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Analysis of 3D Printing Filament Using Polyvinyl Alcohol (PVA)

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ABSTRACT

The widespread adoption of 3D printing as a manufacturing method across various industries offers a diverse range of filaments tailored to specific printing requirements. However, the production of intricate designs presents challenges, particularly in the removal of support structures. This research explores the manual removal and aqueous dissolution times, evaluating resultant model quality. Categorizing eighteen samples into simple, medium and complex groups, with each comprising three units, forms the basis for assessing Polyvinyl Alcohol (PVA) filament's impact on support structures and overall model quality. Nine samples exclusively used Polylactic Acid (PLA) as a control group, while the remaining nine integrated PVA filament, ensuring a comprehensive examination of PVA's influence on different design complexities. For meticulous design, Autodesk TinkerCAD meticulously guides the design process with precision, utilizing two 3D printers of Creality Ender 3 that exclusively uses PLA filament, and the Ultimaker 3 Extended which is equipped with dual print cores that utilize both PLA and PVA filaments. The inclusion of PVA as a support material proves pivotal in facilitating the printing of intricate designs due to its facile removal and environmentally friendly properties. The PVA is better at support compared to PLA with lesser damage. This study significantly contributes to optimizing 3D printing processes, addressing challenges related to intricate designs and support structure removal. The findings are relevant for industries relying on precise components through 3D printing, marking a stride towards enhanced manufacturing efficiency.

Keywords: polyvinyl alcohol; polylactic acid; 3D printing; biodegradable.

Abbreviations

AM	Additive Manufacturing
PPE	Personal Protection Equipment
FDM	Fused Deposition Modelling
PVA	Polyvinyl Alcohol
PLA	Polylactic Acid
ABS	Acrylonitrile Butadiene Styrene

1.0 INTRODUCTION

3D printing stands as a groundbreaking technology in modern manufacturing, revolutionizing the production landscape with its additive approach to fabrication. Unlike traditional subtractive methods, which involve cutting away material from a solid block, 3D printing, also known as additive manufacturing (AM), constructs objects layer by layer, based on digital designs. AM allows designers to create any object including complex parts such as machines, airplanes, and cars at a fraction of the cost and time of standard means like forging molding, and sculpting. This method offers unparalleled versatility, enabling the creation of intricate geometries and customized components with precision and efficiency. 3D printing has emerged as a pivotal technology, offering a diverse array of printing methodologies tailored to the specific demands of various industries. Among these methodologies are Binder Jetting (BJ), Directed Energy Deposition (DED), Selective Laser Sintering (SLS), and Fused Deposition Modeling (FDM) [1]. While these techniques all operate within the realm of additive manufacturing, each possesses distinct characteristics and applications that warrant exploration.

Binder Jetting (BJ) is a type that uses the technique of dispensing a liquid binding agent on the powder which contributes to high production rates [2]. Directed Energy Deposition (DED), in contrast, involves the deposition of feedstock material, whether in wire or powder form onto a substrate using an energy source such as a plasma arc, making it particularly suited for the repair and remanufacturing of metallic components within industries such as aerospace and automotive [3]. Selective Laser Sintering (SLS), renowned for its adaptability in handling flexible materials like nylon and acrylic in powder form, finds application in diverse domains, including the fabrication of metal parts and tissue scaffolds for pharmaceutical applications [4].

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Amidst this array of 3D printing methodologies, Fused Deposition Modeling (FDM) emerges as a prominent and widely embraces technique. FDM operates on the principle of extruding thermoplastic filament material, such as Polylactic Acid (PLA) or Acrylonitrile Butadiene Styrene (ABS), through a heated nozzle onto a build platform, where it solidifies layer by layer to form the desired object. This additive manufacturing process enables the creation of prototypes, parts, and products with intricate detail and complexity, positioning FDM as a preferred choice across various industries, including aerospace, automotive, and healthcare. FDM's simplicity, reliability, and cost-effectiveness have made it accessible to a wide range of users, from hobbyists and entrepreneurs to large-scale manufacturers. Given its accessibility and versatility, FDM widespread adoption across industries such as aerospace, automotive, and healthcare not only demonstrates practical utility but also offers a cost-effective means of producing prototypes, parts, and products with intricate detail and precision.

