1. Question: Explain the fundamental principles of metal cutting operations. In your explanation, describe the formation of a chip, including the primary and secondary shear zones. [4-6 marks]

Answer:

Machining or metal cutting is the process of removing extra material from a metal surface by shearing or cutting action. The cutting occurs along a plane known as the shear plane.

Chip Formation:

- **Primary Shear Zone:** This is a cutting zone where severe plastic deformation occurs due to the compressive force applied by the sharp-edged cutting tool. The extra material, due to this deformation, flows over the tool surface, forming the chip.
- **Friction & Welding:** During the flow of the chip on the rake surface of the cutting tool, the temperature of the newly formed chip increases due to friction, causing it to get welded automatically on the rake surface.
- **Secondary Shear:** Due to the continuous compressive force applied by the newly formed chip (just after the welded chip), secondary shear of the previously welded chip occurs.
- The line generated by the cutting motion is called generatrix, and the line formed by the feed motion is called directrix.

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2. Question: Differentiate between Conventional Machining and Non-Conventional Machining processes. Provide at least two specific examples for each. [5-7 marks]

Answer:

Conventional and Non-Conventional Machining processes differ primarily in their method of material removal and energy sources used:

Conventional Machining:

- **Definition:** Involves physical contact between a harder cutting tool and the workpiece, removing material in the form of chips.
- **Energy Source:** Primarily mechanical energy.
- **Examples:** Turning, milling, drilling, grinding, shaping, and broaching.
- **Suitability:** Suitable for materials that are relatively soft and can be economically machined with standard tools.

Non-Conventional Machining:

- **Definition:** Utilizes various forms of energy (thermal, chemical, electrical, etc.) to remove material, often without direct contact between the tool and workpiece.
- **Energy Source:** Thermal, chemical, and electrical energy.
- **Examples:** Electrochemical Machining (ECM), Electro-Discharge Machining (EDM), Laser Beam Machining (LBM), Ultrasonic Machining (USM), Abrasive Jet Machining (AJM).
- **Suitability:** Suitable for machining hard materials, complex shapes, and materials that are difficult to machine with conventional methods.

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3. Question: Describe the detailed construction and primary functions of the Bed and Headstock of a Lathe machine. [4-6 marks]

Answer:

The Lathe machine is the oldest machine tool, used for shaping parts by rotating the workpiece.

Bed:

- **Construction:** It's the backbone of the lathe upon which all other components are mounted. The top of the bed is formed by guideways.
- **Material:** Made up of cast iron because of its good damping and frictional resistance.
- **Functions:**

    - Rigidly supports all fixed and moving parts of the lathe.
    - The guideways act as a guide for accurate movement of the carriage and tailstock.

Headstock (Live Centre):

- **Construction:** It is a box-like casting mounted at the left end of the machine. It contains a feed gear box or cone pulley.
- **Functions:**
    - Enables the spindle to rotate at different speeds.
    - The gear box distributes the power to the lead screw for threading or to the feed rod for turning.
    - Provides driving mechanism to the job, tool post, carriage, apron, etc..

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4. Question: Explain the "Plain Turning" and "Facing" operations performed on a Lathe machine. Describe their purpose and how the tool and workpiece motions are involved. [4-6 marks]

Answer:

Lathe machines perform various operations by providing rotational motion to the job and translational motion to the cutting tool.

Plain Turning:

- **Purpose:** This is the most commonly used operation in a lathe for producing a cylindrical surface from a workpiece.
- **Motions Involved:** The workpiece, held in the spindle, is rotated, while the single-point cutting tool is fed past the workpiece in a direction parallel to the axis of rotation.

- **Stages:** It is usually done in two stages: rough turning (majority of material removal at high speeds) and smooth or finish turning (finishing the job to required dimensions at lesser speeds).

Facing:

- **Purpose:** Facing is an operation for generating flat surfaces on the ends of workpieces in lathes. It can also be used to produce a square surface with the axis of operation or to achieve a desired length of the job.
- **Motions Involved:** The workpiece rotates, and the tool is fed in a direction perpendicular to the axis of revolution.
- **Tool Consideration:** The tool used should have a suitable approach angle so that it does not interfere with the workpiece during tool feeding.

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5. Question: Explain the "Form tool method" and "Swiveling compound rest method" for Taper Turning on a Lathe. Describe their principles and key features. [5-7 marks]

Answer:

Taper turning is the process of producing a conical surface from a cylindrical workpiece.

