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Graphene-based 3D printed circuit board

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Abstract - Additive manufacturing technologies are in high demand and are transforming the globe. To date, all marketed AM machines adopt a layer-based method, with the main differences being the materials that may be used, how the layers are formed, and how the layers are attached to one other. However, additive manufacturing is mostly limited to polymers, which have a lower strength-to-size ratio. Polymer cannot create heavy structures due to its low structural stiffness. Because certain polymers cannot be recycled, while all metals can, disposal becomes a concern. As a result, introducing another material is critical. The notion of merging graphene with essential technologies will certainly result in a product with great strength and electrical conductivity. Manufacturing electrical circuits is a difficult operation. Manufacturing each and every microscopic element of an electrical circuit is a time-consuming procedure. The research is primarily concerned with merging Additive Manufacturing with Graphene ink to make PCB. An external attachment is created in order to achieve the purpose.

Key Words: Graphene Extraction, AM (Additive Manufacturing), 3D Printing, Graphene Ink, Electrochemical exfoliation.

1.INTRODUCTION

1.1 Background

Traditional manufacturing in the machining field mainly refers to the four leading subtracting manufacturing methods: injection moulding, CNC machining, plastic joining, and plastic forming. CNC machining, also known as Computer Numerical Control machining, is a popular manufacturing method in which pre-programmed computer software controls the motions of industrial machinery and tools. CNC machining is highly helpful and practical for executing complicated 3D cutting jobs that, with the right CNC equipment, may be completed in a single set of instructions.

Typically, traditional manufacturing processes need several production phases, each requiring the use of a distinct equipment to complete the task. Other manufacturing procedures necessitate a rigorous and extensive examination of the component geometry to identify things like the sequence in which distinct features can be produced; what equipment and processes must be employed; and what extra features may be necessary to complete the part. In contrast, AM requires only a few basic dimensional information and a rudimentary grasp of how the AM machine works and the materials used to make the item.

The most significant advantage is that this sort of manufacturing may create intricate geometries that would be extremely difficult to produce using traditional production procedures. These intricate geometries created by additive manufacturing are usually lighter and stronger than their conventional equivalents. Making a part in an AM machine may only take a few hours, and numerous parts are frequently batched together inside a single AM build. Finishing may take a few days if excellent quality is required. Using CNC machining, even 5 speed machining, the same procedure may take weeks, with far greater uncertainty in completion time.

Determining the programme sequence for a CNC machine may be a difficult operation that includes tool selection, machine speed settings, approach position, angle and other variables. Many AM machines include choices that must be chosen, bust the breadth complexity and ramifications of those options are minor in contrast. The worst that may happen in most AM machines is that the component will be poorly constructed if the programming is not done correctly. Incorrect programming of a CNC machine can cause significant damage to the equipment and even endanger human safety.

1.2 Problem Statement

The rate of AM is increasing day by day. The cost of equipment is decreasing while its efficiency is increasing. New composites, Polymers and Metals are already accessible for AM and many more are in the works. As a result, we can replace a certain component with something stronger. Because AM is weaker, Graphene can be used to solve the difficulty. Graphene has higher conductivity than copper it has a wide range of uses in electrical circuits.

1.3 Objectives

1. To identify and select appropriate method to extract graphene.
2. To prepare homogeneous, conductive graphene-based ink.
3. To development of attachment for existing 3D printing machine for graphene-based 3D printing.

2. LITERATURE REVIEW

2.1 Evolution of AM

AM is described as "the technique of combining materials to produce items from 3D model data, generally layer upon layer, as opposed to subtractive manufacturing processes, such as conventional machining".

Additive manufacturing is the codified name for what was formerly known as fast prototyping and is now commonly known as 3D printing. The fundamental idea of additive manufacturing is that a model created using a 3D CAD system may be immediately manufactured without the requirement for process planning. To date, all marketed AM machines adopt a layer-based method, with the main differences being the materials that may be used, how the layers are formed, and how the layers are attached to one other. Such variations will influence aspects such as the finished part's precision, as well as its material and mechanical qualities.

They will also decide how quickly the item can be produced, how much post-processing is necessary, the size of the AM machine utilised, and the total cost of the machine and process.

The SLA is the most often modelled AM method, followed by the SLS/SLM and FDM. The majority of writers are concerned with modelling dimensional accuracy/stability, while many others are concerned with forecasting the mechanical qualities of the end product as well as the overall build time.

