International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 12, Issue 12 [December. 2023] PP: 107-112

Basics of Conductive materials for FDM 3D printing

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ABSTRACT: *Current active manufacturing systems use a large number of materials. It is a wide range of materials that have different properties. They differ in strength, composition and other specific properties. Conductivity can also be included among such specific properties. Although in the case of FDM technology it is thermoplastics that are insulators, it is also possible to find conductive materials on the market, i.e. those that can conduct an electric current, or the conductivity of such materials is used in another way.*

The following article provides basic information in the field of conductive materials, what materials are used and what the system is for ensuring the conductivity of materials.

Date of Submission: 13-12-2023 Date of acceptance: 28-12-2023

I. INTRODUCTION

Fused Deposition Modelling (FDM) builds the geometry by material extrusion technology, a common and widely applied technique of Additive Manufacturing. Thermoplastics are the feed material to this technology.In FDM, to create a geometry by printing layer upon layer, at first everything must work in a synchronized way to get the job done. A special software is used to bridge the communication between various mechanical systems. This software decides and controls various parameters such as nozzle temperature, bed temperature, layer thickness, direction and movements of both printing head and platform to produce accurate model with highly finished geometry [1].

In Fused deposition modelling, the thermoplastic filament is heated to its melting temperature at the nozzle with the help of a heated coil surrounding the nozzle to transform the material to a suitable molten state. This liquid material flows out of the nozzle following the layers of the geometry to print it. These layers will be decided by the slicing software. The extrusion material thickness will be determined by the layer thickness of each layer for printing. As each layer is done, the extruder head moves up to print the next set of successive layers. The adhesion of layers is defined by the layer thickness which means that the layer tends to adhere strongly if the surface area is sufficiently more. Once the molten material leaves the nozzle it solidifies. If they are not properly solidified it creates warping which is a huge concern for FDM thermoplastics which in turn reduces its mechanical strength [2]. cost effective, variety of materials, less time consuming and accessibility are the key benefits to FDM technology. On the other hand, it often tends to result in ribbing, warping and poor mechanical strengths.

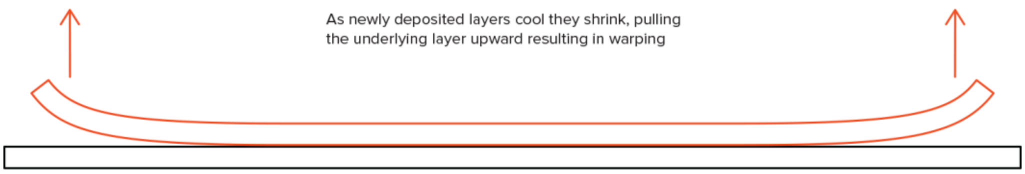

Fig - 1: Warping [3]

Pre-Processing.

The foremost step of FDM technology is to slice the whole 3D geometry to finite number of layers and generate G code for the tool movements. It is practically done by slicing software such as simplify 3D, Cura etc. This software slices the geometry to specified layer heights mentioned in the processing settings. Normally, the slicing or layering height ranges between 0.125mm and 0.30mm.

Geometry production.

If everything seems perfect to print the geometry, print option could be selected to initiate the layering process. In case of printing for two material geometry i.e., one primary material and other for support structures, dual extrusion nozzle should be used. Else single extrusion nozzle could be used.

Post-Processing.

When the whole geometry is complete, it should be gently removed without tending to break by applying greater force. If at all support material is used, it should be separated from the part by using special kind of recommended solvents [4].

II. MATERIALS

To understand about material, first it has to be known its origin which helps to study the material even further.