1. **Form Tool Method:**
    - **Principle:** This method uses a special form tool that has the requisite taper profile. The feed is given by plunging the tool directly into the workpiece.
    - **Suitability:** It is normally used for production applications, especially for short tapers where steepness is not a primary concern, such as chamfering.
2. **Swiveling Compound Rest Method:**
    - **Principle:** The compound rest, which has a circular base graduated in degrees, is swiveled to the desired half-angle of the taper. The cutting tool

    is then made perpendicular to the workpiece, and the feed is given manually by the operator.
  - **Features:**
    - Short and steep tapers can be easily produced.
    - It has limited movement of the compound rest.
    - Feeding is by hand and is non-uniform, which can lead to low productivity and poor surface finish.

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6. Question: Explain the calculation of Machining Time for a single pass in turning operations. Detail the formula and define its variables. How are the number of roughing and finishing passes determined? [5-7 marks]

Answer:

To estimate machining times, it is necessary to select proper process parameters like cutting speed, feed, and depth of cut based on material combinations.

Machining Time for a Single Pass:

- The time (t) for a single pass is given by the formula:
  $t=fNL+Lo$
  - Where:
    - L = length of the job, in mm
    - Lo = over travel of the tool beyond the length of the job to help in the setting of the tool, in mm
    - f = feed rate, in mm/rev
    - N = rotational speed of the workpiece, in rpm

Determination of Number of Passes:

The number of passes required depends on the left-over stock (machining allowance), specified surface finish, and tolerance.

- **Roughing Passes (Pr):**
  - Formula:
    Pr=drA−Af
  - Where:
    - A = Total machining allowance, in mm
    - Af = Finish machining allowance, in mm
    - dr = Depth of cut in roughing, in mm
- **Finishing Passes (Pf):**
  - Formula:
    Pf=dfAf
  - Where:
    - df = Depth of cut in finishing, in mm
- The total allowance is removed through roughing passes, and then finishing passes ensure the specified surface finish and tolerance.

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7. Question: Describe the Drilling operation and the Twist Drill tool. Explain the main parts of a twist drill and the functions of its spiral flutes. [5-7 marks]

Answer:

Drilling Operation:

- **Definition:** Drilling is the operation of making primarily a hole in a workpiece using a drill bit.
- **Mechanism:** The stationary work is held in a fixture, and the rotating tool is fed vertically to make a circular hole.
- **Chip Removal:** The cutting tool used is called the twist drill, which has two cutting edges and two opposite spiral flutes. These flutes provide clearance to

the chips produced at the cutting edges. They also allow the cutting fluid to reach the cutting edges.

Twist Drill Tool:

- **Main Parts:** A twist drill basically consists of two parts:
    - **Body:** Comprising the cutting edges.
    - **Shank:** Used for holding purpose.
- **Flutes:** These are helical grooves cut into the surface of the drill body.
    - **Functions of Flutes:**
        - To carry the chips away from the cutting zone.
        - To admit the coolant to the cutting edges.
        - To make the chips curl for easier removal.
        - To provide the cutting edges on the point.
- Other important parts include the point (conical part with cutting lips), tang (flattened end of taper shank for removal), and lips (cutting edges).

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8. Question: Differentiate between Horizontal Milling Machines and Vertical Milling Machines based on their key features and operations. [6-8 marks]

Answer:

Milling is a metal cutting process where surfaces are generated by a rotating multi-point cutter. Horizontal and Vertical Milling Machines are two main types based on spindle orientation.

SI No.	HORIZONTAL MILLING MACHINE	VERTICAL MILLING MACHINE

1		**Spindle Orientation:** Spindle is horizontal and parallel to the worktable.		**Spindle Orientation:** Spindle is vertical and perpendicular to the worktable.
2		**Cutter Movement (Vertical):** Cutter cannot be moved up and down.		**Cutter Movement (Vertical):** Cutter can be moved up and down.
3		**Cutter Mounting:** Cutter is mounted on the arbor.		**Cutter Mounting:** Cutter is directly mounted on the spindle.
4		**Spindle Tilt:** Spindle cannot be tilted.		**Spindle Tilt:** Spindle can be tilted for angular cutting.
5		**Typical Operations:** Operations such as plan milling, gear cutting, form milling, straddle milling, and gang milling can be performed.		**Typical Operations:** Operations such as slot milling, T-slots, flat milling, and also different drilling operations can be performed.

