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“Recycling Plastic Bottles into 3D Printer Filament: A Sustainable and Cost-Effective Solution"

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Abstract: Plastic filament extruder utilizing thermoplastic granules, including waste materials. The process involves a ceramic band heater to melt materials, a barrelscrew for longitudinal feeding, and a three-zone screw. Efficient heating is achieved with two barrel heaters and one die heater. Control is maintained by ananalog temperature controller. The extruded filament has a diameter of 3mm, adjustable using a DC motor. Potential improvements include increasing barrel and screw diameters for enhanced production and augmenting material properties with fillers.[1]. Limitations in existing Fused Deposition Modeling (FDM) printers, which often restrict printing to monochrome objects due to nozzle structure. Utilizing CAD modeling and simulation tools like UG, ICEM CFD, and Fluent software, the study establishes a color-mixing 3D printer nozzle. Temperature optimization at varying extrusion speeds is determined, andinsights into blockages at the heating block intersection are revealed. The experimental validation demonstrates stable production of mixed-color artifacts.[2][3] This article details a filament extruder designed for producing plastic filaments with precise diameters, utilizing thermoplastic granules, pellets, and even waste materials. The extrusion process involves rod heaters formaterial melting and a screw to longitudinally feed raw materials along the barrel, segmented into feed, melt, and transition zones. Temperature control is achieved with two temperature zones and six rod heaters using an analog temperature controller. The filament extruder, designed for 3D printing, incorporates a 2.5 mm die, yielding a 1.75mm filament diameter, adjustable by aDC motor. Further improvements in production involve increasing barrel and screw diameters, while enhanced mechanical and thermal properties areachieved by introducing various fillers to the raw material.[4][5].

I. INTRODUCTION

Rapid prototyping, achieved through 3D printing, particularly Fused DepositionModeling (FDM), utilizes additive manufacturing principles. FDM employs plastic filaments like ABS, PLA, PC, PA, PS, and PE. However, high costs and imported materials prompted the development of a low-cost extruder machine toproduce plastic filaments of desired sizes. This eco-friendly approach allows theuse of recyclable plastics, reducing manufacturing and filament costs. Strength is enhanced by incorporating fillers during the extrusion process. The project's core objective is to create an affordable, sustainable extruder machine for 3D printing.[1]

This work explores the diverse applications of 3D printing technology, emphasizing the need for color mixing capabilities in current 3D printers, often limited to monochrome filaments. Previous studies on continuous tone imagery and color-managed workflows are discussed. The paper introduces a novel 3D printer nozzle designed for color mixing using UG software.[2] The introductionemphasizes 3D printing's role, especially Fused Deposition Modeling (FDM), inrapid prototyping. It discusses challenges like high costs and reliance on imported filaments, leading to a cost-effective extruder's development. The paper aims to design a color-mixing 3D printer nozzle, using computer simulations to enhance filament feed speeds and address limitations in current monochrome filament-based 3D printers.[4] This review paper explores sustainable polymer composite manufacturing using 3D printing technologies with recycled polymer and fillers. Authored by Daniela Fico, Daniela Rizzo, Valentina De Carolis, Francesco Montagna, and Carola Esposito Corcione.[5][6]. This review delves into the extrusion process of Fused Filament Fabrication 3D printing. Authored by Bahaa Shaqour, Mohammad Abuabiah, Salameh Abdel-Fattah, and others, the paper aims to enhance understanding of this crucial aspect.[7]

II. LITREATURE REVIEW

The review likely covers aspects such as the principles of plastic extrusion, the role of filament extruders in 3D printing, and technological developments in thedomain. It may also discuss the challenges faced in previous designs and the innovations proposed by other researchers. By synthesizing existing literature, the review sets the stage for the development of a new plastic filament extruder,providing a comprehensive background for the research project.[1] Extensively explores advancements in FDM 3D printing technology.