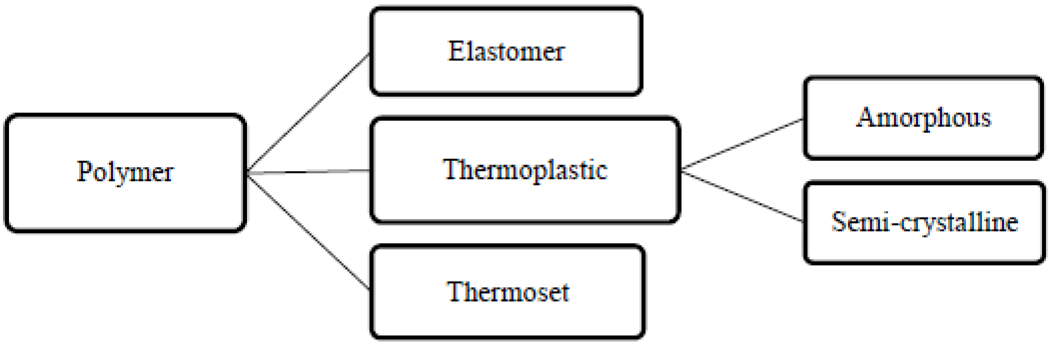

Fig - 2: Classification of polymers

Thermoset polymers also soften and solidifies similar to thermoplastics, but its shape cannot be obtained back by heating it again. Compared to thermoplastics it has higher strength and durability because of its three-dimensional structural linking of polymers. Its structure often knows as rigid three-dimensional structure of polymer network.

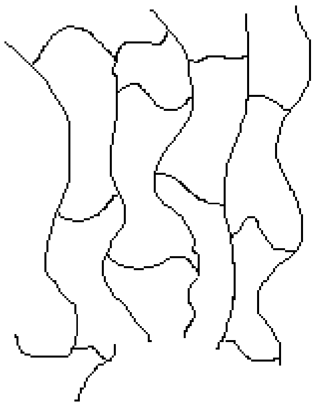

Fig - 3: thermoset polymer 5]

Elastomers are polymers that are rubbery in nature form as this can be stretched and unstretched repeatedly without losing its original shape and dimensions even when external force is applied on it. Again, these are cross linked polymers with slightly less dense than thermosets.

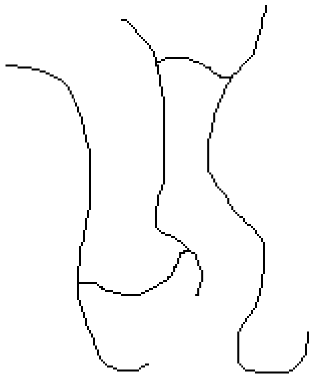

Fig - 4: : Elastomer polymer [5]

Majority of thermoplastics are produced by linear chain polymerization. The type of molecular arrangement seen in thermoplastics is linear chain arrangement. The arrangement of molecules is held closer by a weaker intermolecular force generally Vander Waal's forces which is relatively weaker of all type bond forces. Hence the material could be softened by applying a moderate heat and letting it to solidify by cooling down to room temperature. The arrangement is explained by further classifying the thermoplastics into amorphous and semi-crystalline structure.

Amorphous polymers are generally occurred as entangled chains which means that the arrangement of molecules is often a random chain which is again interconnected with other chains of molecules. Because of these structures it tends to possess lower melting points when compared with crystalline structured polymers. In these types of polymers, the uniformity of arrangement is low.

Semi - crystalline polymers are often considered to have dual region i.e., both amorphous and crystalline structures. It is the most desirable quality for most of the plastics to be thermoplastics. As it said to have both regions, so it possesses strength of crystalline polymers and flexibility nature from amorphous polymers. Because of its flexibility it tends to bend without breaking or possibility of leaving a crack. Here the arrangement of molecules is uniform, and this uniformity is higher than amorphous polymers [5].

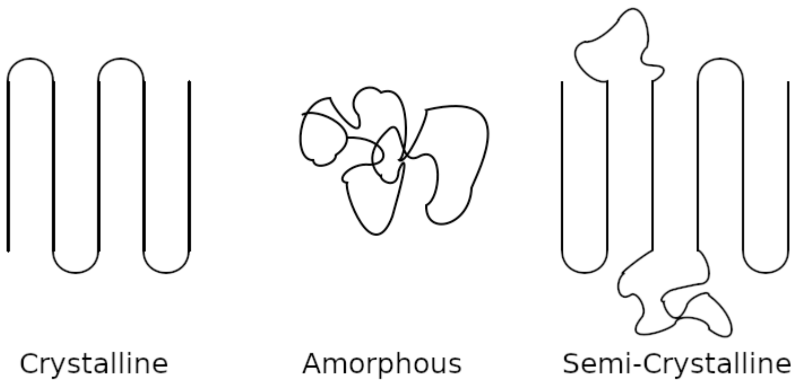

Fig - 5: structure of thermoplastics [6]

