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FEASIBILITY STUDY OF VACUUM TECHNOLOGY INTEGRATED FUSED DEPOSITION MODELING TO REDUCE STAIRCASE EFFECT

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ABSTRACT

Fused deposition modeling (FDM) is currently one of the most used AM technologies and has been around in various industries since its tremendous offering. Most semi-molten layered thermoplastic surface often uneven, which lead to rough and poor surface finish. The FDM process involves temperature gradient since the material extrude was in a semi-molten state. The thermal stresses present and affect the surface quality. This paper proposes an idea of using vacuum technology to reduce the "staircase effect" parts printed. The FDM machine remains in a rectangular acrylic chamber, an oil-flooded-vacuum pump connected will absorb the air inside the chamber until desire pressure while printing object. Mitutoyo SJ-301 portable surface roughness tester and optical microscope used to analyze the quality of surface finish. Result reveal with vacuum technology, improve 9% from normal print.

Keywords: fused deposition modeling; simulation; vacuum technology; surface finish.

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1. INTRODUCTION

Additive Manufacturing (AM) has been widely recognized in various fields to replace existing models or parts, which are claimed to be more competitive in term of time and cost [1]. The Additive Manufacturing terminology was accepted from the constant evolution of "Rapid Prototyping" (RP). AM's term has been identified by the American Society for Testing and Materials (ASTM) International Committee F24 as "process of joining material to make objects from 3D model data, usually layer upon layer as opposed to subtractive manufacturing and methodologies such as traditional machining [2]. Identified as extrusion based 3D printing technology in AM system, Fused Deposition Modeling was the first technology developed by Statasys Inc. [3]. Fused Deposition Modeling (FDM) manufactured model printing method by stacking layer of thermoplastic material upon one another until a complete model produce. FDM has become one of the most used technique to create a 3D object rapid prototyping [4]. FDM offers huge design of freedom and complexity. Due to the simplicity, reliability and affordable if the process, the FDM has widely recognized and adopted by the industry, academia and consumer [5-6]. However, despite of its tremendous offering, this technology present the limitation related to surface finish quality of printed parts. The common problem of the extrusion based which staircase effect markedly affects FDM parts as it employs thick filament. These problems limit the part's surface finishing, which is an important requirement to assure component functionality [7-10].

The Fused Deposition Modeling (FDM), an extrusion based technology has become most popular method to create a 3D object rapid prototyping [11]. Material extrusion refers to process which material is selectively dispensed through an orifice. This principal is based on the technology first develop in the late 1980s by Scoot Trump, who one of the co-founder Statasys Inc. known as Fused Deposition Modeling [3, 12]. In this process, as for many other 3D printing methodologies, the model is built as layer upon layer deposition of a spool material [13]. The extruder will extrude the hot semi-molten material into thin layers and deposited by heated nozzle via a geared motor at constant temperature onto a fixtureless platform [5, 12]. The most common materials used with this machine usually Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA) thermoplastic. FDM has been rapidly evolving and offers immense advantages. The principal of FDM offers great potential because of without any need of machining and human intervention; allow the fabrication of complex 3D parts [5, 14]. The advantages of FDM technology, it does not consist of analysis of part geometry to determine the sequence of the operation, thus only part specification are necessary and process parameters do not depend upon geometrical complexity. Opposite with the traditional ways of manufacturing, FDM can fabricate functional parts, it is clean process and material waste are kept to a minimum [15-17]. Furthermore, FDM requires little manufacturing stage, thus leading to minimal energy consumption. Due to the simplicity, reliability and affordability of the process, the FDM has been recognized and utilized most of the industry, academia and consumers [17-19]. It is used by research and development sectors to improve the process, develop new materials and apply the FDM system in a wide range of engineering application such automotive, aerospace, biomedical, customer product industry and even design and tooling [7, 20-24].

Vacuum integrated system is a proven technology that been extensively used for various applications. Vacuum is an empty space or void space of matter, where there is an absence of particles. Perfect vacuum is impossible to be achieved in the laboratory. Hence, the word vacuum is generally defined as a region or space with gaseous pressure lower than atmospheric pressure [25]. Normally, the atmospheric pressure at 30 inHg contains air molecules that are constantly hitting with each other. By reducing the air molecules, wide range of applications can be used in research areas and industrial use as well. Vacuum can be ranging from low to ultra-high level. At one atmospheric pressure, the molecules will keep bombarding to transmit energy from one place to another. The higher the molecule density, the easier the transmission of energy occurs. The molecules are relatively closer to each other, hitting each other in every direction [26]. However, if the air molecules are reduced, there will be less medium to transfer the energy around. On the contrary, the change of physical properties of air from the change of vacuum pressure also affects different thermal behaviour. Heat loss due to convection can be reduced by the absence of air particles [27].