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The authors delve intoexisting research on 3D printer nozzles, focusing on color mixing capabilities. They likely cover studies addressing the limitations of monochrome filaments incurrent 3D printers, emphasizing the need for color-mixing solutions. The review may discuss methodologies adopted by previous researchers in designing nozzles for color mixing, including analytical models, numerical simulations, and experimental approaches. Insights into the challenges faced in achieving effective color mixing and the proposed solutions are likely examined. By summarizing key findings from the literature, the authors establish a foundation for their own work in designing and analyzing a novel FDM 3D printer nozzle with enhanced color mixing capabilities.[2].

The authors are likely to investigate relevant studies on the design aspects, functionalities, and efficiency of filament extruders in the context of FDM technology. They may discuss advancements in materials used for extrusion, temperature control mechanisms, and overall system optimization. The literature review could also delve into the challenges faced by current extruders and the innovative solutions proposed by other researchers. By summarizing key findings in the literature, the authors aim to provide a comprehensive. background for their work, contributing to the design improvement of 3D filament extruders for enhanced FDM additive manufacturing processes.[5][3],[6], [7].

4.1 Fused Deposition Modeling 3D Printer Nozzle for Color Mixing

The plastic filament extruder for 3D printing comprises several key components. Firstly, ceramic band heaters are employed, with two barrel heatersand one die heater consuming low power to achieve high temperatures ranging from 100ºC to 1300ºC. The barrel screw design features a three-zone structure –feed, compression, and metering zones – driven by an AC motor through a reduction gearbox. The screw facilitates the movement of plastic through the barrel, with heaters aiding in friction and plastic conveyance. The extruder barrel, made of hardened steel, covers the screw and connects to the gearbox. The gearbox, with a speed ratio of 1:3, is crucial for adjusting the motor's 1440rpm to the desired 20 rpm for effective material mixing and melting.[1]

COMPONENTS USED

Table 3.1 Components used

S.No	List of Components
1	Ceramic band heater.
2	Barrel screw
3	Extruder barrel
4	Gear box
5	Motor
6	Hopper
7	Die
8	Pulleys
9	Belt
10	Shaft

Fig 4.1.1[1]

In the overall assembly, the extruder screw resides within the barrel, mountedon a frame, connected to the gearbox powered by an electric motor. The extruder die is positioned at the front, surrounded by heaters, and a hopper supplies plastic. The temperature of the heaters is controlled by an analog temperature controller. This integrated system is designed for efficient plasticfilament extrusion in 3D printing applications.[1]

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S.NO	Symbols	Parameters
1	Q_m	Total Mass Flow Rate
2	Q_{md}	Mass rotational flow
3	Q_{mp}	Mass pressure flow
4	F_d	Shape factor for rotational flow
5	θ_b	Helix angle of the barrel
6	V_{bz}	Barrel velocity
7	η	Shear viscosity – 846.5 pa.sec
9	P_{dis}	Discharge pressure
10	l_m	Axial length of the metering section
11	P	Flight starts
12	$\tan\theta_b$	$\frac{L}{\pi . D_b}$
13	L	Lead length
14	$\frac{\partial p}{\partial z}$	$\frac{P_{dis} . \sin\theta_b}{l_m}$

Fig 4.1.2[1]

4.2 Influence of plastic recycling

The test verification of a nozzle for a color mixing device in a 3D printer. The device is designed to mix colors during the printing process, and the testing involves assessing its performance at different temperatures. The nozzle featuresa heating block, a fixed block, and a unique outlet for color mixing. The test is conducted using orange and green ABS filaments, with a cylinder serving as a printing model.[2] The initial test is carried out at a temperature of 220°C, resulting in a partial blockage at the intersection of the end of the pipe and the heating block, as seenin Figure 15(a).[2] Upon disassembling and cleaning the nozzle device, a second test at the same temperature yields successful color mixing without evident stratification or accumulation issues (Figure 15(b)).[2] Subsequently, the nozzle temperature is increased to 230°C for another successful print test (Figure 16).[2] However, the outcomes reveal important insights. At 220°C, the filament at thenozzle intersection is not completely melted, leading to potential blockages when filament feed is not smooth. At 230°C, while smooth mixing is achieved,there is a clear phenomenon of molten filament accumulation, adversely affecting the print quality. This indicates that molten ABS material at 230°C haslow stickiness and strong liquidity, causing incomplete extrusion. The test results suggest that the mixing nozzle device can essentially fulfill its function, but there are identified risks and flaws. Specifically, the intersection ofthe heating block poses a risk of blockage, and there is a flaw in the design of this intersection. The text concludes by emphasizing the need for structural improvements to eliminate the risk of blockages in future iterations of the device.