9. Question: Explain the concepts of "Up Milling (Conventional Milling)" and "Down Milling (Climb Milling)". Describe how the direction of the cutting tool's rotation relates to the table movement in each, and discuss their impact on cutting forces. [6-8 marks]

Answer:

Milling operations are classified based on the directions of movement of the milling cutter and the feeding direction of the workpiece.

1. **Up Milling (Conventional Milling):**
   - **Direction of Rotation:** In up milling, the cutting tool rotates in the opposite direction to the table movement (feed direction).
   - **Impact on Cutting Forces:** The cutting forces tend to lift the workpiece from the table. This means the workpiece needs to be securely clamped to the work holding device.
   - **Chip Thickness:** The chip thickness starts at zero and gradually increases to its maximum value at the end of the cut where the tooth leaves the work.
   - **Safety:** Up milling is generally safer and commonly used.
2. **Down Milling (Climb Milling):**
   - **Direction of Rotation:** In down milling, the cutting tool rotates in the same direction as that of the table movement (feed direction).
   - **Impact on Cutting Forces:** The cutting force will act downwards and as such would keep the workpiece firmly in the work holding device. This can improve workpiece stability.
   - **Chip Thickness:** The chip thickness starts at maximum and decreases to its minimum value at the end of the cut where the tooth leaves the work.
   - **Advantages:** Down milling generally results in better surface finish and longer tool life.

10. Question: Define Additive Manufacturing and explain its core principle. Discuss its broad impact and where it is currently used. [5-7 marks]

Answer:

Additive Manufacturing (AM):

- **Definition:** Additive manufacturing fabricates parts by building them up layer-by-layer, as opposed to cutting material away or molding it.
- **Core Principle:** It turns a digital model (of the object to be constructed) into a physical one, starting as a 3D software design. This layer-by-layer construction allows for complex geometries and internal structures that are difficult or impossible with traditional methods.

Broad Impact and Applications:

- **New Opportunities:** AM doesn't replace other manufacturing methods but leads to a wealth of new opportunities. Some objects would be almost impossible to make without additive manufacturing.
- **Diverse Domains:** AM and 3D printing are used in multiple domains:
    - Healthcare
    - Construction industry
    - Defense
    - Retail
    - Pharma
    - Automotive industry
    - Aerospace
    - Making parts in almost any area (including human tissue and food, smart manufacturing).
- **Research and Development:** They are also the subject of intensive research and development in methods, materials, new techniques, and application areas.

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11. Question: Describe the Material Extrusion process, specifically Fused Deposition Modelling (FDM). Explain the fundamental mechanism and detail the four key stages of the FDM process. [6-8 marks]

Answer:

Material Extrusion – Fused Deposition Modelling (FDM):

- **Fundamental Mechanism:** FDM is a 3D printing process where a filament of solid thermoplastic material is pushed through a heated nozzle, melting it in the process. The printer then deposits the molten material on a build platform along a predetermined path, where it cools and solidifies to form a solid object.

Key Stages of the FDM Process:

1. **Part Preparation:**
    - The initial stage involves importing the design file into the software.
    - The user chooses build options such as layer height, orientation, and infill percentage.
    - The software then computes sections and slices the part into several layers.
    - Finally, the program creates extruder paths and building instructions based on the sectioning data to drive the extrusion heads.
2. **FDM Machine Setup:**
    - The printer is loaded with a thermoplastic filament spool for both the model and support extruders.
    - Generally, the build platform is heated and maintained at a higher temperature to control the cooling of the extruded material.
    - Extruders are heated, and once the nozzle reaches the required temperature, the head begins pushing and melting the filament into a small ribbon.
3. **FDM Printing:**

- The extrusion head gantry and the build platform operate on a three-axis system, allowing the nozzle tip to move in three directions in space.
    - The extruder starts depositing the material layer by layer in predefined areas, which then cool and solidify.
    - Material cooling is sometimes assisted using cooling fans mounted to the extrusion head.
4. **FDM Part Removal:**
    - This final stage involves removing the completed parts from the build platform.
    - It also includes cleaning the parts by removing all support structures.