AM can provide components with highly complicated and complex geometries with little post processing requirements, constructed from customised materials with near zero material waste, and suitable to a wide range of materials, including plastics and metals. As a result, AM is a tool that allows for greater "design" flexibility. "independence" and allows designers and engineers to develop one-of-a-kind objects that can be mass-produced in low levels at a cheap cost.

Additive manufacturing technologies and methodologies are continually expanding in terms of application and market share, extending into many industrial divisions such as automotive, medical, and aerospace, and this rapid expansion is projected to continue in the coming years. According to Gartner research, sales of sub $100,000 AM machines increased by 49 percent globally in 2014 and are predicted to increase by 75 percent by the end of 2014.

In recent years, there has been a substantial shift toward metal additive manufacturing (AM) for the fabrication of structural components, primarily in fields such as electronics and motorsport applications that might benefit from large weight savings. Much work is being expended to make such AM processes quicker and more dependable. There are several additive manufacturing procedures available today; they differ in the way layers are deposited to build objects, the operating principle, and the materials that may be utilised.

Some technologies, such as selective laser melting (SLM), selective laser sintering (SLS), and fused deposition modelling (FDM), melt or soften materials to create the layers, whilst others, such as Stereolithography, cure liquid materials (SLA). Each approach has advantages and disadvantages, and as a result, some firms give an option between powder and polymer for the substance that the item is made of. The primary factors considered while selecting a machine are normally its speed, the cost of the printed prototype, the cost and variety of materials, and its colour capabilities. [4] Stereolithography is a type of lithography that uses (SLA) When exposed to UV light, photosensitive monomer resins photo polymerizes, which is the basis for Stereolithography.

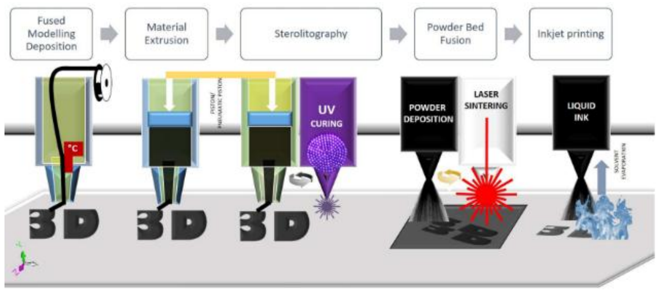

Fig -1: Additive Manufacturing Techniques.

A low power HeCd or Nd: YVO4 laser (up to 1000 mW in contemporary machines) is used as the UV light source. [5] Curing of solid ground (SGC) SGC is a photopolymer-based additive manufacturing process in which the layer geometry is created using a mask and a high-powered UV lamp or laser source. [6] FDM technology is highly adaptable and easily integrates with computer aided design (CAD) software programmes. FDM is the most widely used technique for creating conceptual models, prototypes, and engineering components. The final product's qualities, like as strength, surface polish, and porosity, are highly reliant on the FDM process settings.

As FDM is widely accepted as one of the promising technologies among industrial sectors, research is being conducted to increase the variety of materials that can be processed using this technology in order to sustain competition as it reduces development time and cost of the product, which is the need of the hour. Recently, researchers have examined a variety of methods to expand the range of materials accessible for the FDM process, which has resulted in an expansion of the scope of FDM in numerous production industries. The key advantages of this method are that no chemical post-processing is necessary, there are no resins to cure, and the machine and materials are less costly, resulting in a more cost-efficient procedure.

2.2 Methods to Extract Graphene

Because of its exceptional electronic characteristics, graphene has been identified as a viable material for electronic applications. Many methods have been developed over the last decade by material scientists and engineers to prepare large scale and high-quality graphene samples, which provide the foundation for graphene device level applications, and carrier mobility is one of the most concerned figures of merits of graphene quality as they grow.

1. A microwave approach for extracting graphene and few graphene stacks from turbostatic carbon fibres is a prominent method. In the unzipping of tubular carbon structures, microwave radiation is employed as a supplementary energy source in combination with the hydrogen peroxide, a mild oxidising agent. This reduces the difficulties associated with exercise oxidation while also significantly shortening the overall processing time. In this investigation, a two-stage microwave treatment was performed, with the first step in the presence of hydrogen peroxide and the following dry expansion of exfoliated CF resulting in enlarged carbon fibres. Initially, 5 lm finely chopped carbon fibres were submerged in hydrogen peroxide and microwaved for 30 minutes, resulting in the removal of the CF's outer sheath and partial expansion of its graphene layers. Microwave heated carbon fibres have been seen to undergo fast oxidation with increased porosity. The Xray diffractograms of these extended carbon fibres reveal a very strong peak at 12 in addition to the typical graphitic peak at 26, suggesting significant enlargement of the graphitic layers. The presence of stacked graphene layers in combination with locally folded graphene stacks, as revealed by TEM micrographs, is also suggested by the sharp peaks. The water was cooked off in approximately 20 minutes, leaving behind a dry looking substance in the flask, this product was re exposed to microwave radiation in order to expand further. The graphene layers of CF grew instantly, resulting in the production of weakly adhering graphene layers.