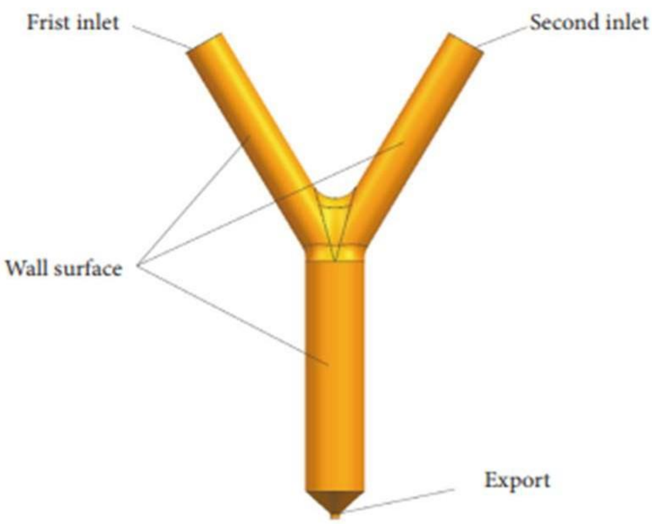

fig 4.2.1[2]

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In summary, the color mixing nozzle device demonstrates its capability to mix colors during 3D printing, but challenges such as blockages and molten filamentaccumulation at specific temperatures are identified. The results inform the need for design modifications to enhance the device's performance and reliability.[2]

4.3 Development of Plastic Filament Extruder for 3D-Printing

The study delves into the utilization of diverse polymer materials, such as PLAIngeo 4043D and recycled PLA Sunlu, in conjunction with ceramic waste, for the production of filaments intended for 3D printing applications. Various samples were identified for testing, encompassing PLA Ingeo 4043D in pellet, filament, and 3D printed forms (labeled A and A_3D, respectively).

Recycled PLA Sunlu waste was designated as B, with color variations (transparent, white,blue, red, and black) and corresponding filaments and 3D printed samples (labeled BF and B_3D). Ceramic waste, labeled C, was employed as a filler for the composite filament (CF) in conjunction with PLA Ingeo 4043D. Additionally, a commercial filament from Sunlu was labeled D, accompanied byits corresponding 3D printed sample (D_3D).[4]

The process involved converting PLA Ingeo 4043D pellets into filaments using a 3Devo Composer 450 Filament Maker.[4] Recycled PLA Sunlu waste was gathered from remnants of 3D printing processes, subjected to washing, and size reduction. Ceramic waste, sourced from a ceramic workshop, underwent washing and crushing to obtain powder. Filaments were subsequently producedfrom these raw materials utilizing the 3Devo Composer 450 Filament Maker. The filaments underwent characterization based on morphological, thermal, andmechanical properties.[4]