FDM process is initiated with the creation of a digital model using Computer-Aided Design (CAD) software, or by utilizing pre-existing designs. CAD software is the key to further expansion of 3D printing servicing as the gateway for translating conceptual designs into printable objects [5]. Subsequently, the digital model undergoes slicing, a fundamental step where the model is meticulously segmented into horizontal layers. Slicing software plays a critical role in this phase, as it translates the layered model into instructions comprehensible to the 3D printer as shown in Figure 1. These instructions, often encoded in G-code, dictate the precise path that the printer's extrusion nozzle follows and the deposition of material for each layer [6]. Essentially, slicing software acts as a bridge between the digital design and the physical object, ensuring accurate translation from virtual to tangible.

Following the completion of the slicing process, the FDM printer commences fabrication by introducing thermoplastic filament, typically in spool form, into the printer's extruder assembly. Within the confines of the extruder, the filament is subjected to controlled heating, reaching temperatures where it transitions into a malleable or molten state. Subsequently, the extruder's nozzle orchestrates the precise deposition of the liquefied filament material onto either the build platform or previously deposited layers, adhering meticulously to the layer-by-layer instructions generated during the slicing phase. As the molten filament material is gradually deposited, it undergoes rapid cooling and solidification, culminating in the formation of the desired object's structure. Throughout the printing process, the build platform may maneuver vertically or horizontally to facilitate the deposition of each layer, ensuring optimal alignment and geometry.

Fused Deposition Modeling (FDM) is renowned for its adaptibility in proccesing diverse array of materials, notably accomodating polymers such as Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), Polyvinyl Alcohol (PVA), Polycarbonate (PC), and Polyethylene Terephthalate (PET) [7]. Among these materials, PVA filament offers unique advantages in the fabrication of complex structures. Its solubility in water revolutionizes the post-printing process by enabling effortless removal of support structures, thereby preserving the integrity and details of the final product. The significance of Polyvinyl Alcohol (PVA) filament extends to its role as a support material and its impact on support structure removal in FDM printing. Unlike traditional support materials, PVA's water solubility enables the dissolution of support structures without manual intervention, simplifying post-processing workflows and enhancing overall printing efficiency, especially for designs requiring intricate support structures. Extensive research underscores this attribute, highlighting PVA's pivotal contribution to streamlining the production of detailed and complex models through FDM technology [8].

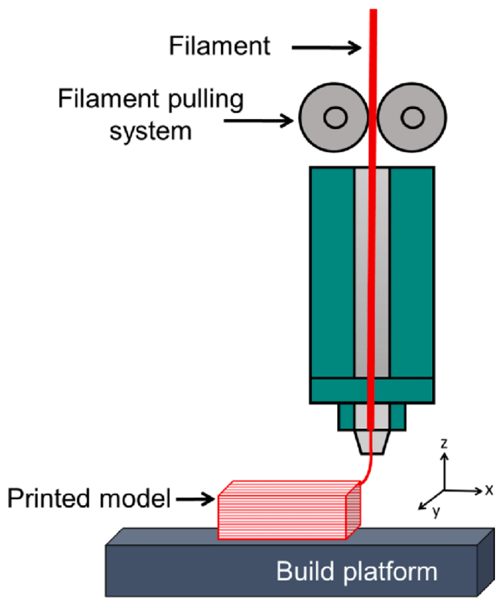


Figure 1. Schematic Diagram of FDM

One of the primary techniques employed to eliminate support structures when using PVA filament is the water leaching method. This method involves immersing the printed object in water, allowing the gradual dissolution of the PVA supports over time. The water leaching approach provides a gentle and eco-friendly means of support removal, reducing the risk of damage to the printed object during post-processing. It is particularly advantageous for intricate designs and delicate structures where manual support removal may pose challenges. Through an investigation into the effectiveness of Polyvinyl Alcohol (PVA) filament and the water leaching method in support structure removal, this study aims to provide valuable insights into optimizing the FDM printing process. By conducting experimental analyses and evaluations, we seek to understand how PVA filament affects model quality, printing efficiency, and post-processing workflow. Additionally, we aim to compare the water leaching method with traditional support removal techniques to delineate their respective advantages and limitations, thereby contributing to the advancement of 3D printing methodologies across diverse industries.

