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INVESTIGATION ON DIMENSIONAL ACCURACY OF ADDITIVE MANUFACTURED SAMPLES

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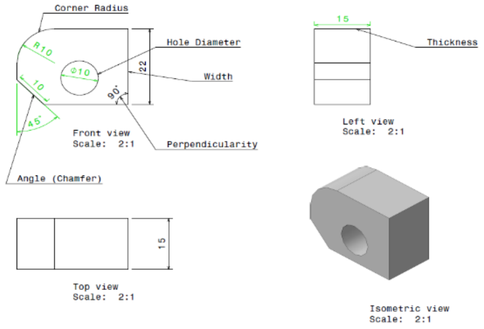
Graphical abstract



Abstract

Fused deposition modelling (FDM) is a typical 3D printing process. Some benefits of FDM-printed components are durability, mechanical property stability, and the quality of the parts. However, it has several drawbacks, such as the emergence of seamlines between layers and the creation of extra material residue on the surface of the printed object, which compromises the dimensional accuracy of the printed part. When making pieces that fit correctly, the dimensions of 3D-printed components must be accurate. This article discusses the dimensional accuracy of 3D-printed components created using an open-source FDM 3D printer. The filament material for printing the test samples is stainless steel, ABS and tough PLA. The test samples were printed three times each and examined using a coordinate measuring machine (CMM). The geometries measured and compared between the three printed sample materials are the thickness, corner radius, angle, perpendicular, hole diameter, and flatness. The result shows that the printed samples could not achieve 100% dimensional accuracy, with stainless steel having the highest accuracy ranging from 99 - 98%. The data of stainless steel were then compared side by side with Tough PLA and ABS, where the accuracy of stainless steel is similar to ABS while PLA has the lowest accuracy. The accuracy of the stainless-steel specimen was then analysed and compared to tough PLA and ABS to identify the printing accuracy of the stainless-steel specimen, which is relatively new.

Keywords: Dimensional accuracy, fused deposition modeling, stainless steel, ABS, Tough PLA, coordinate measuring machine

Abstrak

Pemodelan deposis lakur (FDM) ialah teknik biasa digunakan untuk pencetakan 3D. Ketahanan bahan, kestabilan sifat mekanikalnya dan kualiti bahagian adalah beberapa kelebihan bahagian cetakan FDM. Walau bagaimanapun, ia juga mempunyai beberapa batasan contohnya penampilan garis cetakan antara lapisan dan pembentukan sisa bahan yang berlebihan pada permukaan bahagian yang mempengaruhi ketepatan dimensi bahagian yang dicetak. Ketepatan dimensi bahagian bercetak 3D adalah kritikal apabila menghasilkan bahagian yang mesti muat dengan betul. Artikel ini membentangkan penemuan ketepatan dimensi bahagian yang dicetak daripada pencetak 3D FDM sumber terbuka. Bahan filamen yang digunakan untuk mencetak sampel ujian ialah keluli tahan karat, ABS dan PLA teguh. Sampel ujian dicetak tiga kali dan diuji menggunakan mesin pengukur koordinat. Ketebalan, jejari sudut, sudut, serenjang, diameter lubang dan kerataan adalah geometri yang diukur dan

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perbandingan antara tiga jenis bahan sampel yang dicetak telah dijalankan. Keputusan menunjukkan tiada sampel yang dicetak mampu mencapai ketepatan dimensi 100% dimana sampel Keluli Tahan Karat berjaya mencapai nilai 99 - 98%. Data sampel keluli kemudian dibandingkan Bersama data sampel PLA Teguh dan ABS dimana data besi keluli direkod dan dianalisa kerana data besi keluli adalah data yang agak baharu di dalam duni pencetakan 3D.

Kata kunci: Ketepatan dimensi, pemodelan deposis lakur, Keluli tahan karat, ABS, PLA teguh, mesin pengukur koordinat

1.0 INTRODUCTION

Additive manufacturing (AM) is a unique manufacturing technique that includes layer-by-layer addition of materials from 3D CAD model data to create components or products. It has various advantages over conventional production. AM, often known as 3D printing, is a cost-effective and time-saving process for producing low-volume, customised objects with complicated geometries, advanced material properties, and functionality [1]. 3D printing, additive fabrication, and freeform fabrication are all terms used to describe AM. While specific AM advanced approaches are still in their infancy, they are generally expected to influence future product design and development significantly. This is due to AM providing new design freedom, reducing waste, reducing energy consumption, and reducing time to market [2].

AM is experiencing a dramatic transition, culminating in exponential growth in its use [3-4]. The expansion is partly attributable to its precise and reproducible design skills across various materials. Initially, AM was utilised to make moulds and prototypes. This accelerated the prototyping process for multiple sizes, styles, materials, and colours. Currently, 3D printing is available to the general public, and a simple open-source fused deposition modelling (FDM) printer may be acquired for a low price. FDM technique is much less costly than other AM technologies because of its simplicity. FDM was created for printing polymer materials. However, FDM printers are presently utilised to print a variety of materials. In the FDM method, a filament material is first melted in the printing nozzle at a temperature slightly over the material's melting point, deposited layer by layer onto the printer hotbed under computer control, and eventually fused with the bottom neighbouring layers.