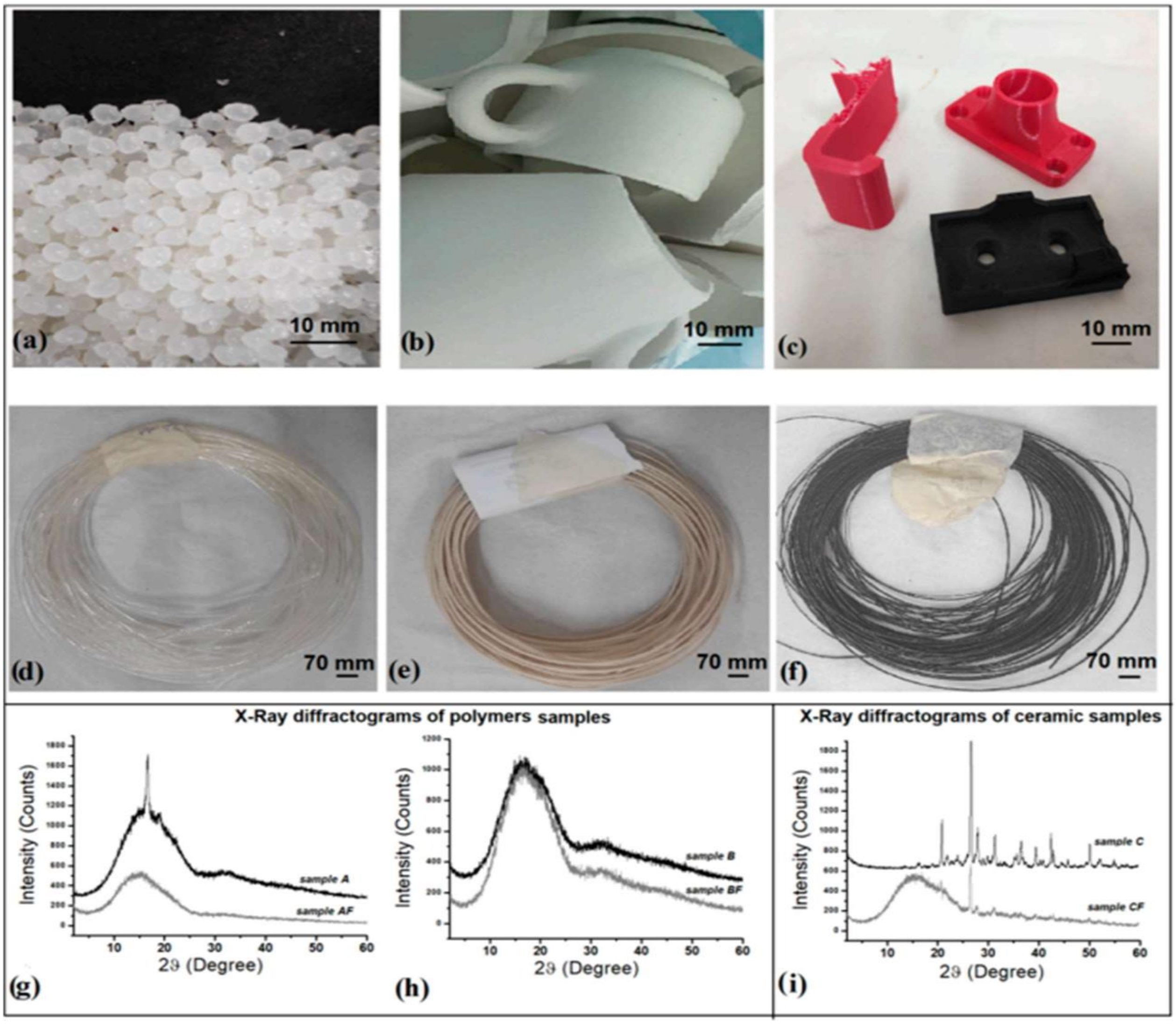

fig 4.3.1[4]

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Morphological analysis incorporated scanning electron microscopy (SEM) anddigital microscopy to scrutinize surface uniformity and layer adhesion in 3D printed bars. X-ray diffraction (XRD) and differential scanning calorimetry (DSC) analyses were carried out to evaluate crystallinity, glass transition temperature (Tg), and melt temperature (Tm).

Rheological analysis was conducted using a rheometer to examine the flow behavior of the materials at the 3D printing temperature.

