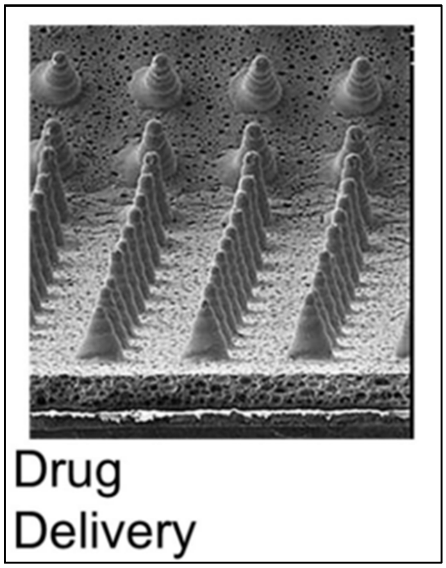

Figure 3 Drug Delivery *[34]*

C. *Safety Equipment*

In 2020 COVID-19 epidemic has raised the standing of polymer 3D printed safety equipment, as the traditional safety equipment source was insufficient in certain areas when the essential for personal protection kits massively surpassed demand. The Polypropylene 3D printed unit filters and masks were projected as a substitute source to help fulfill the demand and avoid supply chain matters [40]. Furthermore, in one research, a 3D printed ventilator was industrialized using TPU, ABS, and PLA materials [5]. This ventilator was ecological, easy to clean, and usable with a subjective number of filtration systems. Figure 4 shows a 3D printed helmet for use as personal protection kit [4]. The main helmet module fits in a breathing filter with a traditional safety helmet to provide an effective means of producing safety equipment locally. The researchers has confirmed that 3D printed construction materials are usable as liners for protection from head damages and offer helpful energy absorption performance [41]. Helmet liners achieve well for the multi-impact freight that is normally experienced through motorcycle accidents [42]. The Helmet testing has shown that the liners can accomplish standards for impact testing, while design differences in hole sizes provide tuning for best performance.

Figure 4 Safety equipment *[4]*

VI. CONCLUSION

This review paper for the application of polymer and bio materials for 3D printing technology concludes that how material structure, material capabilities, and material properties affect application performance, thus dictating engineers to wisely consider all aspects of configuring parts. The current study has proved a diversity of polymer materials with wide-ranging properties conferring to 3D printing processing parameters. Material capabilities allow the focused placement of materials to achieve better performance with formations such as multi-material structures. Because of the difficulties involved in all factors that influence application performance, it is suggested that scholars conduct more experiments considering the relations of materials and process, while developed new practices to handle decision making and configuration for applications. Inclusive, developments in 3D polymer printing have proved numerous successes for implemented designs, with an essential for sustained research to fully influence the technology for extensive applications in engineering and medical.

VII. ACKNOWLEDGMENT

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VIII. CONFLICT OF INTEREST

No Conflict of Interest has been found between the authors of this article.

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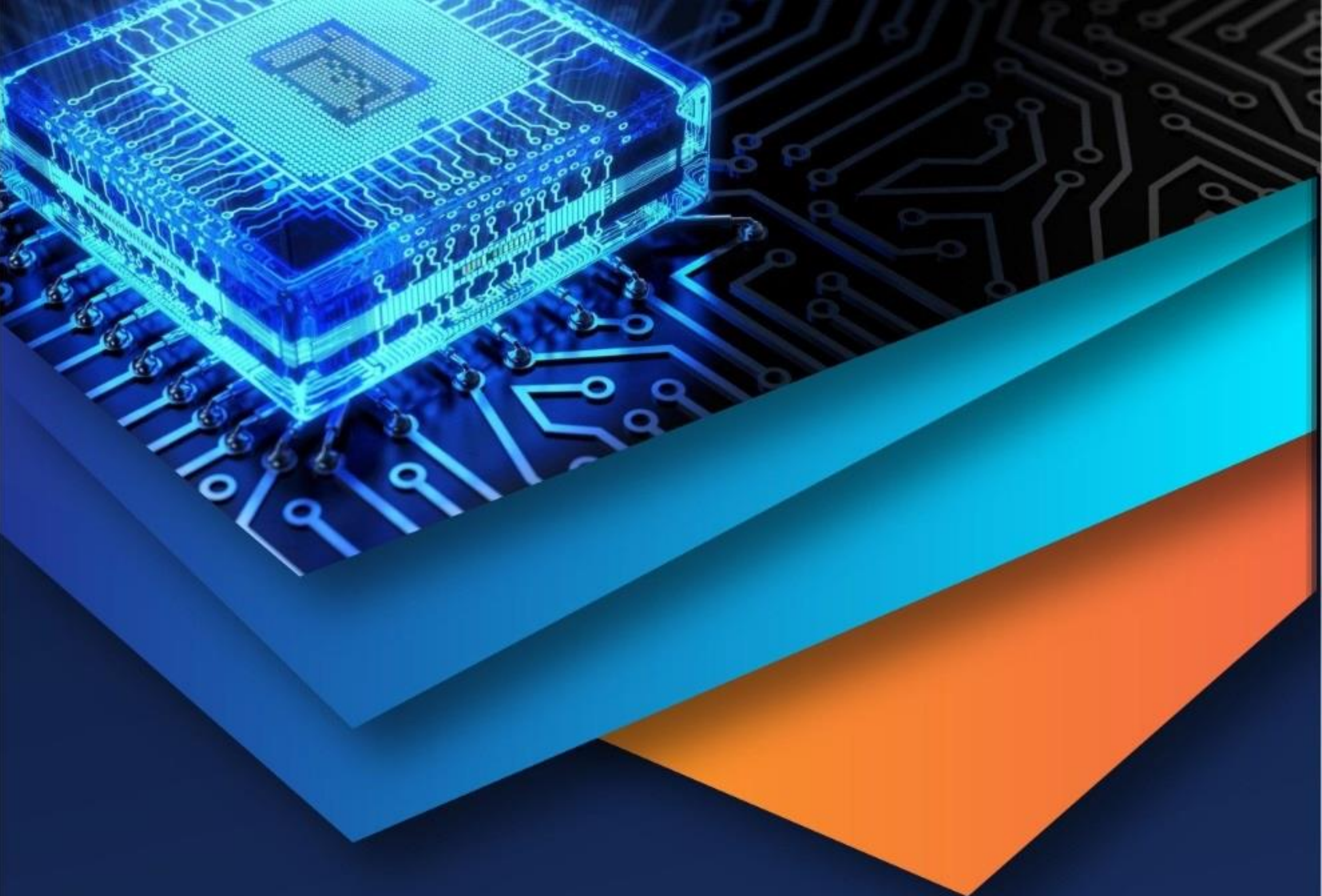

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