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12. Question: Explain the concept of Unconventional Machining Processes (UCM). What distinguishes them from conventional machining, and what are their main characteristics? [5-7 marks]

Answer:

Unconventional Machining Processes (UCM):

- **Definition:** UCM processes are completely non-mechanical. In these processes, there is no chip formation.
- **Material Removal Mechanism:** Material removal occurs through methods like melting and evaporation of unwanted metal, or by removal of metal in the form of powder due to brittle fracture of metallic layers.
- **Distinction from Conventional Machining:** UCM processes utilize various forms of energy (thermal, chemical, electrical, etc.) to remove material, often *without direct contact* between the tool and workpiece. In contrast, conventional machining involves physical contact between a harder cutting tool and the workpiece, removing material in the form of chips.
- **Suitability:** UCM processes are used for machining difficult profiles and for very hard materials, which are challenging for conventional methods.

Main Characteristics of UCM:

- There is no chip formation.
- No residual stress is set up in work materials.
- There is no mechanical contact between the tool and work materials.
- Tool wear is lesser compared to conventional processes.
- The tool does not need to be harder than the work material.
- Better surface finish and close tolerance may be achieved.
- Intricate shapes, very hard, and fragile materials can be machined.

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13. Question: Describe the principle of operation for Abrasive Jet Machining (AJM). Explain how material removal occurs and list its key advantages and limitations. [6-8 marks]

Answer:

Principle of Operation for Abrasive Jet Machining (AJM):

- In AJM, material removal occurs due to the tiny brittle fracture of the metallic layer caused by the high-velocity impact of abrasive particles.
- A high-velocity jet of dry air, CO_2, or nitrogen gas containing abrasive particles strikes the workpiece at the point where cutting or machining is desired. These gases act as a carrier medium for abrasives such as Al_2O_3, SiC, boron carbide, and diamond.
- The abrasive particle sizes typically range from 10 to 50 µm, and the jet velocity ranges from 150 to 300 m/s. The gap between the nozzle tip and the work surface is usually kept at about 1 mm.

Key Advantages of AJM:

- Low capital investment is involved.
- Brittle materials of thin section can be easily machined.
- Cavities and holes of any shape can be drilled in material of any hardness.

- The amount of heat generation is low.
- There is no direct contact between the tool and workpiece, resulting in a very low tool damage rate.

Key Limitations of AJM:

- This process is not suitable for machining ductile material due to the embedding of abrasive particles in the work surface.
- The metal removal rate is very low.
- It gives poor machining accuracy.
- Cleaning is required after the operation to remove abrasive particles from the work surface.
- The abrasive powder cannot be reused.

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14. Question: Explain the principle of operation of Electron Beam Machining (EBM). Describe the mechanism of material removal and list at least three advantages and three disadvantages of this process. [6-8 marks]

Answer:

Principle of Operation for Electron Beam Machining (EBM):

- EBM is a thermal process of material removal.
- **Mechanism:** A stream of high-speed electrons impinges on the work surface. The kinetic energy of these electrons is transferred to the work material, producing intense heating. Depending on the intensity of the generated heat, the material can melt or vaporize.
- **Beam Generation & Control:**
  - Electrons are emitted from a cathode (a hot tungsten filament).
  - The beam is shaped by a grid cup and accelerated by a large potential difference between the cathode and the anode.
  - Electromagnetic lenses are used to focus the beam.

    - Deflecting coils control the beam movement as required.
- **Power Density:** A very high velocity electron beam can be focused on a small point (10–200 μm diameter) with a power density up to 6,500 billion W/mm², which is sufficient to evaporate the material immediately.
- **Environment:** The entire operation is carried out in a high vacuum environment (10^{-5} mmHg) to prevent filament oxidation, electron scattering, and atmospheric contamination of the weld.

Advantages of EBM:

- No burr is produced on the workpiece.
- There is no heat-affected area, and no machining stress is set up.
- It is one of the fastest methods of metal removal on tough alloys.
- Very close tolerances (0.02 mm) can be obtained.

Disadvantages of EBM:

- The initial cost of machine setup and tooling is high.
- It requires complex electrodes and flushing arrangements.
- It requires high power consumption.
- Machining requires a vacuum of 10^{-5} mmHg.

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15. Question: Define Heat Treatment and explain its purpose. Describe the "Normalizing" process, including its process steps, main purposes, and effects on the properties of steel. [6-8 marks]

Answer:

Heat Treatment:

- **Definition:** Heat treatment is a process used to control the mechanical properties of engineering materials by heating, cooling, and alloying the metal as per requirement.