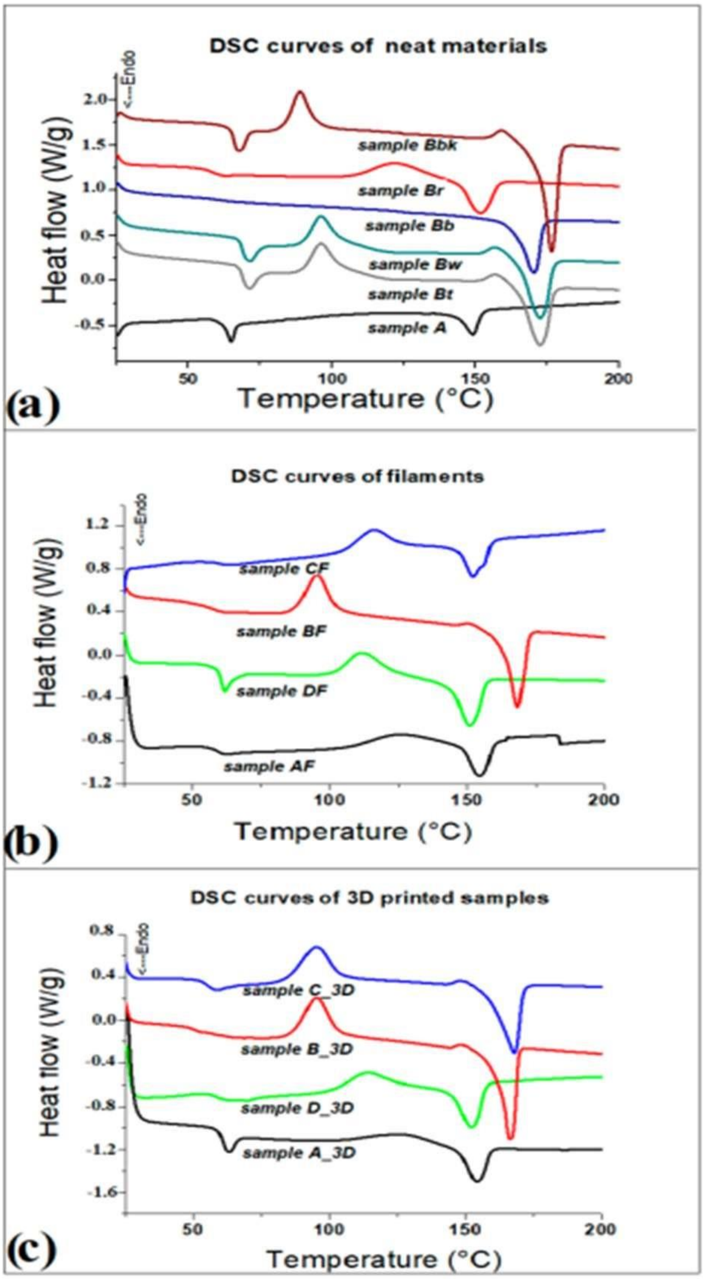

fig 4.3.2[4]

Mechanical characterization entailed flexural tests on 3D printed bars followingISO178 standards. The primary objective of the study was to assess the performance of filaments derived from recycled materials and augmented with ceramic waste in terms of morphological, thermal, and mechanical attributes.[4]

Furthermore, the research encompassed the modification of a 3D printer (3DPRN LAB) to accommodate dual extruders, facilitating two-color prints orthe use of filaments with varying mechanical properties. This modified printerwas deployed to 3D print representative objects utilizing the recycled polymer(BF) and waste ceramic (CF) filaments.[4]

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In summary, the investigation explores the viability of employing recycled polymers and ceramic waste as filaments for environmentally sustainable 3Dprinting. The comprehensive analysis of material properties and the performance of 3D printed objects seeks to contribute to environmentally friendly practices within the additive manufacturing domain.[4]