Metals, polymers, composites, and other powders materials may now be used to "print" a variety of functional components, including complicated structures that can't be made any other way, using AM technology. FDM has also been widely employed in printing working prototypes in various metal printings [5-6]. Steel and its alloys are the most often used metals in additive manufacturing because of their accessibility, affordability, and biocompatibility as bone and dental implants. Nickel, aluminium, copper, magnesium, cobalt-chrome, and tungsten are the least commonly utilised metals, followed by titanium and its alloys [7]. To increase mechanical properties, crack-free metal matrix composites (MMC) with a density of 99.9% may be coupled with tungsten carbide-cobalt (WC-Co), ceramic, or nonferrous reinforcements [8].

The dimensional precision of AM components is particularly crucial, especially in producing assemblies or parts that fit precisely together [9]. The research identifying the standard parameters that might impact dimensional accuracy, such as raster angle, printing speed, layer thickness, and build orientation, will be essential for determining the dimensional accuracy of a particular item. The design significantly impacts the dimensional correctness of the printed component. AM is poorly appropriate for flat surfaces or extended thin unsupported features. As component sizes increase, the dimensional accuracy may decrease, while smaller, more complicated parts need more precision [10]. In addition, changes in cooling and curing might cause internal tensions that ultimately lead to warping or shrinking, impacting the dimensional accuracy of the printed components.

This research analyses and evaluates printed samples' dimensional accuracy of stainless steel, Tough PLA, and ABS materials. This is because Tough PLA and ABS are vastly used materials in the 3D printing industry, which can be used as the benchmark for comparative analysis with stainless steel. Using a coordinate measuring machine (CMM), the dimensional accuracy of the samples produced by an open source 3D printer was determined. The thickness, corner radius, angle, perpendicular, hole diameter and flatness are the geometries measured and compared between the three types of specimen printed. For certain materials such as Tough PLA and ABS, extensive research has been done to identify the dimensional accuracy as it is a well-known material.

On the other hand, the material itself has not been assessed more in terms of dimensional accuracy for stainless steel. Studies regarding stainless steel in AM that have been conducted before involve more regarding the material's strength and efficiency, thus lacking data regarding the dimensional accuracy of the material itself [11]. stainless steel will be studied more in the paper by comparing it with Tough PLA and ABS as a direct comparison.

2.0 BACKGROUND

2.1 Additive Manufacturing Process

AM techniques use the information from a computer-aided design (CAD) file that is afterwards transformed into a stereolithography (STL) file. In this procedure, the CAD-created structure is approximated by triangles and sliced with the information for each layer that will be printed [12]. The aerospace industry utilises them because of the potential of constructing lighter structures to cut weight. AM is revolutionising the practice of medicine and making work more straightforward for architects [13].

Metal AM methods are applied to build complicated geometrical items using 3D CAD model data. The metal powders are placed in consecutive layers until the final product is created. Process parameters of AM include layer thickness, scan speed, hatch spacing, size of the powder particles and orientation of the layer [14]. This AM technology is employed in numerous sectors such as biomedical and aerospace since AM contains features such as little waste and flexibility in the design of the complicated form. AM adequately replaced traditional manufacturing procedures, and it has obtained the immense capacity to create metal components with excellent integrity. AM seems a potent method for minimising complexity and producing customised goods [15-17].

2.2 Fused Deposition Modeling Process

FDM is a well-established AM technique primarily used to produce functional prototypes, reducing lead time and end-use items in certain circumstances. Consequently, it is vital to carefully inspect and create a component with the highest feasible degree of dimensional precision. The designed CAD model is converted to the STL file format and sliced layer-by-layer using slicing software and the FDM printer [18-19]. The material filament is semi-melted in the print head before extruding onto the build platform. The thermoplastics ABS and PLA are the most common materials employed in the FDM process. FDM components are among the most resilient compared to other polymer-based AM methods. Layer by layer, the material is extruded from the nozzle head to create the component. The nozzle is heated to melt the material before printing. FDM printers are equipped with a device that regulates the flow of molten plastic [20]. As the liquefier moves, the extruded polymer is deposited, first with the object's perimeter and then filling it in. The nozzle is positioned on a mechanical, movable stage in horizontal and vertical planes. Instead of adhering to the standard, several producers took the reverse route and moved the table [21].

Various applications have successfully used AM technology. FDM is one of the most common AM processes and the most extensively used method for generating thermoplastic components. It is mainly utilised as quick prototypes for functional testing because of its cheap cost, minimum material waste, and simplicity of material change. Due to the inherently restricted mechanical qualities of pure thermoplastic materials, there is an urgent need to enhance the mechanical properties of pure thermoplastic components manufactured using FDM. One of the conceivable approaches involves incorporating reinforced materials (such as carbon fibres) into plastic materials to create thermoplastic matrix carbon fibre reinforced plastic (CFRP) composites that may be utilised in practical application sectors, such as aerospace, automotive, and wind energy [22].

In recent years, FDM has accomplished a growing number of novel advancements and applications, demonstrating the immense potential of this AM technology. During the COVID-19 pandemic, FDM made personal protective equipment (PPE), like face masks and respirator face shields. Between 2020 and 2021, a significant number of new materials designed for FDM were developed, including new fibre-reinforced composites with superior mechanical properties, advanced polymer-based nanocomposites prepared with the addition of carbon nanomaterials, and numerous other polymer-based composites with improved physical properties [23].

FDM is increasingly used in the industry because of its benefits over traditional procedures like casting and machining. One of these advantages is that, compared to these conventional technologies, FDM has the potential for better resolution, making it suitable for fabricating complex components with intricate internal structures [24].