   Although the bulk of the oxide groups were predicted to be removed during the microwave stage, some residues of the oxides were eliminated during this phase. Graphene with primarily disc shaped platelets, as revealed by SM and TEM, indicates that the cutting process in carbon fibres is predominantly cross sectional, as opposed to longitudinal unzipping as described in other tubular carbon nanostructures such as MWCNT and SWCNT.

2. A quick, fast and straightforward method for obtaining few graphene layers by microwave induced exfoliation of turbostatic carbon fibres has also been studied. The entire procedure is straightforward, involving the use of environmentally acceptable chemicals such as hydrogen peroxide and a residential microwave as an external energy source. When the same procedure was repeated with highly graphitized carbon structures such as carbon nano-fibres and graphite, it didn't yield graphene because the carbon atoms in these structures are chemically less accessible for oxidation reactions, resulting in a significantly lower degree of oxidation and making these structures difficult to exfoliate. The emphasis is on the widely utilised sonication, with the most recent insight into sonication induced flaws, freshly investigated ball milling, developing fluid dynamics in the last three years and revolutionary supercritical fluid. The discussion took place on how to effectively produce high quality graphene. Different exfoliation procedures are thus linked together by a similar mechanism. Then we will go through mechanical exfoliation techniques in detail, such as the original micromechanical cleavage, the most often used sonication, the newly discovered ball milling, the lately developing fluid dynamics, the revolutionary supercritical fluid and so on. Finally, the findings and perspective: the ability to produce graphene on a wide scale has been made achievable via sonication assisted liquid phase exfoliation of graphite. Coleman's group originally reported the high yield synthesis of graphene by sonication aided liquid phase exfoliation of graphite in 2008, after their expertise in dispersing carbon nanotubes by sonication.

2.3 Characteristics of Graphene using Raman Test and Scanning Electron Method

Graphene based materials have extraordinary electrical, optical, and mechanical capabilities, which has sparked a lot of scientific curiosity as well as a lot of promise for a wide range of applications. Furthermore, due to advancements in preparation processes, the variety of graphene-based compounds is expanding.

Raman spectroscopy is a flexible method for identifying and characterising these materials' chemical and physical characteristics, both in the laboratory and on a large scale. This approach is so significant that most studies on these materials include at least one Raman spectra.

Graphene possesses exceptional electrical, optoelectronic, and mechanical characteristics, as well as a wide range of device applications. All Raman modes in intrinsic graphene, including the first-order G mode and DR-activated first- and second order Raman modes, have been investigated. The C, LB, and 2D modes in NLGs have also been thoroughly examined, as they are highly sensitive to the number of layers N and stacking order (AB, ABC, and twist stacking).

NLG resonance Raman spectroscopy was also reported. External disturbances to graphene flakes may influence their lattice vibrations as well as band structures, which Raman spectroscopy may show.

The effects of point defects, line defects, and edges on the D, G, and 2D modes have been thoroughly addressed, and it has been convincingly established how to use Raman spectroscopy to examine the nature of defects in graphene. The Raman spectral characteristics of the C, LB, and 2D modes, as well as the intensity of the G mode of NLG and the Si mode of the substrate, have been used to determine the value of N of graphene flakes.

Raman spectroscopy has also been used to study graphene-based materials such nanographene, carbon dots, graphene oxide, epitaxial graphene on SiC, CVD-grown NLG, and graphene-based van der Waals heterostructures. Raman imaging has also been proven to offer regionally dispersed information about graphene flakes' number of layers, stacking order, edges, strain, and growth method.

Finally, Raman spectroscopy has been demonstrated to be a non-destructive, on-line characterization technique for monitoring the property modification or designed function on demand of graphene materials in related devices such as FETs, energy storage devices, solar cells, OLEDs, NEMS, and graphene-based vdW heterostructures. There are numerous well-resolved bands in the Raman spectra of single-layer graphene (SLG). [16] The E2G vibrational mode of the Brillouin zone (BZ) centre phonons correspond to the G band. The D band, also known as the defect-related or disorder-related mode, is associated with the breathing mode of a carbon ring and results from the resonant intervalley process near the BZ edge. Because of the relaxation of the phonon momentum conservation principles, this band emerges with defects in graphene. The intervalley resonant process is represented by the D0 band. Even in the absence of defects, the 2D band, an overtone of the D band, is always present in the Raman spectra of graphene.