4.4 Extrusion process in fused filament fabrication 3D printing

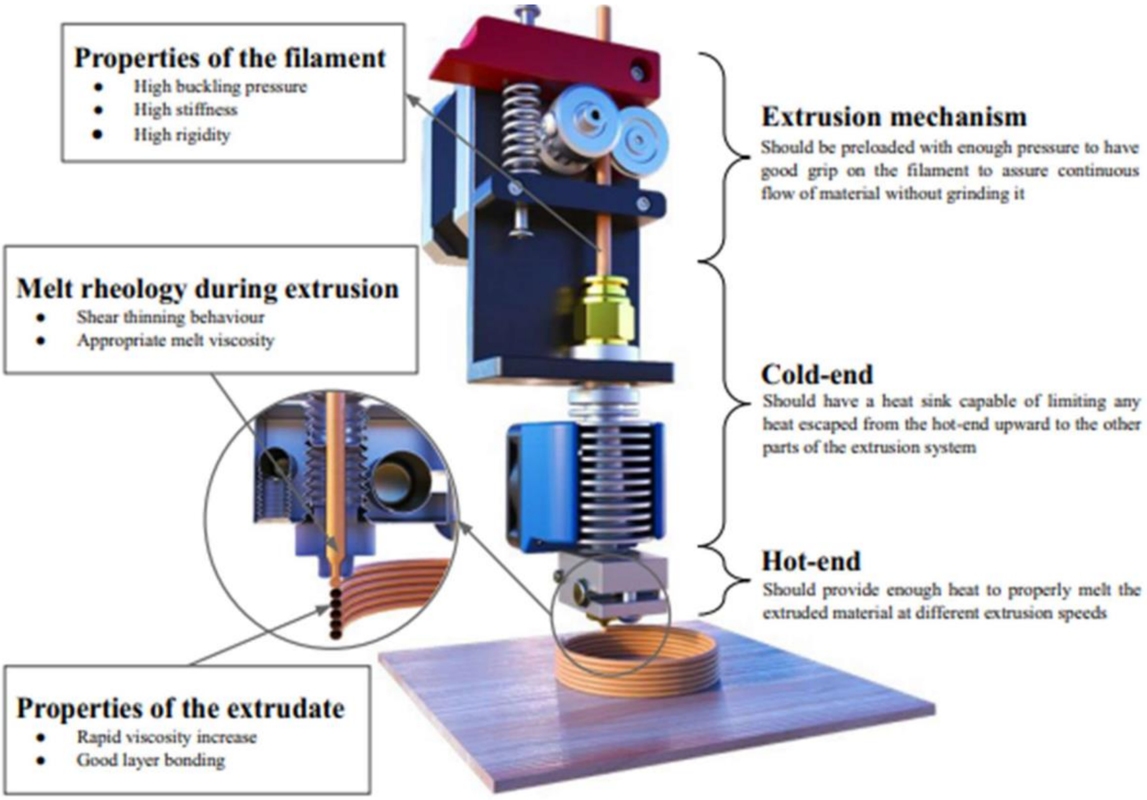

Fig 4.4.1[5]

Researchers have extensively explored the intricacies of the extrusion process inFused Filament Fabrication (FFF) 3D printers, focusing on various components such as the motor, barrel, heating block, and nozzle. The process begins with a motor extruding filament through a barrel, which contains a heating block where the filament melts, and finally, the material exits through the nozzle, determining the cross-sectional area of the printed road[5].

The initial extrusion phase is crucial for ensuring a continuous material flow, affecting the quality of the printed parts. A stepper motor, connected to a drivinggear, exerts pressure on the filament, which must be regulated to prevent issues like grinding or inconsistent flow. Inadequate pressure can lead to slipping between the filament and the driving gear.[5]

The barrel serves as a heat sink, preventing heat from escaping upwards and causing filament expansion or blockages. Preserving a portion of the filament ina non-melted state aids in maintaining a successful extrusion process.[5]

The heating block is where the material undergoes melting, with thermoplastic polymers or composites exhibiting reversible phase changes upon heating abovethe glass transition temperature (Tg). Proper design of the heating block ensuressufficient material melting, involving considerations such as increasing its length to enhance material residence time during extrusion.[5]

The nozzle, directly connected to the heating block, plays a critical role in determining the cross-sectional area of the material. Nozzle diameter influencesobject accuracy, surface finish, and extrusion pressure. Smaller diameters produce finer details but at the cost of reduced printing speed.