- **Purpose:** It deals with changes in properties by alloying different elements to the metal at various temperatures. It controls mechanical properties such as hardness, toughness, ductility, machinability, and grain refinement.

Normalizing Process:

- **Process Steps:**
  - Steel is heated to about 30–50°C above its higher critical point.
  - It is then held at this temperature for a time duration of 15 minutes.
  - Finally, the steel is cooled in still air.
- **Main Purposes of Normalizing:**
  - To reduce the grain size of the steel.
  - To remove internal stress caused by working.
  - To improve some of the mechanical properties.
- **Effects on Properties of Steel:**
  - The normalized structure of hypoeutectoid steel consists of ferrite and pearlite, while for hypereutectoid steel, it consists of pearlite and cementite.
  - Normalized steel exhibits higher yield point, ultimate tensile strength, and impact strength.
  - It also results in lower ductility compared to annealed steel.
- **Suitability:** Normalizing is advantageous for low and medium carbon steel. For alloy steel, a 2-hour cooling time in a furnace may be required.

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16. Question: Explain the "Annealing" heat treatment process. Discuss its general purposes and differentiate between "Process Annealing" and "Full Annealing." [6-8 marks]

Answer:

Annealing:

- **Definition:** Annealing is a heat treatment process that involves heating metal and then slowly cooling it.
- **General Purposes:**
    - To soften the metal for easy machining.
    - To remove internal stress caused by working.
    - To increase ductility.
    - To refine grain size.
    - To modify electrical and magnetic properties.

Types of Annealing:

1. **Process Annealing:**
    - **Process:** The metal is heated below or very close to its lower critical temperature (e.g., 650°C for steel) and then slow cooled.
    - **Purposes:** Primarily aims to increase the ductility of cold-worked metal and to remove internal stress.
    - **Use:** Frequently used in wire drawing to increase the plasticity of the metal.
2. **Full Annealing:**
    - **Process:** Steel is heated 20–30°C above the upper critical limit for 0.9% C-steel, or by the same amount below the critical point for high carbon steel. Carbon steel is cooled 100–200°C per hour. The workpiece is often closed in a metal box and placed in the furnace to prevent carburization and oxidization.
    - **Purposes:** Its main purposes are to soften the steel and to refine its grain structure.
    - **Microstructure:** Austenite changes to pearlite and a mixture of pearlite and ferrite.

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17. Question: Describe the "Tempering" heat treatment process. Explain its definition, primary purposes, and differentiate between its three main temperature-based types. [6-8 marks]

Answer:

Tempering:

- **Definition:** Tempering is a process of reheating hardened steel to a temperature below its critical range, followed by cooling at a decreased rate (approximately 4–5 minutes for each mm of the section).
- **Effect:** This process results in a partial transformation of martensite to secondary constituents like troostite and sorbite.
- **Primary Purposes:**
    - To reduce some amount of hardness produced during hardening and increase the ductility.
    - To remove strain produced during heating.

Types of Tempering:

1. **Low Temperature Tempering:**
    - **Process:** Steel is heated to 150–250°C and then cooled down.
    - **Use:** Primarily employed to remove internal stress, reduce hardness, and increase ductility without changing the steel structure.
2. **Medium Temperature Tempering:**
    - **Process:** Steel is heated to 350–450°C and cooled down. During this process, martensite is changed to secondary troostite.
    - **Effect:** It results in a reduction in strength and hardness, and an increase in ductility.
    - **Use:** It is used for parts that are subjected to impact loading, such as chisels, hammers, springs, and spring plates.
3. **High Temperature Tempering:**

- **Process:** Steel is heated to 500–600°C and cooled down. In this range, martensite is changed to sorbite.
- **Effect:** Internal stress is relieved completely.
- **Use:** This type of tempering is used for parts subjected to high impact and stress, such as gear wheels, shafts, and connecting rods.

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18. Question: Discuss the concepts of "Open Loop" and "Closed Loop" control systems. Provide a clear example for each to illustrate the presence or absence of a feedback mechanism. [5-7 marks]

Answer:

Control systems are mechanisms that maintain or alter a quantity of interest in equipment according to a desired manner. There are two basic forms: open loop and closed loop.