Plethora of materials available is one of the greatest strengths for Additive manufacturing. Materials that have a significant contribution to FDM technology are ABS, PLA, PA, glass filled polyamide, SLA materials (epoxy resins), silver, titanium, steel, wax, photopolymers and PC [7].

For FDM technology, Materials could be furthermore classified into specific groups based on their applications and properties. They can range from widely available commercial thermoplastics to high-performing thermoplastics with engineering thermoplastics at an intermediate level [3].

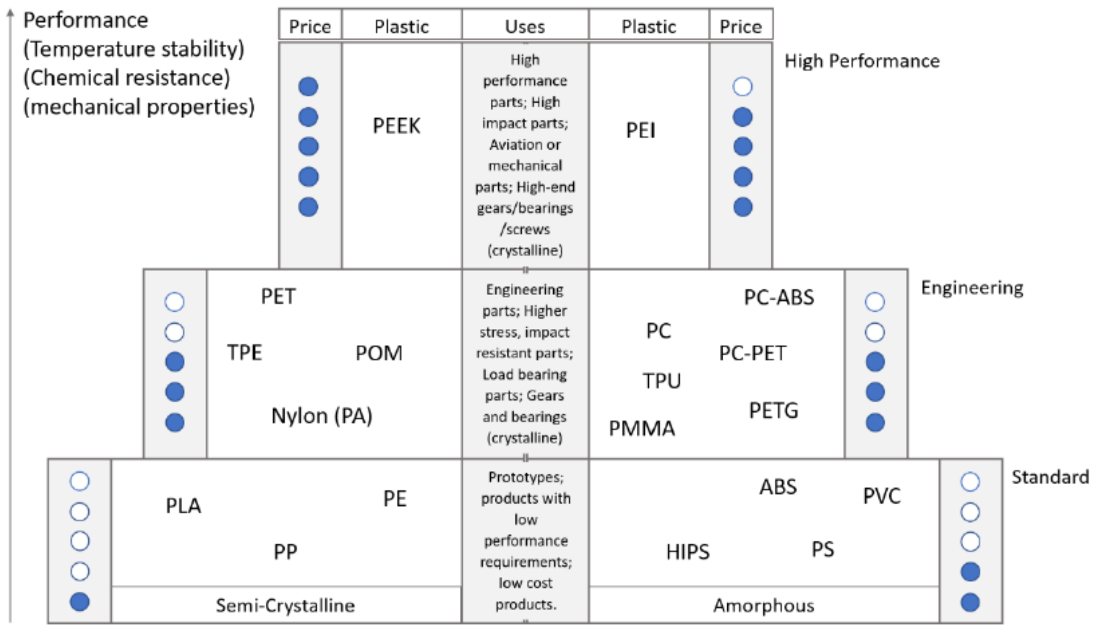

Fig - 6: material classification [6]

It is the most commonly used 3D printing filament material. Different crystallinity, degrees of polymerization, variation in chain length distribution, dyes, added plasticizers exists with different types of the ABS plastic. ABS is obliged for its unique properties which in-turn makes relatively smooth outer surfaces through FDM technology. ABS plastics can be used as for smoothening the surface of 3d printed parts by using an acetone vapor or liquid [9].

Printing conceptual modelling and functional prototyping. This material is suitable to withstand higher impact, tensile strength and flexural strength than standard ABS plastic [8].

It is a translucent material appropriate for inspecting the flow of materials and transmission of light. Frequently used in automotive and medical applications. It has strength superior to standard ABS and right material for constructing conceptual modelling, functional prototype testing and an excellent choice for use in Direct Digital Manufacturing (DDM)[8].