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Understanding the material's behavior during extrusion is vital. Thermoplastic polymers exhibit shear-thinning behavior and viscoelasticity upon heating and cooling. The shear-thinning behavior involves a reversible relationship between viscosity and shear rate, crucial for optimal material feeding.[5]

To summarize the extrusion process, thermoplastic polymer material is fed intothe extrusion system, acts as a piston to ensure continuous flow, and is then heated just above its melting point. Material exits the nozzle into a smaller cross-sectional area, and factors like viscosity changes and shear-thinning behavior are crucial for successful 3D printing.[5]

Researchers have also investigated the extrusion process inside the extruder, considering factors such as pressure, temperature, flow velocity, and material behavior after extrusion. Experimental setups, numerical simulations, and finite element modeling have been employed to gain insights into the complex dynamics of filament extrusion and its impact on the final printed objects.

Studies have addressed issues like nozzle clogging, temperature control, and theinfluence of extrusion speed on material behavior. Additionally, models have been developed to understand the flow behavior of fiber-reinforced polymers and the orientation of fibers during and after extrusion.[5]

These investigations contribute to a deeper understanding of the extrusion process, enabling improvements in 3D printing technology and the developmentof more reliable and efficient printing systems.[5]

4.5 Fused Deposition Modeling (FDM)

Plastic waste management is a critical issue due to the widespread use of plastics in various applications, leading to significant environmental challenges.Plastics, known for their versatility, mechanical strength, low density, and low cost, have become indispensable in packaging, automotive, construction, medical, and other industries. However, the exponential growth in plastic production has resulted in a substantial increase in plastic waste.[6]

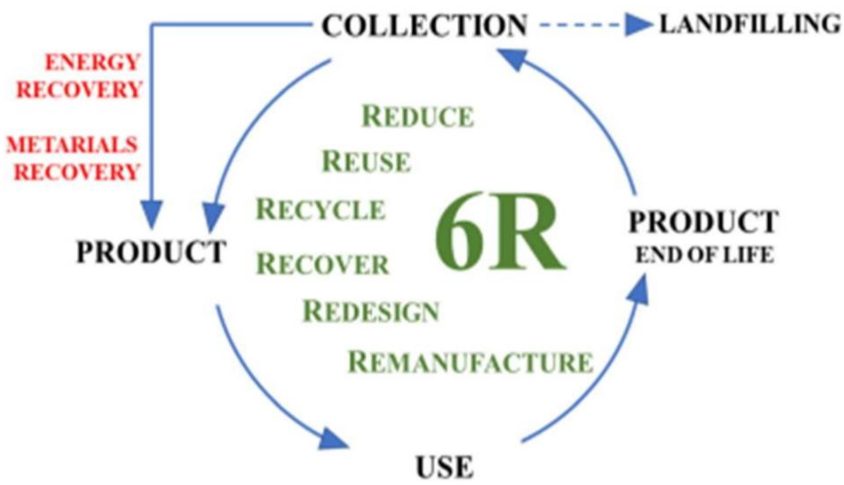

fig 4.5.1[6]

Global plastic production in 2018 reached 359 million metric tons, with predictions of doubling over the next 20 years. The mismanagement of plastic waste, often ending up in landfills, poses a severe environmental threat. In the European Union, only 75.1% of plastic waste is processed, with 24.9% still being landfilled. To address this issue, various methods of plastic waste management are employed, including primary recycling, mechanical recycling, chemical reuse, and thermal methods such as combustion, pyrolysis, and gasification.[6]

Primary recycling involves recovering uncontaminated polymer residues with properties similar to the original material. Mechanical recycling processes materials that may contain impurities, resulting in lower-quality recycled materials.

Chemical recycling employs processes like depolymerization (solvolysis) to convert plastics into compounds suitable for production. Thermalmethods focus on energy recovery from plastics, though they are considered less environmentally friendly.[6]