Most powder-bed-based AM systems use a powder deposition technique involving a coating machine to apply a powder layer to a substrate plate and a powder reservoir. After dispersing the powder layer, a 2D slice is bonded (3D printing). A powder bed can be melted by directing an energy beam onto the bed. Direct process powder bed systems are marketed as laser melting processes and are sold under a variety of brand names, including Selective Laser Melting (SLM), Laser Curing, and Direct Metal Laser Sintering (DMLS) [25-26]. The machine selection is determined by the user's needs, with the kind of laser unit, powder handling, and build chamber being among the essential aspects of the system to consider. There are several metal materials available for metal 3D printing systems. The most often used materials include alloys of stainless Steel, aluminium, nickel, cobalt-chromium, and titanium. Other materials include tool steels, alloys based on nickel, alloys containing precious metals, and copper alloys [27]. When selecting a material, it is essential to consider its tensile strength, hardness, and elongation. Because there is a vast selection of materials, it is simple to include the ideal material for a project in the specification of a product.

2.3 Dimensional Accuracy

The most crucial element of maintaining the dimensional repeatability of produced components is the component's dimensional correctness and the degree of agreement between the manufactured dimension and its specified specification. A part's dimensional accuracy is the degree of agreement between the manufactured dimension and its intended specification [28]. A component's dimensional correctness is determined by its size (size tolerance) and shape (geometric tolerance, including form, orientation, and location). Dimensional accuracy measures how closely the product's dimension matches the ideal products. The intended precision of components is denoted by the numerical numbers provided by machine makers and material suppliers.

All specified tolerances pertain to properly built and calibrated components and equipment. It is possible to verify the dimensional correctness of a part by utilising callipers, micrometres, intelligent scopes, and coordinate measuring devices. Tolerance refers to the overall permissible mistake inside an item, regardless of whether the error is above or below the target value. Typically, it is stated as a +/- value relative to a specification. The goods may distort due to variations in temperature and humidity that result in material expansion and contraction [29]. Errors involving design values must thus be considered throughout the production and inspection procedures. The mistake is ruled unacceptable if it does not fall within the permissible tolerance.

2.4 Factors Affecting Dimensional Accuracy

The dimensional accuracy of 3D-printed components is crucial when fabricating large assemblies or pieces that must fit precisely. Numerous frequent issues may affect its accuracy. Due to the wide variety of associated factors, achieving dimensional precision in these technologies is challenging [30]. AM's extreme versatility (in terms of shape, materials, processes, form and size of the powder particles, and post-processing procedure) generates a high degree of uncertainty about the quality of the final output. This uncertainty affects the surface roughness, mechanical properties, and absolute product quality. This uncertainty affects surface roughness or mechanical properties and considerably affects dimensional accuracy [31], even when no further post-processing is included.

Dimensional measurement is crucial for interoperability and international commerce. This is how we ensure everything fits together correctly. A globalised industry would not be sustainable without universal length standards as the basis for standardised components [32]. Measuring dimensions is also vital for verifying that things function as planned. For instance, the structure's strength is calculated using information such as flange thickness or beam span. Uncertainty in these measures increases the strength's tension [33]. This is essential for safety-critical structures that need precise construction. Maintaining the dimensional correctness and integrity of goods necessitates a continuing focus on enhancing the dimensional accuracy of printed components.

3.0 METHODOLOGY

The sample was printed with an Ultimaker S5 FDM 3D printer with a 330 x 240 x 300 mm build volume and 0.4 mm nozzle diameter. The Ultimaker S5 also comes with a 0.8 mm nozzle, but it was not used in this study, as a 0.4 mm nozzle is the absolute standard in modern 3D printers found in almost all popular machines. This diameter provides an outstanding balance between speed and precision [34]. The intelligent and innovative printer features advanced auto bed levelling and filament compatibility with over 200 materials. In addition, the printers were chosen due to their accessibility, efficient operation and low cost.

Additionally, upgrades to the active bed levelling mechanism guarantee excellent first-layer adhesion for each print job. Glass doors are another feature of the S5, which reduces airflow and improves temperature stability inside the build chamber. Utilising Cura software, the STL file of the sample was prepared. After being deposited via the nozzle, the material hardens swiftly and bonds with the preceding layer as it builds up the component layer by layer. The material employed in this investigation is stainless Steel. Following the Cura software, the stainless-steel filaments were extruded through the heated nozzle at a temperature of 270°C. Each of the material samples were printed three times. The specifications for the printing process can be observed in Table 1, while the printing parameters used for the printing process are shown in Table 2.

Table 1 Expected geometry accuracy

Geometry	Dimension
Thickness	15 mm
Corner Radius	10 mm
Angle (Chamfer)	45°
Perpendicularity	90°
Hole Diameter	10 mm
Flatness	Pass/fail

Table 2 Printing Parameters

Parameters	Value
Infill Percentage	50%
Infill Pattern	Triangles
Printing Temperature	200-260.0 °C
Bed Temperature	95.0 °C
Print Speed	45.0 mm/s
Support Overhang Angle	90.0 / No support

3.1 Sample Printing

Figure 1 shows the printed samples dimension for the corner radius, hole diameter, width, angle and thickness. A pre-set parameter has been pre-determined before the printing process began. This pre-set parameter was determined using the standard printing parameter set in the CURA software. This ensures all the filaments used do not differ by the parameters but solely by the material's properties. Ensuring the parameters are uniform will give a better understanding of how the materials would be printed in the given parameters. These parameters have been sliced and simulated using CURA software before printing to estimate the printing time and ensure no unexpected error occurs while printing the various samples. The design was converted to STL file format, which is supported by AM systems since the printer can only take the file in STL format after the 3D CAD model of the sample was created. As a result, it will switch to pro-processing data, which will thinly split the file into layers. The printer has some pre-set default settings that are unique to that procedure. Lastly, the samples were printed three times with three different filaments, which are stainless Steel (Ultrafuse 17-4 ph), Tough PLA (Polymaker Tough PLA) and ABS (Polymaker PolyLite ABS). The sample was designed to fit five of the geometries used in the study, resulting in a specimen size of 1.5 cm x 1.5 cm x 1.5 cm.