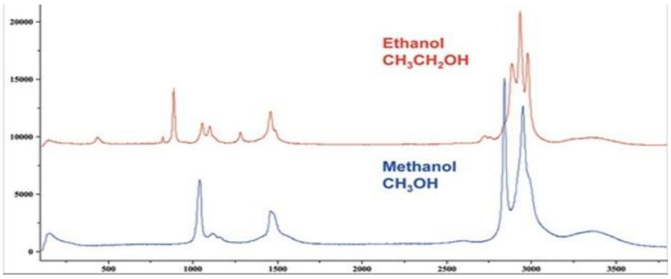

Fig -2: RAMAN Test

3. GRAPHENE

3.1 Advantages

Due to unusual physiochemical features, graphene, a single atom thick layer of two- dimensional closely packed honeycomb carbon lattice, and its derivatives have gotten a lot of attention in the biomedical area. The valuable physicochemical properties of graphene-based bioelectronics devices, such as high surface area, excellent electrical conductivity, remarkable biocompatibility, and ease of surface functionalization, have shown great potential in applications such as electrochemical biosensors for biomarker analysis.

Due to its unique physicochemical features, graphene, a single 2-dimensional(2D) layer of a hexagonal structure comprised of sp^2 hybridised carbon atoms, and its derivatives have gained increased attention in biomedical domains. High surface area, great electrical conductivity, robust mechanical strength, exceptional thermal conductivity, and ease of surface functionalization are all features of this material.In particular, the rate of electron transfer is inversely related to the exponential distance between the electrode surface and the molecules electroactive redox site. Because electron transmission between graphene and redox active molecules usually occurs at the graphene layers edges or flaws in the basal plane, graphene's large surface area makes it an ideal conducting medium for electrical charge and heterogeneous electron transfer.

3.2 Properties

Graphene is a material with a lot of intriguing features. These characteristics, together with the abundance of carbon in nature, have made graphene a highly researched substance with a wide range of applications. The followings are some of them:

1. Thermal and electrical conductivity is high.
2. Extreme suppleness and adaptability
3. High abrasion resistance
4. Resistance is high.

5. Graphene is 200 times stronger than steel, with resistance equivalent to diamond but much lighter.
6. The effects of ionising radiation are unaffected
7. Sunlight can be used to generate electricity.
8. Material that is transparent
9. High density prevents Helium atoms from passing through, but it does enable water to get through, which evaporates at the same pace as if it were in an open container.
10. Antibacterial properties.
11. Bacteria are unable to develop in this environment.
12. When conducting electrons, the low Joule effect causes heating.

In comparison to other compounds, it uses less electricity.

4. METHODOLOGY

4.1 Simulation

A simulation is the imitation of the operation of a real-world process or system over time. Simulations require the use of models; the model represents the key characteristics or behaviours of the selected system or process, whereas the simulation represents the evolution of the model over time. Often, computers are used to execute the simulation.

- *Thermal analysis of nozzle:*

  The primary goal of a thermal study of the nozzle is to determine the temperature distribution of the liquid and whether the liquid inside the nozzle is hotter than the ambient temperature. Also, if the temperature inside the nozzle climbs above ambient, we can identify where the fins should be installed to the nozzle.

- *Thermal analysis of platform preheating of a 3D printer:*

  The platform must be prepared before printing so that the model sticks to the platform sufficiently to allow printing without the model shifting. Platform preheating is one of the keys to successful printing on the UP.

- *Velocity Analysis of Nozzle:*

  To determine the velocity of the liquid material flowing out of the nozzle end, a velocity study of the nozzle attachment is performed. Again, the feeder requires a particular amount of force and velocity to transfer the material through the nozzle at the start of the attachment, so we can establish these parameters using velocity analysis.

4.2 Extraction of Graphene Powder

- Electrochemical Exfoliation:

For creating graphene from graphite, Electrochemical Exfoliation is a potential bulk approach. Natural graphite in the form of foils, rods, sheets or highly oriented pyrolytic graphite, are the most commonly employed graphite electrodes in electrochemical exfoliation. To extend the interlayer space between graphene layers, electrochemical exfoliation of graphite relies on efficient ion intercalations among graphene layers.