Therefore, this study aims to experimentally investigate the feasibility of using vacuum technology integrated with FDM machine to minimize the staircase effect of parts built. The contribution of this study obvious as the resulting outcomes that can be capitalized as guidelines for future work with other AM technology.

2. METHODOLOGY

Fig. 1 shows extrusion based FDM machine, UP Plus 2 3D printer available with a single printing head, nozzle tip size of 0.04mm, maximum printing area of 140x140.130mm and capable of printing ABS and PLA thermoplastic with a maximum temperature range of 230^{o}C-250^{o}C and 100^{o}C heated bed. Material used in this study was Acrylonitrile Butadiene Styrene (ABS), which widely used for various of applications due to its capability reconcilable with vacuum technology structure as well as by virtue of its acceptance among user in conjunction with its availability. UP Plus 2 FDM machine deposition parameters for this experiment which constant variables are ABS materials, layer height (0.15mm) and fill of density (loose fill) are fixed with default setup as influence factor that would effect the surface finish quality as shown in Fig. 2.

Fig.1. FDM UP Plus 2 machine

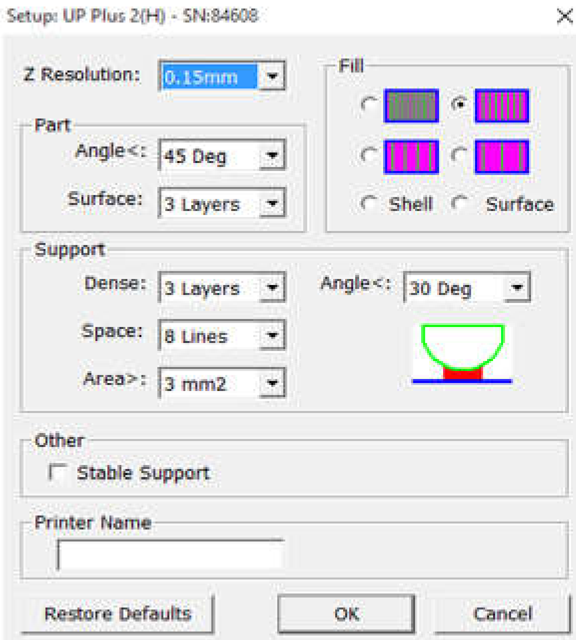


Fig.2. Print preference for FDM UP Plus 2 machine

Number of each sample print will be four, which represent different printing vacuum pressure. The vacuum pressure ranges used in this experiment are 0kPa for normal printing and follow by integrated with 10kPa, 20kPa and 30kPa to study the effect of vacuum pressure on the sample with regard t surface finish. Fig. 3 shows a 3D model printed sample of rectangular shape with size of 20x20x25mm.

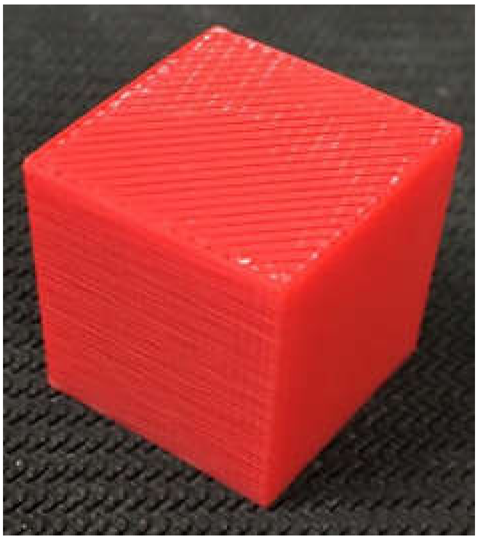


Fig.3. 3D model printed sample

Fig. 4 shows the experimental setup to run vacuum technology integrated FDM UP Plus 2. An acrylic rectangular shape of 12mm thickness and 350x390x400mm inner dimension securely closed, inside with the FDM machine. Connected with the acrylic vacuum chamber is an oil-flooded vacuum pump, which used to absorb and remove air inside the vacuum chamber from atmospheric pressure until the stated vacuum pressure (0kPa, 10kPa, 20kPa and 30kPa).