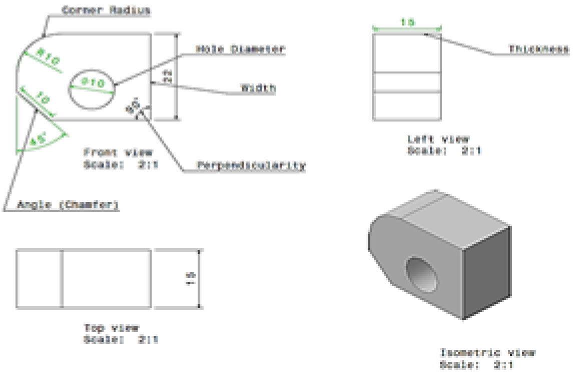

Figure 1 Sample dimensions

3.2 Dimensional Accuracy Testing

A coordinate measuring machine (CMM) is a device that measures the geometry of physical things by using a probe to sense discrete points on the object's surface. For this specific study, the machine used is WENZEL XOPLUS 55 Coordinate Measuring Machine. The XOplus has a bridge size of 55 (500 mm by 500 mm), 77 and 98. Depending on the machine, the probe position may be manually managed by an operator or automatically controlled by a computer. Using a CMM, the printed samples were measured. Using a probe that can travel along three axes, x, y, and z, the machine can test the accuracy of a printed sample by identifying each surface of the sample.

CMM's three axes from the machine's coordinate system function similarly to our fingertips while tracing map coordinates. Instead of a finger, the CMM measures points on a workpiece using a probe. According to the machine's coordinate system, each point on the workpiece is unique. The conventional 3D "bridge" CMM permits probe movement along three orthogonal axes in a three-dimensional Cartesian coordinate system: X, Y, and Z [35].

4.0 RESULTS AND DISCUSSION

4.1 Dimensional Accuracy Results

To further obtain the data for this study, CMM has been used to measure and identify each sample's total dimensional accuracy. The probe of the machine is used to contact the surface, which will result in the tabulation of data. Figures 2, 3 and 4 show the printed samples, respectively.

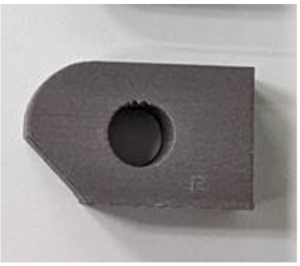

Figure 2 Stainless steel Printed sample

Figure 3 ABS Printed sample

Figure 4 Tough PLA Printed sample

The dimensional accuracy of each printed sample stainless steel, Tough PLA and ABS were measured and recorded in Table 3, Table 4 and Table 5 respectively. The readings are recorded using the machine right after the printing process.

Table 3 Results of Stainless-Steel Specimens

Geometry	Expected Accuracy	Sample 1	Sample 2	Sample 3
Thickness (mm)	15	15.20	15.24	15.17
Hole Diameter (mm)	10	10.05	10.09	10.02
Angle/Chamfer (°)	135	135.45	135.41	135.48
Perpendicular (°)	90	90	90	90
Corner Radius (mm)	10	10.04	10.11	10.06
Width (mm)	22	21.97	21.91	21.84

Table 4 Results of Tough PLA Specimens

Geometry	Expected Accuracy	Sample 1	Sample 2	Sample 3
Thickness (mm)	15	15.19	15.13	15.11
Hole Diameter (mm)	10	9,80	9.75	9.86
Angle/Chamfer (°)	135	135.79	134.65	135.04
Perpendicular (°)	90	90	90	90
Corner Radius (mm)	10	9.80	9.87	9.89
Width (mm)	22	21.80	21.86	21.93

Table 5 Results of ABS Specimens

Geometry	Expected Accuracy	Sample 1	Sample 2	Sample 3
Thickness (mm)	15	15.09	15.03	15.07
Hole Diameter (mm)	10	9.75	9.81	9.79
Angle/Chamfer (°)	135	135.04	135.11	135.07
Perpendicular (°)	90	90	90	90
Corner Radius (mm)	10	9,80	9.76	9.82
Width (mm)	22	21.83	21.91	21.86

The results from Table 3, Table 4 and Table 5 show that none of the samples achieved 100% of the expected accuracy when the measurements were set during the initial phase of the study. It is also identified that stainless steel samples can have a similar overall value compared to the expected accuracy. In contrast, tough PLA and ABS specimens have slightly lower accuracy than stainless steel. Comparing all of the geometries included in this study, it is clear that the perpendicular aspect of the geometry is the only measurement that can be achieved by 100% of its value by all three specimens. This is due to the absence of warping in the printing process due to the calibration process in the earlier printing stages and the application of an anti-warping agent on the bed. On the other hand, the thickness and corner radius aspect of the geometry is identified as the weakest aspect, where all three filaments have a high differential margin of accuracy compared to the expected precision.