1. **Open Loop Control System:**
   - **Definition:** In an open loop system, there is no information fed back from the output to adjust the input. The output is determined solely by the input and the inherent characteristics of the system, without any compensation for changes in conditions.
   - **Example (Electric Fire):** Consider an electric fire with a selection switch (e.g., 1kW or 2kW element) to heat a room. If the user switches on the 1kW element, the room heats up to a temperature determined by that setting. If conditions change, like someone opening a window, the heat output is not automatically adjusted to compensate. This is an open loop system because there is no feedback to maintain a constant temperature.
2. **Closed Loop Control System (Feedback Control System):**
   - **Definition:** In a closed loop system, there is feedback, meaning a signal related to the actual output condition is fed back to modify the input signal

to a process. The input to the system is adjusted based on the deviation of the actual output from the desired output.

    - **Example (Electric Fire with Thermometer):** The electric fire heating system can be made a closed loop system if a person uses a thermometer to monitor the room temperature. The person (acting as a comparison element) switches the 1kW and 2kW elements on or off according to the difference between the actual temperature (measured) and the required temperature. Here, the thermometer provides the feedback, and the input to the switch is adjusted based on this feedback to maintain a constant room temperature.

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19. Question: Define Additive Manufacturing and explain its core principle. Discuss its broad impact and list at least three distinct domains where it is currently used. [5-7 marks]

Answer:

Additive Manufacturing (AM):

- **Definition:** Additive manufacturing fabricates parts by building them up layer-by-layer, as opposed to cutting material away or molding it.
- **Core Principle:** It essentially turns a digital model (of the object to be constructed), typically a 3D software design, into a physical one. This process is revolutionary because it allows for the creation of complex geometries and internal structures that are often impossible to achieve with traditional subtractive or formative manufacturing methods.

Broad Impact and Applications:

- **New Opportunities:** AM does not simply replace existing manufacturing methods but opens up a wealth of new opportunities. It enables the creation of objects that would be almost impossible to make using conventional techniques.

- **Diverse Domains:** Additive manufacturing and 3D printing are widely used across multiple domains:
    - **Healthcare:** (e.g., custom prosthetics, implants, surgical guides, even human tissue).
    - **Automotive Industry:** (e.g., prototyping, custom parts, lightweight components).
    - **Aerospace:** (e.g., complex, lightweight, high-performance parts for aircraft and spacecraft).
    - **Construction Industry:** (e.g., 3D printed buildings).
    - **Defense:** (e.g., rapid prototyping, on-demand parts for military equipment).
    - **Retail/Consumer Goods:** (e.g., customized products, footwear).
- **Innovation & Research:** This technology is also a subject of intensive research and development, exploring new methods, materials, and application areas.

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20. Question: Describe the Material Extrusion process, specifically Fused Deposition Modelling (FDM). Detail the four key stages of the FDM process, explaining the activities involved in each. [6-8 marks]

Answer:

Material Extrusion – Fused Deposition Modelling (FDM):

- **Fundamental Mechanism:** FDM is a 3D printing process where a filament of solid thermoplastic material is pushed through a heated nozzle, causing it to melt. The printer then deposits this molten material onto a build platform following a predetermined path, where it cools and solidifies to form a solid object layer by layer.

Key Stages of the FDM Process:

1. **Part Preparation:**

- This initial stage involves importing the 3D design file into specialized software.
- Users select various build options, such as desired layer height, part orientation on the build platform, and infill percentage.
- The software then computes sections and slices the 3D part into numerous individual layers.
- Finally, the program creates specific extruder paths and building instructions based on this sectioning data, which will drive the extrusion heads during printing.

2. **FDM Machine Setup:**
    - The 3D printer is loaded with the chosen thermoplastic filament spools for both the model material and any necessary support material.
    - The build platform is generally heated and maintained at a specific temperature to control the cooling rate of the extruded material, preventing warping.
    - The extruders are heated to the required temperature. Once the nozzle reaches this temperature, the extrusion head starts pushing and melting the filament, turning it into a small ribbon-like stream.
3. **FDM Printing:**
    - The extrusion head gantry and the build platform operate on a three-axis system, allowing precise movement of the nozzle tip in three dimensions.
    - The extruder systematically deposits the molten material layer by layer in the predefined areas. This material then cools and solidifies, gradually forming the 3D object.
    - In some cases, the material cooling process is actively assisted by cooling fans mounted to the extrusion head to ensure proper solidification and layer adhesion.
4. **FDM Part Removal:**
    - This final stage, like in other 3D printing processes, involves carefully removing the completed part from the build platform.

- Post-processing includes cleaning the part by removing any support structures that were printed to hold overhanging features during the build.