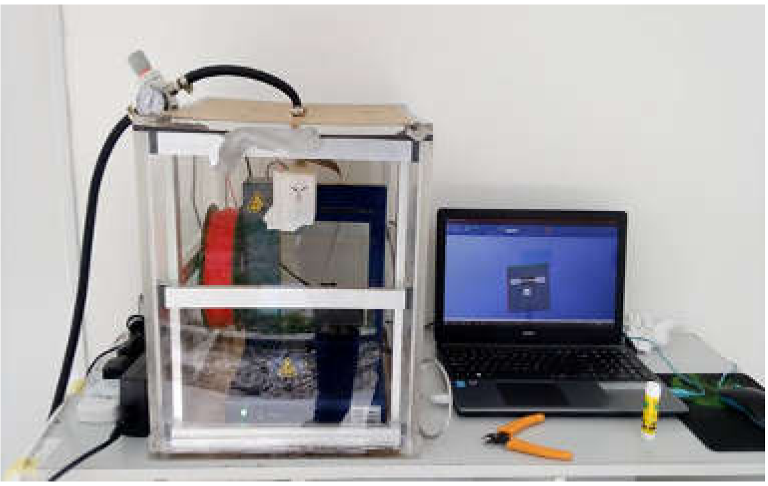


Fig.4. Vacuum technology integrated FDM Up Plus 2

Portable surface roughness tester, Mitutoyo SJ-301 was used to analyze and calculate the surface quality of sample printed. The method of data construction is RA, which arithmetic mean of the departures of the roughness profile from the mean line within the evaluation length. In order to ensure the consistency and accuracy of the result data obtain, fixed variable has to be taken care off carefully. There might be some inaccuracy at the X and Y axis of the machine related to the different speed of each stated motor and might not perfectly perpendicular to one another. Thus, only the side surface will be measured as it is the most fine and regular line produce. The surface roughness diamond stylus must placed in perpendicular to the seam lines and in order to achieve that several custom designs of the probe and sample holder will be created as shown in Fig. 5 and 6. The three sample holder were capable to measure different surface roughness area by replacing and attaching to the probe holder. The data consists of 7 readings or area of surface with different vacuum pressure.

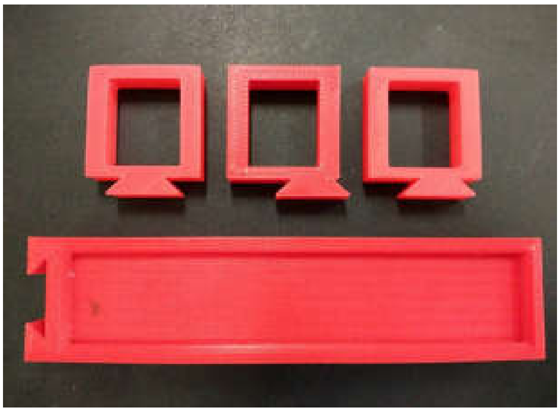


Fig.5. Sample and probe holder

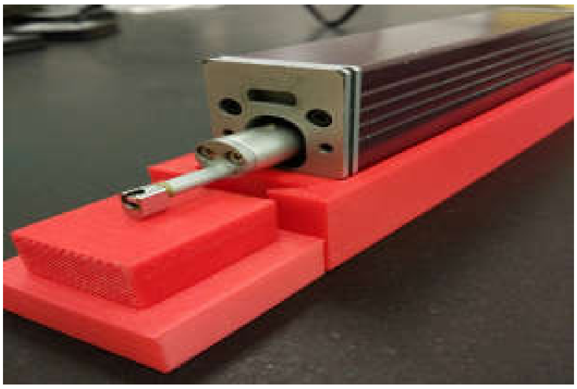


Fig.6. Surface roughness test

The data obtained will be recorded and analyze. To confirm the reliability of the result, another approach performs which used an Optical Microscope with the aid of Pro VIS software version 2.90 as shown in Fig. 7. This method will provide the close up image up to a certain value for further analysis