This study delves into the impact of Polyvinyl Alcohol (PVA) filament on the 3D printing process, focusing specifically on support structure removal and overall model quality. It involves categorizing models into three complexity levels: a simple block for basic structures, a Hilbert cube for intermediate complexity, and a mini gyro for intricate designs, by assessing the time required for support removal and the resulting model quality. Utilizing specific 3D printing techniques with dual extrusion, samples are fabricated with and without PVA filament to comprehensively evaluate its effects throughout the printing process. By comparing outcomes between PLA and PVA filaments, this research aims to offer insights into the practical applications and benefits of PVA in FDM printing, contributing to the ongoing development and optimization of 3D printing technologies.

2.0 METHODOLOGY

The core objective of this study’s methodology is to conduct a comparative analysis between two sets of support material configurations in Fused Deposition Modeling (FDM) 3D printing processes. Specifically, the study aims to assess and compare the outcomes when using Polylactic Acid (PLA) for both the object and its support structures using PLA for the object with Polyvinyl Alcohol (PVA) as the support material. This comparison intends to elucidate the advantages and potential challenges associated with the use of water-soluble PVA as a support material, particularly focusing on the ease of support structure removal, the impact on the quality of the final printed product, and overall printing efficiency.

2.1. Sample preparation

This study's experimental design includes the utilization of three geometrically distinct models, each embodying different levels of complexity to rigorously evaluate the effects of support material choice on the printing process and final print quality. The selected models are: a basic block, representing simple geometric forms; a Hilbert cube, which introduces intermediate complexity with its intricate voids and overhangs; and a mini gyro, embodying high complexity with its closely packed, delicate features. These models are specifically chosen to thoroughly test the support removal process across a spectrum of design intricacies and to scrutinize the impact on print quality under varied conditions. The model is designed using Autodesk TinkerCAD, a CAD system renowned for its user-friendly interface and wide accessibility. TinkerCAD is chosen due to its simplicity and the convenience it offers, allowing for rapid design iterations without the need for software installation, being accessible directly online. Its extensive library of pre-existing models further augments its utility, serving as a robust platform for creating the required digital models.

To conduct a comprehensive comparison of the use of PVA support structures against traditional methods, we fabricated three variants of each model type, culminating in a total of nine models specifically designed to utilize PVA as a support material. To establish a control group, an identical set of nine models was produced without using PVA supports, amounting to eighteen samples in total. This dual approach allows for an in-depth comparative analysis between the two sets of models - nine employing PVA supports and nine without. The specific details of each model, including dimensions, complexity level, and the categorization into groups for subsequent analysis, are systematically outlined in Table 1, which serves as a reference for the evaluation phase of the study. This structured approach to sample preparation is pivotal for assessing the practical advantages and limitations of using PVA as a support material in the context of FDM 3D printing.

Table1: Design detail of the 3D model

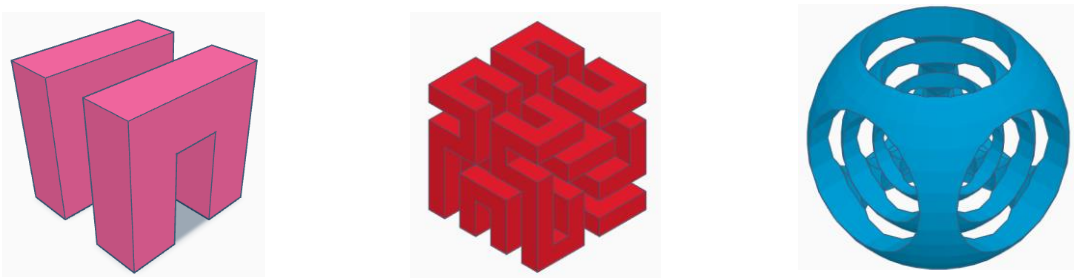
Design category	Design model	Dimension (mm)
Simple	Simple block	40 x 40 x 40
Medium	Hilbert cube	40 x 40 x 40
Complex	Mini gyro	50 x 50 x 50

The simple block design consists of an uppercase letter “H” formed by a series of rectangular prism shapes. Two vertical sections, representing the vertical strokes of the letter “H”, are solid rectangular prisms. These vertical elements are connected by a horizontal rectangular prism positioned in the middle. This design presents a straightforward geometric configuration, characterized by its clear delineation of shapes and minimal complexity. The Hilbert cube design is inspired by the mathematical concept of a Hilbert curve, a continuous fractal space-filling curve [9]. In this context, the design comprises a series of interconnected cubes arranged in a recursive, self-similar pattern. The arrangement of cubes follows the trajectory of the Hilbert curve, resulting in a structure that traverses three-dimensional space while maintaining a coherent geometric progression. Each cube in the design is linked to its neighbours through shared faces or edges, contributing to the overall continuity and complexity of the pattern. The Hilbert cube design offers a visually intriguing and mathematically inspired representation of recursive geometry.