Based on the results above, it is safe to conclude that all three different types of filaments produced different results regarding the final printing dimension. Since the parameters have been set in a controlled state as applied above, the other measurements in the final dimension can be safely concluded due to the material properties themselves. All three materials produced accurate printing results concerning the desired parameters set before printing. There is, however, no material that can produce an outcome that achieves 100% accuracy in the result, but this can refer to the properties of the materials reacting to the pre-determined parameter, although an exception can be made for the perpendicularity aspect of the printing where all three materials can achieve the desired parameter.

4.2 Filament Property

Further analysis has been conducted after identifying the data obtained from Tables 3 and 4, which have resulted in specimens being unable to achieve the 100% desired accuracy in terms of parameters set beforehand. To prove the theory behind the result that has been obtained, a study regarding the filaments has been conducted for the three materials that have been used throughout the study, which are stainless steel, tough PLA and ABS. The idea behind transition temperature is that the molecules' energy rises when a crystalline solid is heated. When a particular temperature is achieved, the heat releases the bonds holding the molecules together and transforms the solid into a liquid state [36-37]. This is a phase transition. The equilibrium between the solid and liquid phases occurs when the temperature approaches the melting point. However, in non-crystalline materials, the intermolecular crystal is not broken; the molecules' distance from one another progressively widens. The molecule transforms into a rubbery state that may move incrementally when it passes the glass transition temperature [38].

The reduction in the size of a 3D-printed item is known as shrinkage. The print shrinks dramatically when molten filaments used in 3D printing cool and compress. Although heated filament expands, the temperature drops as it leaves the printer's nozzle causing the filament to shrink. Physically, these three filament materials consist of a similar physical state before being heated in the nozzle and printed, except for their unique molecular bonds that react differently on different temperature levels.

The idea behind the transition temperature is that thermoplastics become liquid at a specific temperature, which is most certainly true in AM. These three filaments have different transition temperatures that put them apart from each other in their transition state from solid to liquid form. Tough PLA has a relatively low transition temperature between 111 and 145°F. In contrast, ABS have a transition temperature of 212°F. Stainless steel has the longest transitional state, which results in the material not shrinking immediately when the material leaves the nozzle during the printing process [39]. Tough PLA, on the other hand, has a slightly lower transitional temperature. Still, when compared to ABS, it shows that ABS have the shortest transition between a glassy state and a rubbery state which explains the reason why ABS filament usually struggles to reach the highest accuracy when it comes to printing and why it is more prone to defects such as warping when printing material. The molecular structure moves freely when heated and stops when cooled [39]. The longer the molecular structure takes time to lose energy, the more likely the material will not shrink drastically after the complete printing process [40].

4.3 Geometry Accuracy

Accuracy measures how closely the created pieces matched the original design's size and shape. Since 3D printers have several moving elements, this approach will never result in an item that is 100% correct. Accuracy is generally expressed in units of percentage or millimetres, such as ±1% or ±0.5 mm. Complex geometry plays a considerable part in accuracy; the nozzle must be close to the parts to create a complex part. In particular geometry, it is hard for the nozzle to maintain the optimum distance between the nozzle and the layers. Figure 4 shows the thickness comparison for all 9 printed specimens compared to the expected accuracy measurement while Figure 5 shows the corner radius accuracy comparison for all 9 printed specimens. Both of these dimensions are deemed the weakest accuracy dimensions, and the difference can be observed from Figures 4 and 5.

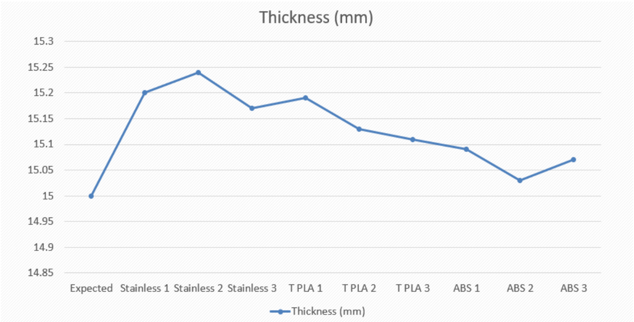

Figure 4 Thickness accuracy comparison

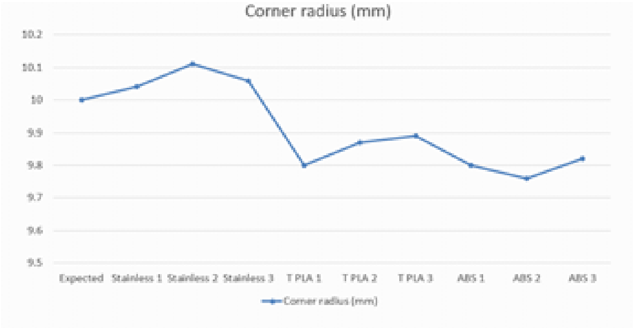

Figure 5 Corner radius comparison

Figure 4 and 5 shows that all 3 filaments have different printing results when it comes to the given dimensions. Stainless steel is more prone to produce results that exceed the expected accuracy due to the presence of a sintering process in the next stage of the process. Tough PLA produces slightly lower accuracy of printing. But is closer to the expected printing dimension. ABS on the other hand shows the highest amount of shrinkage after the printing process which yields a lower general accuracy after the printing process. The layer is laid down vertically on top of each other without the need for complex movement. This gives the printers' nozzle stable movement for the Z-axis, eventually allowing the layer to be perfectly layered on each other, resulting in perfect accuracy [41]. More complex geometry, such as chamfer angle, can be slightly lower in accuracy than other geometrical parts. This can also be related to the previous explanation. Here it is harder for the printer's nozzle to maintain the proper distance between the nozzle and the layer. Maintaining optimum distance while moving two axes at the same time will be challenging for the printer, which most of the time will result in inaccuracy in printing.