4.3 Preparation of Ink

Since graphene in the market is much more costly so we cannot even think about buying ready-made ink. So we have to go through number of steps for preparing the ink. And the sonication process is also critical but it gave an easy solution to our problem.
Ink number 01

- The first ink made was the Glycerol based ink.0.3gram of extracted graphene powder was taken.
- Added 20 ml glycerol as a base so as the powder will mix with it properly.
- Then took the solution and kept it in the sonicator for around 30 minutes + 30 minutes for dispersion.
- But the proper expected mixture in 60 minutes wasn't obtained so the whole procedure was repeated again.

Ink number 02

- Since the glycerol base didn't work, the glycerol base was replaced with the Toluene base.
- The mixture of 10 ml of toluene with 10 ml of calcium hypochlorite was mixed the 0.3 gm of graphene powder.
- Then the solution was kept in the sonicator for around 30 minutes + 60 minutes for dispersion.
- After the sonication process we solution got dispersed but it was somewhat lacking the expectation, so the whole procedure was repeated again.

Ink number 03

- The third and final ink was with the use of pure toluene.
- 30 ml of toluene base was taken and mixed it with 2.0 gm of graphene powder.
- The solution was kept in the sonicator again for around 60 minutes + 60 minutes for dispersion.

- After 120 minutes i.e.in two hours in total, the required mixture was obtained successfully with the expected properties.

This required mixture was nothing but the graphene ink which was then used to develop 3D circuit. A solution-based and scalable graphene ink was developed and characterized for its properties.

4.4 Sonication

Sonication therapy causes micro streaming, which can improve mass transfer during cavitational bubble collapse. As a result, cell wall is destroyed allowing for improved contact and interactions of solvents in and out of plant component. The most critical step in the creation of nanofluids is Sonication. We followed magnetic stirring of mixture in a magnetic stirrer, sonication is performed in an ultrasonication part, ultrasonic vibrator and mechanical homogenizer.

4.5 Properties of Graphene Ink

Graphene ink, like other conductive inks, may be used to print the objects that carry heat and electricity. Solvents, surfactants and graphene powder are mixed into a thick paste to make graphene conductive ink. The product's primary use is in the field of printed electronics. A C-C bond contributes to the sp2 firmly linked carbon in graphene, which has a 2-dimensional structure and honeycomb lattice shape.

4.6 Working Principle

A linear actuator is a mechanical device that generates force and motion in a straight line. A stepping motor is used as the source of rotary power in a stepper motor-based linear actuator. Instead of a shaft, the rotor contains a threaded precision nut. A lead screw is used to replaced shaft. Linear motion is provided directly through the nut and threaded screw as the rotor rotates (as in a traditional stepper motor). The rotary to linear conversion should be done directly inside the motor, as this substantially simplifies design of rotary to linear applications. This provides excellent resolution and accuracy, making it ideal for applications requiring precision movements.

4.7 Changes to be made in existing 3D Printer

- Removal of heating coil

In every 3d printer there is a heating coil set up near the extruder nozzle. This heating coil in a 3d printer is used to convert the solid string of PLA into the viscous liquid. Since we have used raw material in our project and this material is already in the liquid state so we don't need the heating coil in our mechanism. Hence, we have eliminated the heating coil.

- Disabling Wire Extruder Mechanism

Wire extruders are employed in the current mechanism to pass ink from the printer and obtain the product. Because we used a syringe system (linear actuator), our mechanism is unique. As a result, we had to detach the current wire extruder machinery and replace it with our own.

- Providing a facility to fit the external attachment to the printer

Our goal is to create an attachment that can be readily installed on a 3d printer without causing any damage to the existing 3d printer's parts or increasing the load and pressure on the 3d printer. As a result of which we used the chromatography process for printing, in which the base (in our case, toulin) separates from the solid combination.

- Reprogramming the device

The present programme is designed to move the extruder nozzle in a regular pattern, but we created a new mechanism to pass our ink through. As a result, the movement of our mechanism is distinct. So, we had to build another G-code application to obtain desired product.

5. DISCUSSION

We have presented Graphene and the techniques for extracting Graphene, as lightweight materials have become a new trend in the material world. The higher the graphene concentration, the lower the apparent density of the graphene-based structure, and the higher the carbon atom saturation, the lighter the material. In 3D printing, extrusion and printing speeds are critical.

To get intake and outlet specifications such as motor power, motor type, feeder force and velocity, nozzle outlet diameter, and material velocity at several crucial locations during the nozzle attachment, a simulation programme is used.

6. CONCLUSION

Electrochemical exfoliation, we believe will become more important in creation of graphene materials. The ink developed is solution based and scalable, and its properties have been described.

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