PLA is the most prevalent material in FDM technology because of its simplicity to print. It is a biodegradable thermoplastic produced from corn starch (renewable sources). One of the greatest advantages for using PLA in FDM technology is that its biodegradability property which doesn’t generate any poisonous or toxic gases while melting and hence it can be printed without any aid of ventilating system. PLA is more suitable to print frequently in any atmosphere (heated or unheated) and simultaneously it doesn’t require heated printing platform or adhesives as it can oppose warping which is considered as a huge concern in ABS[10].

It is the most common industrial thermoplastics widely used where accuracy, stability, durability, creating strong parts that could withstand in repeated testing are considered important. Most common applications are in automotive and aerospace industries. It has surpassing mechanical possessions than other thermoplastics such as ABS. It is better candidate for prototyping, creating conceptual models, manufacture of tools[8].

PC-ABS is the most anticipated thermoplastic for application in industries. It has the ability to offer dual properties from two different thermoplastics. It possesses superior strength and heat resistance of PC and outstanding attribute of ABS. It has the outrageous impact strength ever produced by a thermoplastic. Its combinations are widely applied in automotive industries, in electronic gadgets and telecommunications related applications [8].

Properties that really makes Nylon fascinates for 3D printing are because of its flexibility, toughness, stiffness, fatigue resistance, pretty good layer adhesion , heat and wear resistance.

Thermoplastic that offers outstanding thermal and chemical resistance. It is exemplary choice for automotive and aerospace industrial applications. It offers the highest thermal resistance of any FDM thermoplastic could yield, superior material for mechanical strengths, resistant to petroleum products. Its applications are predominant in extremely heated environments and also in caustic related[8]

PET/PETG is also the most commonly used thermoplastics in FDM technology. Since it has an excellent mechanical property capable to print mechanical parts where stress is high. It is highly suitable for printing huge objects. Some of the properties of PET/PETG are great resistant to heat, less brittle and highly flexible when compared to standard PLA. Application of PET/PETG lies in printing sturdy mechanical parts. As this material has a good layer adhesion it is also ideal for waterproof printing and applications. Both wet and dry sanding is distinctly viable for post processing PET/PETG [11].

High Impact Polystyrene (HIPS) is the commonly used supporting material in FDM. It is copolymer that blends the hardness of a polystyrene and elasticity of a rubber. It is an extraordinary support material. It is sturdy than both ABS and PLA and also produces less warps when compared with ABS. It really excels where the overhangs require some sort of structure beneath to support the actual material[10].

Polypropylene (PP) is one of the most widely used thermoplastics due to its flexibility, toughness, resistant to chemicals and also food safe. PP has broadly applied in engineering plastics, textiles, packaging for food etc. Even though it has few limitations but capable of printing with physically astonishing mechanical properties. Unlike PLA, it has poor layer adhesion between layers and considerable amount of warping[10].

Polyetherimide PEI also known as Ultem*9085 is a thermoplastic material with relatively higher strength to weight ratio. Because of this high strength to weight ratio, it is an exceptional choice in transportation industries. Its exceptional property which makes it highly not reactive to toxic, smoke and flame. PEI is in use for transportation business especially in marine and aerospace [8,9,10,11].