Although the inaccuracy might not be critical, it still lacks around 1-2% of inaccuracy, which is still acceptable by the modern-day standards of AM [42]. The design and materials used are the aspects that determine the accuracy of dimensions. Using 3D printing for flat surfaces or long, thin, unsupported features is not advised. This is the main reason the support overhang angle is set at 90^0, which leaves no room for support in the material. In addition, the precision will decrease as the size of the part increases [43-44]. However, in this instance, the design was not altered. The primary cause of this phenomenon is contraction. Shrinkage might be one of the primary concerns in 3D printing. ABS shrink by around 8% as it cools after printing, whereas PLA and metal shrink by only 2%. Both materials were printed at a temperature comparable to one another. However, the metal sample's shrinkage is more significant after the sintering process which explains the excess printing on certain dimensions compared to the expected printing parameters [45].

5.0 CONCLUSION

In conclusion, the dimensional accuracy has been identified thoroughly. Based on the result obtained, no material has reached 100% of the desired geometry, which was identified due to the shrinkage of the material after the printing process. However, the stainless steel sample has the most similar result to the desired parameter. The samples have been set beforehand with a controlled parameter to find out the issue that might occur. The utilisation of FDM printers specifically in this study is to highlight the accuracy of the printers and how well they work with the software used in this study which is Cura. This study has highlighted the accuracy produced by using proper nozzle size as suggested with the filaments property, software utilisation of Cura which gives pre-set parameters and adequate calibration of the machine. The printer may not have achieved 100% accuracy. However, it still resides between the tolerance that comes with the materials, which in this case is 98% accuracy for stainless steel, 98% for Tough PLA and 97% for ABS. With controlled parameters, it is easier to identify the issues present within the samples, in this case, the shrinkage and complex geometry. The idea of transitional temperature and geometry complexity is prone to be helpful in future studies which involve 3D printing. This proves the dimensional accuracy issue is present in this study, and there are ways to improve the dimensional accuracy by choosing the proper filaments and deciding the geometrical factor before printing the specimen.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

References

[1] N. Asnafi, T. Shams, D. Aspenberg, and C. Öberg. 2019. 3D Metal Printing from an Industrial Perspective-Product Design, Production, and Business Models. *BHM Berg- und Hüttenmännische Monatshefte*. 164(3): 91-100. Doi:10.1007/s00501-019-0827-z. https://doi.org/10.1007/s00501-019-0827-z.

[2] Attaran, M. 2017. The Rise of 3-D Printing: The Advantages of Additive Manufacturing over Traditional Manufacturing. *Business Horizons*. *60*(5): 677-688. https://doi.org/10.1016/j.bushor.2017.05.011.

[3] Ayrilmis, N., Mechanics, W., Faculty, F., & University-cerrahpasa, I. 2018. Effect of Layer Thickness on Surface Properties of 3D Printed Materials Produced from Wood Flour/PLA Filament. *Polymer Testing*. 71(July): 163-166. https://doi.org/10.1016/j.polymertesting.2018.09.009.

[4] Babu, V. V. P., & Gb, V. K. 2022. Materials Today: Proceedings A Review on 3D Printing Process on Metals and Their Surface Roughness and Dimensional Accuracy. *Materials Today: Proceedings*. 64(1): 523-530. https://doi.org/10.1016/j.matpr.2022.05.018.

[5] Blakey-Milner, B., Gradl, P., Snedden, G., Brooks, M., Pitot, J., Lopez, E., Leary, M., Berto, F., & du Plessis, A. 2021. Metal Additive Manufacturing in Aerospace: A Review. *Materials and Design*. 209: 110008. https://doi.org/10.1016/j.matdes.2021.110008.

[6] Bose, S., Vahabzadeh, S., & Bandyopadhyay, A. 2013. Bone Tissue Engineering using 3D Printing. *Materials Today*. 16(12): 496-504. https://doi.org/10.1016/j.mattod.2013.11.017.

[7] Cano-Vicent, A., Tambuwala, M. M., Hassan, S. S., Barh, D., Aljabali, A. A. A., Birkett, M., Arjunan, A., & Serrano-Aroca, Á. 2021. Fused Deposition Modelling: Current Status, Methodology, Applications and Future Prospects. *Additive Manufacturing*. 47(September): 102378. https://doi.org/10.1016/j.addma.2021.102378.

[8] Berman, B. 2012. 3-D Printing: The New Industrial Revolution. *Business Horizons*. 55(2): 155-162. https://doi.org/10.1016/j.bushor.2011.11.003.

[9] Beslagic, E., & Varda, K. 2022. Dimensional Accuracy and Tolerances -n Additive Manufacturing. April. https://doi.org/10.5644/PI2022.202.25.

[10] Carneiro, O. S., Silva, A. F., & Gomes, R. 2015. Fused Deposition Modeling with Polypropylene. *Materials and Design*. 83: 768-776. https://doi.org/10.1016/j.matdes.2015.06.053.