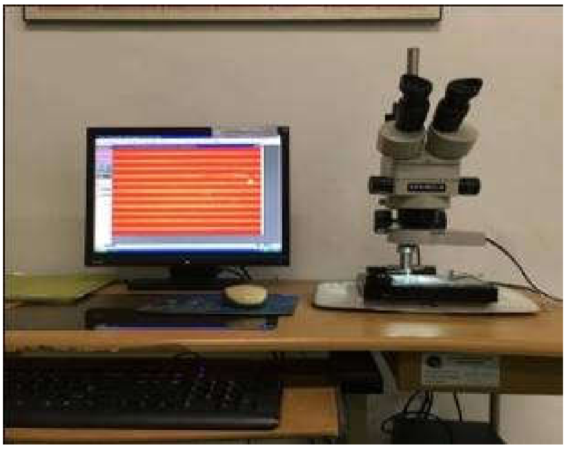


Fig.7. Optical microscope

3. RESULT AND DISCUSSION

Table 1 provides the image of the side plane for each sample printed with different vacuum pressure. At normal print (30inHg), three different poor defects can be seen. Firstly, normal print sample showed an unsightly bumps across the vertical left side. These marks are commonly called as blobs. Next, uneven layers can be found across the whole middle surface with curling wavy surface at about 45 degrees. Lastly, stringing layers can be seen at the right side. When the pressure was reduced at -27inHg, the defects were reduced. The vertically left blobs were less obvious with much better appearance. The middle surface was less wavy but a lot of irregular lines were still present. Lastly, no stringing can be found. The experiments were carried on with lower pressure at -24inHg showing better surface finish. The blobs were eliminated, middle surface with less irregular lines and no stringing as well. The last sample at -21inHg was with best overall surface finish. No blobs and stringing can be found. The middle irregular lines were much lesser compared to the other three samples.