The mini gyro design draws inspiration from geometric shapes reminiscent of a geodesic sphere or polyhedron composed of triangular facets. The overall structure approximates the spherical form through the arrangement of interconnected triangles, creating a network of intersecting circular openings or cutouts. These circular openings punctuate the surface of the mini gyro, resulting in a pattern of curved, hollow sections that enhance its visual appeal and structural integrity. The geometric arrangement of triangles contributes to the overall stability and balance of forces within the design, showcasing an efficient distribution of mass and reinforcing its geometric complexity. Figure 2 illustrates the design of the 3D model for each design category.

Following the design phase, the models are prepared for printing through the process of slicing, using Ultimaker CURA. This software is selected for its reliability and compatibility with the chosen dual-extrusion FDM 3D printers, ensuring that the digital designs are accurately translated into printable G-code, optimized for employing PVA as a soluble support material in conjunction with PLA for the object itself. The Simple Block design features straightforward geometric shapes with minimal intricacies. Due to its simple geometry, the Simple Block design necessitates minimal support structures. Supports is only required beneath the horizontal voids within the “H” shape to prevent drooping or deformation during printing as shown in Figure 3 (a).

The Hilbert Cube design exhibits a moderate level of complexity, derived from its recursive, self-similar pattern of interconnected cubes. Supports are needed to prevent deformation or sagging along the outer edges of the cubes, especially in areas where the design changes direction. As the cubes progress along the Hilbert curve, supports become increasingly crucial to uphold the integrity of the intricate geometric pattern. The support structure for the design is illustrated in Figure 3 (b).



(a) (b) (c)

Figure 2. 3D model design for (a) simple cube, (b) Hilbert cube, and (c) mini gyro

(a) (b)

Figure 3. Support structure after slicing for (a) simple cube, and (b) Hilbert cube

(a) (b)

Figure 4. Support structure after slicing for mini gyro (a) orthogonal view, and (b) front view.

The Mini Gyro design comprises interconnected triangles forming circular openings, resulting in a visually complex and structurally sophisticated design. Given its intricate geometry and intersecting surfaces, the Mini Gyro design requires extensive support structures to uphold its integrity during printing. Supports are necessary at the points where the triangular facets intersect and along the edges of the circular openings to prevent drooping or distortion.

2.2. Printing

The 3D printing process begins with exporting the TinkerCAD design files into STL format, followed by importing them into Ultimaker CURA slicing software for processing. Two different 3D printers are utilized in this production process: the Ultimaker 3 Extended and the Creality Ender 3. The Ultimaker 3 Extended is equipped with a dual extrusion mechanism, with the first nozzle dedicated to PLA filament and the second to PVA support material. Conversely, the Creality Ender 3 exclusively uses PLA filament. Both FDM 3D printers are calibrated to ensure uniform printing conditions across all experiments. Standardizing printing parameters such as layer height, nozzle temperature, and print speed minimizes variability in the printing process as tabulated in Table 2.

To accommodate the use of different support materials, two sets of each model are generated using the respective 3D printers. Models utilizing PVA as the support material are printed using the Ultimaker 3 Extended's dual extrusion mechanism, with the first nozzle allocated for PLA filament and the second for dispensing PVA support material. Conversely, model sets produced solely with PLA filament as the object and also the support material are printed using the Creality Ender 3. This strategic selection of printers facilitates precise evaluation of the impact of support material type on post-processing and final print quality, while also considering the influence of printer specifications and capabilities.

Table 2: Parameters of 3D printer

Parameter	Creality Ender 3	Ultimaker 3 Extended	
		PLA	PVA
Build plate temperature (ºC)	60	60	
Layer high (mm)	0.15	0.15	
Infill Density (%)	40	40	
Infill Pattern	Triangles	Triangles	
Printing Temperature (ºC)	200	205	220
Printing Speed (mm/s)	50	50	35
Support Density (%)	10	-	5
Support Pattern	Grid	-	Grid
Support Structure	Normal	Normal	
Build Plate Adhesion	Brim	Brim	

(a) (b)

Figure 5. 3D printer (a) Creality Ender 3, and (b) Ultimaker 3 Extended.