[11] A. Kanyilmaz *et al*. (2022). Role of Metal 3D Printing to Increase Quality and Resource-efficiency in the Construction Sector. *Additive Manufacturing*. 50: 102541. Doi: 10.1016/j.addma.2021.102541.

[12] Reddy, V., Flys, O., Chaparala, A., Berrimi, C. E., Amogh, V., & Rosen, B. G. (2018). Study on Surface Texture of Fused Deposition Modeling. *Procedia Manufacturing*. 25: 389-396. https://doi.org/10.1016/j.promfg.2018.06.108.

[13] Yoo, I. S., Braun, T., Kaestle, C., Spahr, M., Franke, J., Kestel, P., Wartzack, S., Bromberger, J., & Feige, E. 2016. Model Factory for Additive Manufacturing of Mechatronic Products: Interconnecting World-class Technology Partnerships with Leading AM Players. *Procedia CIRP*. 54: 210-214. https://doi.org/10.1016/j.procir.2016.03.113.

[14] Tronvoll, S. A., Elverum, C. W., & Welo, T. 2018. Dimensional Accuracy of Threads Manufactured by Fused Deposition Modeling. *Procedia Manufacturing*. 26: 763-773. https://doi.org/10.1016/j.promfg.2018.07.088.

[15] Petrovic, V., Vicente Haro Gonzalez, J., Jordá Ferrando, O., Delgado Gordillo, J., Ramon Blasco Puchades, J., & Portoles Grinan, L. 2010. Additive Layered Manufacturing: Sectors of Industrial Application Shown through Case Studies. *International Journal of Production Research*. 49(4): 1061-1079. https://doi.org/10.1080/00207540903479786.

[16] Wong, K. V., & Hernandez, A. 2012. A Review of Additive Manufacturing. *ISRN Mechanical Engineering*. 2012: 1-10. https://doi.org/10.5402/2012/208760.

[17] Gao, W., Zhang, Y., Ramanujan, D., Ramani, K., Chen, Y., Williams, C. B., Wang, C. C. L., Shin, Y. C., Zhang, S., & Zavattieri, P. D. 2015. The Status, Challenges, and Future of Additive Manufacturing in Engineering. *CAD Computer Aided Design*. 69: 65-89. https://doi.org/10.1016/j.cad.2015.04.001

[18] Islam, M. N., Boswell, B., & Pramanik, A. (2013). An Investigation of Dimensional Accuracy of Parts Produced by Three-Dimensional Printing. I, 5–8.

[19] Lalehpour, A., Janeteas, C., & Barari, A. 2018. Surface Roughness of FDM Parts After Post-processing with Acetone Vapor Bath Smoothing Process. *The International Journal of Advanced Manufacturing Technology*. 95: 1505-1520. https://doi.org/10.1007/s00170-017-1165-5.

[20] Nurhudan, A. I., Supriadi, S., Whulanza, Y., & Saragih, A. S. 2021. Additive Manufacturing of Metallic Based on Extrusion Process: A Review. *Journal of Manufacturing Processes*. 66: 228-237. https://doi.org/10.1016/j.jmapro.2021.04.018.

[21] Ning, F., Cong, W., Qiu, J., Wei, J., & Wang, S. 2015. Additive Manufacturing of Carbon Fiber Reinforced Thermoplastic Composites using Fused Deposition Modeling. *Composites Part B: Engineering*. 80: 369-378. https://doi.org/10.1016/j.compositesb.2015.06.013.

[22] Lim, W., Bae, J., Seo, M., Min, J., Lee, J., Hyun, S., Jung, Y., & Huh, P. 2022. A Novel UV-curable Acryl-polyurethane for Flexural 3D Printing Architectures. *Additive Manufacturing*. 51: 102625. https://doi.org/10.1016/j.addma.2022.102625.

[23] Robert, J., Leigh, S. J., Bradley, R. J., Purssell, C. P., Billson, D. R., & Hutchins, D. A. 2012. A Simple, Low-Cost Conductive Composite Material for 3D Printing of Electronic Sensors. *Plos One*. 7(11). https://doi.org/10.1371/journal.pone.0049365.

[24] Cuesta, E. 2019. Dimensional Accuracy Analysis of Direct Metal Printing Machine Focusing on Roller Positioning Errors Focusing on Roller Positioning Errors. *Procedia*

Manufacturing. 41: 2-9. https://doi.org/10.1016/j.promfg.2019.07.022.

[25] Hanon, M. M., Zsidai, L., & Ma, Q. 2021. Accuracy Investigation of 3D Printed PLA with Various Process Parameters and Different Colors. Materials *Today: Proceedings*. 42(5): 3089-3096. https://doi.org/10.1016/j.matpr.2020.12.1246.

[26] Melchels, F. P. W., Feijen, J., & Grijpma, D. W. 2010. A Review on Stereolithography and Its Applications in Biomedical Engineering. *Biomaterials*. 31(24): 6121-6130. https://doi.org/10.1016/j.biomaterials.2010.04.05.

[27] Olakanmi, E. O., Cochrane, R. F., & Dalgarno, K. W. 2015. A Review on Selective Laser Sintering/Melting (SLS/SLM) of Aluminium Alloy Powders: Processing, Microstructure, And Properties. *Progress in Materials Science*. 74: 401-477. https://doi.org/10.1016/j.pmatsci.2015.03.002.