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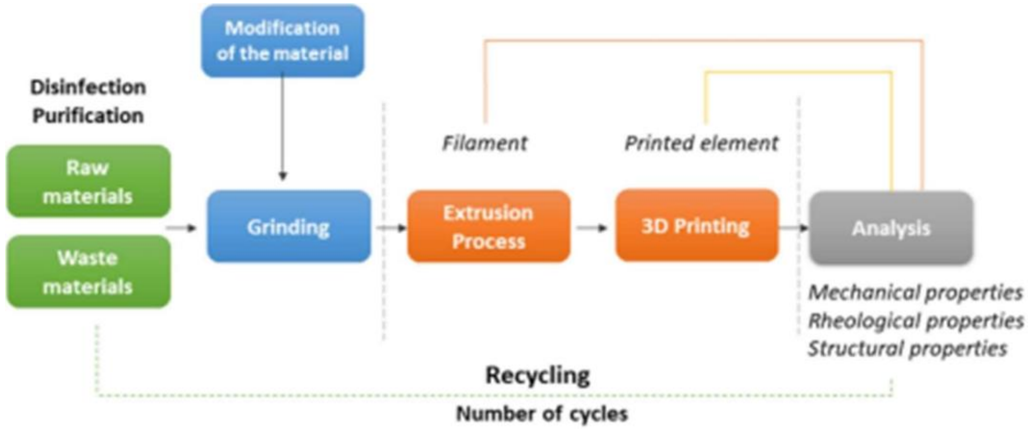

Fig 4.5.2[6]

4.6 3D printing filament as a second life of waste plastics

The urgency to find cost-effective plastic processing technologies has led to theexploration of 3D printing using waste polymers. The 3D printing market, experiencing rapid growth, utilizes thermoplastics like acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA). These filaments contribute to the generation of plastic waste, prompting interest in recycled filaments for 3D printing. The mechanical properties of recycled filaments, however, need thorough investigation to ensure their compatibility with 3D printing technology.[7]

Fig 4.6.1[7]

In conclusion, effective plastic waste management is crucial to mitigate environmental impacts. While various methods exist, exploring recycled filaments for 3D printing presents a promising avenue for sustainable plastic utilization. This approach aligns with the growing 3D printing market and the increasing need for environmentally friendly solutions in the plastic industry. [7]

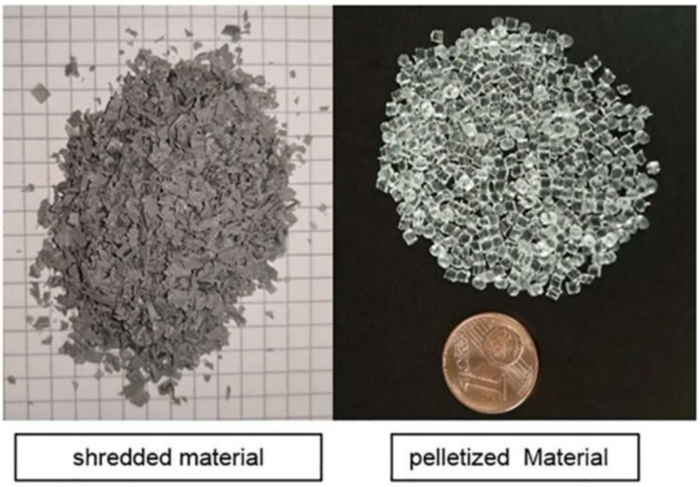

Fig 4.6.2[7]

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III. CONCLUSION

The paper discusses the development of a plastic filament extruder for 3D printing .The literature review likely explores existing research on 3D printingtechnologies, filament extrusion methods, and advancements in the field. The authors aim to contribute to the development of an efficient and cost-effective extruder for 3D printing applications.[1] In paper on Fused Deposition Modeling (FDM) 3D printer nozzle design and color mixing explores prior research in nozzle design, FDM technology, and color mixing techniques. Theauthors aim to enhance the performance of 3D printers by analyzing and optimizing the design of the printing nozzle for effective color mixing.[2] The review in the paper by focuses on the design of a 3D filament extruder for Fused Deposition Modeling (FDM) additive manufacturing. The authors likely survey existing research on extruder design, FDM technology, and additivemanufacturing methods to inform the development of an innovative and efficient filament extruder.[3] In Fico et al.'s paper on sustainable polymer composites manufacturing through 3D printing, the literature review likely explores prior research on 3D printing technologies, with a focus on using recycled polymer and filler materials. The authors aim to contribute to the advancement of eco-friendly practices in polymer composite manufacturing.[5]–[7].

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