2.3. Post-processing

The post-processing phase for 3D printed constructs involves two principal methods for the removal of support structures: water leaching and manual excision using fine nipper cutters. Water leaching entails the immersion of the additive manufactured object in a water bath to facilitate the dissolution of water-soluble materials such as PVA. For more efficient dissolution, ultrasonic waves may be utilized, followed by a meticulous rinse and subsequent drying of the object to ensure the complete removal of support material as shown in Figure 6. In contrast, manual excision necessitates the utilization of precision nipper cutters to strategically sever the supports, thus offering superior precision and control but at the expense of increased labor and time investment. A detailed inspection of the 3D printed object is imperative for identifying the precise locations of support attachments before commencing manual removal to prevent inadvertent damage to the object. While water leaching is the method of choice for complex or delicate structures, manual excision is favored for materials impervious to water or for constructs with substantial support structures. The selection between these post-processing methods is dictated by factors pertaining to the material composition, the complexity of the printed form, and the requisite quality of the final output.

Removing support structures for 3D printing manually with nipper cutters is a meticulous process that provides precise control over the removal. By carefully identifying and trimming away support structures using sharp nipper cutters, users can effectively remove unwanted material without damaging the main printed object. While this method demands attention to detail and may be time-consuming, it ensures a clean and smooth finish, especially in areas where automated support removal might be challenging. With proper technique and the right tools, manual support removal using nipper cutters enables users to achieve high-quality results, preparing the printed object for further processing or immediate use.

When using nipper cutters to remove support structures from 3D prints, there is a risk of damaging the product. This may result in scratches on the surface, changes in shape, or weakened strength. Careless removal of supports can lead to small pieces getting stuck in the print or incorrect fitting of parts. To prevent these issues, it is crucial to handle the cutters gently, proceed slowly with the process, and thoroughly inspecting the print afterwards.

Figure 6. Ultrasonic Cleaner for Water Leaching

2.4. Evaluation

Following the printing process, a comprehensive assessment is conducted to evaluate the surface finish and support structure removal efficacy of the fabricated models. This evaluation aims to elucidate the performance of different support materials and their impact on print quality. The assessment includes visual inspection for surface finish quality and the ease of support removal. Additionally, any resulting damages or imperfections throughout the process is documented. Through this evaluation, significant differences between models printed with PVA supports and traditional materials are highlighted, providing insights into the advantages and potential limitations of PVA in FDM 3D printing. By comparing results from models using PLA supports with those using PVA supports, the study seeks to offer concrete insights into how the choice of support material influences the overall 3D printing process.

The efficacy of support structure removal is a critical aspect of the evaluation process, particularly for models printed with PVA support material. The support structures are carefully removed from the printed models using appropriate techniques, such as manual removal, water leaching, or solvent dissolution. The efficiency of support removal is assessed based on factors such as ease of removal, completeness of support structure dissolution, and any residual marks or damage left on the models' surfaces. Surface finish evaluation is conducted to evaluate the smoothness, uniformity, and overall quality of the printed models' surfaces. This assessment involves visually inspecting the surfaces for imperfections such as layer lines, rough patches, or surface irregularities that may affect the models' appearance or tactile properties. Techniques such as surface roughness measurement using profilometers or visual inspection under magnification may be employed to quantify surface roughness and identify areas requiring improvement.

3.0 RESULTS AND DISCUSSION

3.1 Printed model

The printed models were produced in two sets to facilitate a comparative evaluation of the printing process and final print quality. The first set of models was printed using only PLA filament without the incorporation of PVA support material. While PLA is a commonly used filament known for its ease of use and reliability, it requires the addition of support structures to facilitate the printing of complex geometries. Support structures printed with PLA filament typically need to be manually removed after printing, which can be time-consuming and may result in surface imperfections or damage to the final print. The printing process for the PLA-only version involves single extrusion, utilizing the Creality Ender 3 3D printer. Although this printer lacks dual extrusion capabilities, it still produces high-quality prints using PLA filament alone.