[28] Palomba, G., Crupi, V., & Epasto, G. 2022. Additively Manufactured Lightweight Monitoring Drones: Design and Experimental Investigation. *Polymer*. 241: 124557. https://doi.org/10.1016/j.polymer.2022.124557.

[29] Patel, R., Desai, C., Kushwah, S., & Mangrola, M. H. 2022. A Review Article on FDM Process Parameters in 3D Printing for Composite Materials. *Materials Today: Proceedings*. 60(3): 2162-2166. https://doi.org/10.1016/j.matpr.2022.02.385.

[30] Kadivar, M. A., Akbari, J., Youse, R., Rahi, A., & Nick, M. G. 2014. Investigating The Effects of Vibration Method on Ultrasonic-assisted Drilling of Al/SiCp Metal Matrix Composites. *Robotics and Computer-Integrated Manufacturing*. 30(3): 344-350. https://doi.org/10.1016/j.rcim.2013.10.001.

[31] Reddy, V., Flys, O., Chaparala, A., Berrimi, C. E., V, A., & Rosen, B. 2018. Study on surface texture of Fused Deposition Modeling. *Procedia Manufacturing*. *25*: 389-396. https://doi.org/10.1016/j.promfg.2018.06.108.

[32] Lekurwale, S., Karanwad, T., & Banerjee, S. 2022. Selective Laser Sintering (SLS) of 3D Printlets using a 3D Printer Comprised of IR/red-diode Laser. *Annals of 3D Printed Medicine*. 6: 100054. https://doi.org/10.1016/j.stlm.2022.100054.

[33] Kwok, S. W., Hin, K., Goh, H., Tan, Z. D., Ting, S., Tan, M., Tjiu, W. W., Soh, J. Y., Jie, Z., Ng, G., Chan, Y. Z., Hui, H. K., Eng, K., & Goh, J. 2017. Electrically Conductive Filament for 3D-printed Circuits and Sensors. *Applied Materials Today*. 9: 167-175. https://doi.org/10.1016/j.apmt.2017.07.001.

[34] A. Kanyilmaz *et al*. 2022. Role of Metal 3D Printing to Increase Quality and Resource-Efficiency in the Construction Sector. *Additive Manufacturing*. 50: 102541. Doi: 10.1016/j.addma.2021.102541.

[35] Naveed, N. 2021. Investigate the Effects of Process Parameters on Material Properties and Microstructural Changes of 3D-printed Specimens using Fused Deposition Modelling (FDM). *Materials Technology*. 36(5): 317-330. https://doi.org/10.1080/10667857.2020.1758475.

[36] Kulkarni, M. V. 2015. Selective Laser Sintering Process-A Review. *International Journal of Current Engineering and Scientific Research (IJCESR)*. 2(10): 2393-8374.

[37] Mohamed, O. A., Masood, S. H., & Bhowmik, J. L. 2015. Optimisation of Fused Deposition Modeling Process Parameters: A Review of Current Research and Future Prospects. *Advances in Manufacturing*. 3(1): 42-53. https://doi.org/10.1007/s40436-014-0097-7.

[38] Basavaraj, C. K., & M. Vishwas. 2016. Studies on Effect of Fused Deposition Modeling Process Parameters on Ultimate Tensile Strength and Dimensional Accuracy of Nylon. IOP Conference Series: Materials Science and Engineering, 149(1). https://doi.org/10.1088/1757-899X/149/1/012035.

[39] A. S V and K. V. 2018. Analysis of Ductile to Brittle Transition Temperature of Stainless Steel. *SSRN Electronic Journal*. Doi:10.2139/ssrn.3178568.

[40] Maidin, S., Hayati, N. M. N., Rajendran, T. K., & Muhammad, A. H. 2023. Comparative Analysis of Acrylonitrile Butadiene Styrene and Polylactic Acid Samples' Mechanical Properties Printed in Vacuum. *Additive Manufacturing*. 67: 103485.

[41] Beniak, J., Križan, P., Šooš, Ľ., & Matúš, M. 2019. Research on Shape and Dimensional Accuracy of FDM Produced Parts. *IOP Conference Series: Materials Science and Engineering*. 501: 012030. https://doi.org/10.1088/1757-899x/501/1/012030.

[42] Kitsakis, K., Alabey, P., Kechagias, J., & Vaxevanidis, N. 2016. A Study of the Dimensional Accuracy Obtained by Low Cost 3D Printing for Possible Application in Medicine. *IOP Conference Series: Materials Science and Engineering*. 161: 012025. https://doi.org/10.1088/1757-899x/161/1/012025.

[43] C. C. Seepersad. 2014. Challenges and Opportunities in Design for Additive Manufacturing. 3D Printing and Additive Manufacturing. 1(1): 10-13. Doi:10.1089/3dp.2013.0006.

[44] Wimmer, M. G., & Compton, B. G. 2022. Semi-solid Epoxy Feedstocks with High Glass Transition Temperature for Material Extrusion Additive Manufacturing. Additive Manufacturing, 54: 102725. https://doi.org/10.1016/j.addma.2022.102725.

[45] Sehhat, M. H., Mahdianikhotbesara, A., & Yadegari, F. 2022. Impact of Temperature and Material Variation on Mechanical Properties of Parts Fabricated with Fused Deposition Modeling (FDM) Additive Manufacturing. *The International Journal of Advanced Manufacturing Technology*. 120(7-8): 4791-4801. https://doi.org/10.1007/s00170-022-09043-0.