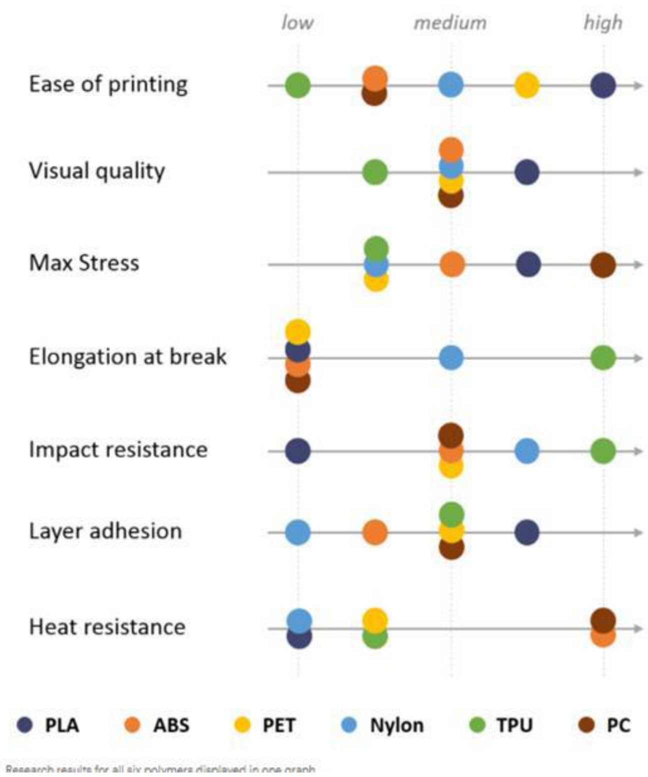

Fig - 7: Comparison of properties between thermoplastics[3]

Filler materials are some type of additives that are being impregnated to a matrix to alter its physical and mechanical properties. Not only it alters the mechanical and physical properties but also the composition of the material such as its interior shape and size which cannot be noticed with naked eye. The amount of the filler particles that are being impregnated has a direct influence over its corresponding factor and performance. These tiny powder-like particles determine the properties of the materials. Some of the basic filler materials are carbon, wood, ceramics and conductive carbon black[9].

For this experiment, special material Proto-Pasta's conductive PLA filament with 1.75mm as diameter has been purchased from a webstore www. shop.3dfilaprint.com and experimented as this thermoplastic has a special quality to conduct electricity. The special material Proto-pasta's conductive PLA is a product of 4043D PLA by Nature Works, is a dispersing agent and contains carbon black as the filler materials which is conductive and responsible to lead electricity [12]. The presence of carbon black in the blend makes it to be a conductive filament.

The important ingredients in conductive PLA filament are polylactide resin, carbon black and polymer. The weight percentage of polylactide resin, carbon black and polymer are found to be > 65%, <21.43% and <12.7% respectively. The volume resistivity of the Proto-pasta's conductive PLA filament is found to be 15 ohm-cm (0.15 ohm-m or 15 x 10-2 Ω-m) which has been claimed by the manufacturer [13]. Carbon black contains fine particles consisting mainly of carbon. Carbon black is widely used in various applications from black coloring pigment of newspaper inks to electric conductive agent of high-technology materials.

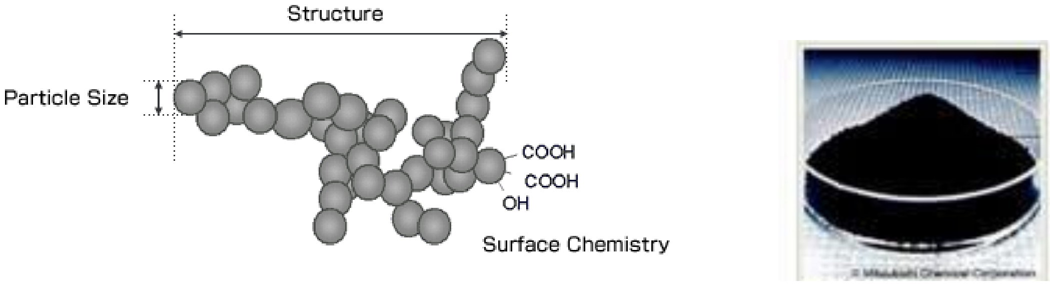

Fig - 8: (a) molecular arrangement of carbon black when viewed under electron microscope (b) Mitsubishi Carbon black filler powder (source Mitsubishi chemical)

III. CONCLUSION

Conductive materials have great potential in the field of additive manufacturing. It is possible to use them mainly for low-current applications, where it is necessary to transmit electric current. It is also possible to use them, for example, in the shielding of electrical circuits. Therefore, it is advisable to pay attention to this area and bring new knowledge and new materials.

Acknowledgments

The paper is a part of the research done within the project APVV-19-0607 "Optimized progressive shapes and unconventional composite raw materials of high-grade biofuels" funded by the Slovak Research and Development Agency. The research presented in this paper is a part of the research done within the project KEGA 024STU-4/2022– Virtual laboratory of additive manufacturing and reverse engineering.

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