The next set was printed using a combination of Polyvinyl Alcohol (PVA) as the support material and Polylactic Acid (PLA) as the primary filament. The utilization of PVA as a support material offers the advantage of water solubility, enabling easy removal of support structures without manual intervention. This approach is particularly beneficial for printing intricate and complex designs, where support removal can be challenging using traditional methods. The printing process involves dual extrusion, with the Ultimaker 3 Extended allocating one nozzle for PLA filament and the other for PVA support material. This setup ensures precise deposition of both materials, resulting in high-quality prints with minimal post-processing requirements. The final result of the printed model is complemented in Figure 7 and Figure 8, which illustrate the two sets of the printed models and highlight the differences in print quality and support structure implementation.

(a) (b) (c)

Figure 7. PLA samples with PLA support (a) Simple (b) Medium (c) Complex

(a) (b) (c)

Figure 8. PLA sample with PVA support (a) Simple (b) Medium (c) Complex

3.2 Ease of support removal

When examining the methodologies for removing support structures from 3D printed models, a direct comparison between dissolving in water and using a manual remover as shown in Table 3 and Table 4 reveals insightful trends regarding efficiency and suitability. For simple samples, the dissolution process shows a fairly consistent time requirement of roughly 23 minutes, suggesting reliability but not necessarily efficiency. On the other hand, the nipper cutter method offers a marked improvement in time management, with simple supports being removed in under 3 minutes. The discrepancy between the two methods is substantial, indicating a clear preference for mechanical cutting with simpler geometries.

As the complexity of the samples increases to a medium level, the dissolving method continues to maintain a consistent time band, albeit slightly longer, averaging around 39 minutes. In contrast, the nipper cutter method exhibits a significant variance in removal times for medium samples, which can be attributed to the intricacies involved in accessing and manually cutting the supports, leading to times that range from about 13 to 22 minutes.

What is particularly intriguing is the performance of both methods with complex samples. Despite the elaborate nature of complex supports, the time taken to dissolve them in water slightly decreases, potentially due to the support design facilitating more efficient water flow. In a similar timeframe, the nipper cutter again has a wide-ranging removal time, comparable to the dissolution times, suggesting that its effectiveness is mitigated by the complex nature of the supports which may hinder access and cutting actions.

Ultimately, the choice between dissolving and using nipper cutters is a trade-off between the time savings and the practical challenges presented by the support complexity. For simple geometrics, nipper cutters are undeniably efficient and practical. However, as complexity escalates, the nipper cutter's advantage diminishes, and for more consistent but slower, dissolving method may be a more suitable choice, particularly when dealing with intricate and densely supported structures which are cumbersome to remove manually.

Table 3: The time taken for removing support of the 3D model by dissolving in water

Type of samples	Time taken		
	1st	2nd	3rd
Simple	22 min 44 sec	22 min 32 sec	23 min 19 sec
Medium	38 min 13 sec	40 min 24 sec	38 min 46 sec
Complex	20 min 58 sec	21 min 37 sec	21 min 17 sec

Table 4: The time taken for removing support of the 3D model by using a nipper cutter

Type of samples	Time taken		
	1st	2nd	3rd
Simple	1 min 25 sec	2 min 46 sec	47 sec
Medium	22 min 13 sec	12 min 51 sec	17 min 5 sec
Complex	23 min 16 sec	20 min	25 min 18 sec

3.3 Surface finish evaluation

The evaluation of surface finish is pivotal in determining the overall quality and visual appeal of 3D printed models. Upon meticulous examination, it becomes evident that the choice of support material plays a significant role in influencing surface finish. Models produced with PVA supports showcase notably smoother surfaces compared to those relying solely on PLA filament for support. This distinction can be attributed to the water-solubility of PVA, which facilitates cleaner support structure removal, thus minimizing post-processing needs. Moreover, the use of PVA supports contributes to reduced surface imperfections, such as visible layer lines and rough patches, enhancing the overall aesthetic quality of the models. Conversely, models printed with PLA supports often exhibit more pronounced layer lines and surface irregularities, particularly around support attachment points. These findings underscore the critical importance of selecting an appropriate support material to achieve desired surface finish quality in 3D printing.

Furthermore, variations in surface texture are observed across different sections of the printed models. While certain areas display smoother surfaces, others exhibit slight inconsistencies and roughness, particularly near support attachment points. This uneven surface texture is more evident in models printed with PLA supports, highlighting the challenges associated with support removal and its impact on surface quality. The surface finish evaluation emphasizes the crucial role of support material selection in achieving desired surface smoothness and quality in 3D printed models. The smoother surface finish observed in models printed with PVA supports underscores the advantages of utilizing water-soluble support materials, offering potential benefits for applications requiring high-quality surface finishes.