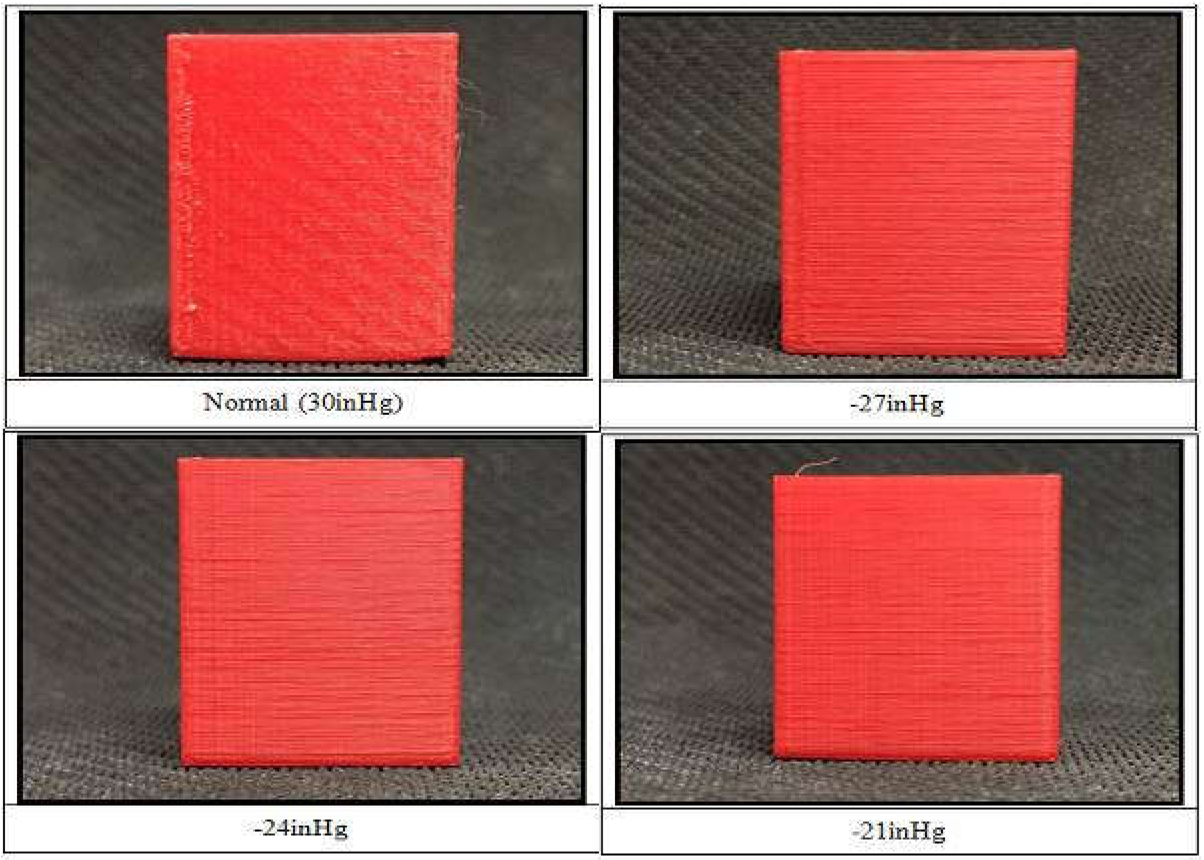


Fig.8. Plane of sample printed

Plotted in Fig. 8 clearly shows the bar chart comparison of surface quality in term of roughness value for normal print and integrated with vacuum system. What is interesting in this data is that there is an improvement by using vacuum integrated. Based on the graph, there is significant reduction surface roughness value compared between normal and integrated. The improvement of vacuum system integrated around 9% of the surface roughness value.

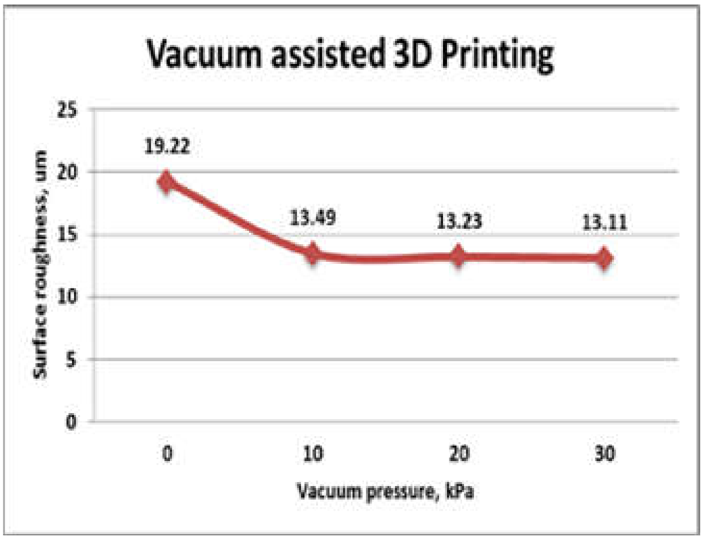
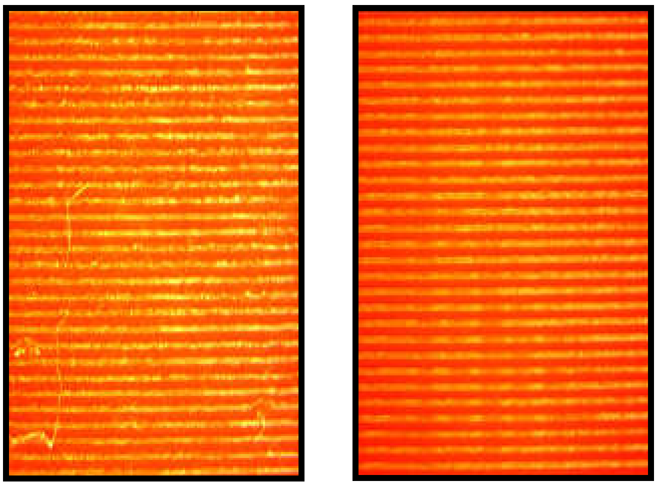


Fig.9. Comparison of surface finish value for normal vs integrated

The zoom in surface finish printed by normal and vacuum integrated provide in the Fig. 9. Our finding revealed that normal print shows the inequality of lines, which lead to rough and poor surface quality compared to vacuum integrated that the lines much more even. Furthermore, the colour pigmentation of vacuum integrated is created uniformly. Interestingly, this correlation is related to surface roughness value as stated in the graph shown.



Normal print Vacuum integrated print

Fig.10. Comparison of normal vs vacuum printed sample

4. CONCLUSION

Vacuum occur when the air is removed from the chamber, means there will be no air particle inside the chamber. Hence, the heat will not transfer from one place to another because there is no medium for them to transfer. Therefore, the energy source from the nozzle part when it transferred to the 3D printer part, the heat energy will remain much longer and rapid cooling can be reduced. The most obvious finding to emerge from this study is that by adopting with vacuum technology, it can help to minimize the staircase effect of the 3D printed models in term of reducing the value of surface roughness. This research will serve as a base for future study and has gone some ways towards enhancing our understanding of vacuum technology integrated with extrusion based 3D printing FDM. More information and discussion on the effect of high vacuum pressure would help us to establish a greater degree of accuracy on this matter. If the debate is to be forward, a better understanding of the vacuum technology [28] needs to be developed.

5. ACKNOWLEDGEMENTS

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