The findings presented in Table 6 show that the overall quality of the printed models is satisfactory, with no noticeable defects observed. However, the surface texture appears slightly rough, attributed to the absence of post-finishing processes and the utilization of a printing profile with a 0.15mm layer height. Employing a finer printing profile, such as 0.1mm or lower, could potentially result in smoother surface finishes. Additionally, the use of PVA as a support material facilitates zero waste, as the supports are dissolved in water post-printing. Upon analyzing the data from Table 5, it is evident that some models incur damage during the support removal process. While the simple cube model remains undamaged and exhibiting good quality, the Hilbert cube model experiences breakage in a specific part, resulting in compromised quality. Similarly, the mini gyro model exhibits subpar quality due to the effects of support removal, particularly affecting the inner sphere's rotation capability. These observations underscore the importance of utilizing PVA as a support material, especially for complex designs, to ensure high-quality output while minimizing the risk of model damage.

Table 5 showcases the results obtained when solely utilizing PLA filament without PVA support, while Table 6 illustrates the outcomes of printing models using a combination of Polyvinyl Alcohol (PVA) as support material alongside Polylactic Acid (PLA) filament.

Table 5: The quality of 3D model with PLA samples as support structure

Model	Diagram	Damage
Simple block		No damage
Hilbert cube		2 units damaged
Mini gyro		Damage at the support area

Table 6: The quality of 3D model with PVA samples as support structure

Model	Diagram	Damage
Simple block		No damage
Hilbert cube		No damage
Mini gyro		No damage

3.4 Limitation

In the context of removing supports from 3D printed objects, the complexity of a model's geometry can lead to significant challenges. Simplistic models with minimal overhangs and easily accessible supports can often be quickly and cleanly processed using mechanical methods such as nipper cutters. However, as the complexity increases, with more intricate overhangs, delicate features, and dense support structures, the limitations of mechanical removal become apparent. The risk of damaging the model rises due to the force applied and the difficulty in reaching tight spaces without impacting the model's integrity.

Dissolution methods offer an alternative where supports are chemically or water-solubly removed, mitigating the risk of physical damage to the object. This is particularly beneficial for complex shapes with detailed geometries that are more susceptible to breakage or distortion during mechanical support removal. Yet, this approach is not without its drawbacks; the time required for complete dissolution can be excessive, and the need for specific materials like PVA for supports constrains material selection and can increase costs.

Additionally, both methods may impose limitations when scaling up production. For single prints or small batches, the slower dissolution process may be acceptable, but in a production environment where time is a factor, the slow processing time becomes a bottleneck. Conversely, manual mechanical removal might be feasible for a low volume of prints but becomes labor-intensive and impractical at scale.

These limitations emphasize the importance of future advancements in 3D printing technology and materials to overcome the challenges posed by complex geometries. Continuous development in support materials designed for easy removal and improved 3D printing techniques that reduce the need for supports can help alleviate such constraints, leading to more efficient post-processing even for the most complex designs.

4.0 CONCLUSION

In summary, comparing the use of water dissolving and a manual remover for removing support structures from 3D printed models shows that while the manual remover method is more effective for simple shapes, the dissolution method is better suited for intricate and densely supported structures. The assessment of surface finish also highlights the importance of choosing an appropriate support material, with PVA supports resulting in noticeably smoother surfaces compared to those relying solely on PLA filament for support. Moreover, using PVA as a support material not only reduces surface imperfections but also enables zero waste since the supports dissolve in water after printing. It is evident that utilizing PVA supports minimizes model damage risk, especially for complex designs. These findings underscore the advantages of employing water-soluble support materials for applications requiring high-quality surface finishes and reducing post-processing requirements. Additionally, there is potential noted for achieving smoother surface finishes by employing a finer printing profile such as 0.1mm or lower. Overall, these results demonstrate how crucial selecting the right support material is in achieving high-quality output and visual appeal in 3D printed models, with PVA emerging as a favourable choice to achieve the desired surface finish quality. The way forward for this product can be included in the medical industries for the pallet design. The design also needs to be high complexity.

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