International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249 – 8958 (Online), Volume-9 Issue-4, April, 2020

Amplitude Uniformity in Ultrasonic-Assisted Fused Deposition Modeling

S. Maidin, K. H. Ting, Z. Abdullah, M. R. Alkahari

Abstract: ***Fused Deposition Modeling (FDM) is one of the Additive Manufacturing (AM) technology. Ultrasonic-assisted FDM system has been proven to improve the mechanical properties of the printed specimens. This study aims to explore the uniformity of the amplitude of ultrasonic vibration that was used during the printing process. The uniformity of vibration affected the improvement of the mechanical properties of the 3D printed part. If there is a bad uniformity of ultrasonic vibration, it will influence and increase the variation of the tensile test result. An open-source FDM printer attached with the piezoelectric transducer in various locations of the printer platform was set up. Five different positions and numbers of piezoelectric transducer were set up in order to determine the best position and number of the piezoelectric transducer for transmitting the vibration uniformly to the printing platform. A laser scanning vibrometer was used to determine the amplitude of ultrasonic vibration that transmitted over the printing platform of an open-source FDM 3D printer. From the results, it shows that with two piezoelectric transducers at "Position 4" improved the uniformity of ultrasonic vibration as it had the lowest standard deviation. The test also revealed that the ultrasonic vibration effect uniformly on the 3D printed specimens. In addition, it also reduces the variation and provide better tensile test results of the printed specimens.***

Keywords: Ultrasonic vibration, Fused Deposition Modeling, uniformity, amplitude

I. INTRODUCTION

Fused Deposition Modeling (FDM) is a process that able to effectively print a part with the high complexity of shape in a short time [1]. FDM technology was developed by Scott Crump (founder of Stratasys), which is easy to use, clean and user friendly process [2], [3]. FDM is broadly utilized in various industries area which used for 3D printing a prototype, modeling and end-user product [2]. Besides, FDM also acts as an important role in education areas that provide the education of graphic design and the courses of rapid prototyping [4]. Some researchers investigated the quality of the FDM 3D printed part and implemented it in the medical field [5]. A lot of investigation on the open-source FDM 3D printer and the material properties were performed to study the quality of the part that was produced with the FDM process [6], [7]. Generally, FDM can produce a part with lower cost, shorter production time, excellent and high consistency of quality [8].

3D computer-aided design (CAD) model is needed before starting to 3D print the part. 3D part is produced according to the CAD data without the need for process planning [9]. Then, the CAD file is converting to the STL format and transferred to the FDM machine. When the FDM machine software starts to generate the printing path and the support structure. The input material of FDM is in filament form. The filament is heated and turns into a semi-molten state and extrude it out from a nozzle. The nozzle of 3D printer moves in the horizontal and vertical direction so that the melted material can be deposited on the desired position by following the computer-controlled path. The melted material deposited on the printing platform by using a layer-by-layer approach to form a 3D shape product after the material is cooled and hardened. When the melted material was cooled, the layers are bonded together with the adjacent layers [10].

The material properties of the FDM 3D printed part can be improved by post-processing. Hence, many researchers had done the investigation to enhance the mechanical properties of the FDM printed part to remove the need for post-processing. Lederle et al. [11] found that the nitrogen atmosphere can avoid the oxidative decomposition while the part was 3D printed. Investigation of the high-pressure atmosphere for assisting the FDM 3D printing process was done for improving the mechanical properties of FDM printed products [12]. Besides, the ultrasonic vibration was produced by the piezoelectric transducer that mounted on the printing platform was used as an assisting tool for the FDM 3D printer to decrease the surface roughness [13]. Besides, some of the researchers declared the mechanical properties of the 3D printed part was enhanced through applying the ultrasonic vibration which can improve the interlayer bonding strength of the part [14], [15]. The frequency of ultrasonic vibration should more than or equal to 20 kHz. Ultrasonic vibration had been proved that it could enhance the mechanical properties of 3D printed parts through strengthening its interlayer bonding. This is because ultrasonic vibration can enhance the fusion between layers which makes a larger area of fusion. Besides, ultrasonic vibration also can smoothen the surface of the 3D printed part by reducing the staircase effect [16]. Ultrasonic vibration had been implemented for more than 50 years in various processes [17].

Revised Manuscript Received on April 25, 2020.
* Correspondence Author
S. Maidin*, Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia. Email: shajahan@utem.edu.my
K. H. Ting, Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, City, Country. Email: tingkunghieng1995@gmail.com
M. R. Alkahari, Faculty of Mechanical Engineering/Advance Manufacturing Centre, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia. Email: rizalalkahari@utem.edu.my
Z. Abdullah, Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia. Email: zulkeflee@utem.edu.my

This study aims to explore the uniformity of ultrasonic vibration on the printing bed of the open-source FDM 3D printer. This is because the ultrasonic vibration tends to be attenuated or its amplitude is decreased due to the vibration energy is diverged and dissipated along the travel distance [18]-[20]. There is limited information on the application of a piezoelectric transducer that is mounted on the printing bed of the FDM printer. Hence, the aim of this study is to determine the effect of the number and position of transducers on the uniformity of ultrasonic vibration that is transmitted to the printing platform. The uniformity of amplitude of ultrasonic vibration will affect the improvement of mechanical properties, due to amplitude is one of the important factors for ultrasonic strengthening [21]. If the amplitude is not uniform, this will cause variation in the mechanical properties testing results such as surface roughness of the 3D printed part [22].

II. METHODOLOGY

A. Ultrasonic-assisted Fused Deposition Modeling

Fig. 1 shows the experimental setup for the ultrasonic-assisted FDM. The components of the ultrasonic-assisted FDM 3D printer includes the Up Plus2 FDM machine, oscilloscope (Tektronix DPO 4032), function generator (BK Precision 4052), Piezoelectric transducer (PSI-5A4E), personal computer and UP 3D printing software. The piezoelectric transducer mounted on the printing bed of the FDM machine firmly. So, the ultrasonic vibration transmitted thoroughly to the printing bed of the FDM machine while the 3D printing process was carried out. The function generator was used to control the frequency and amplitude of the vibration. Besides, the step-by-step of this study is shown in Fig. 2.

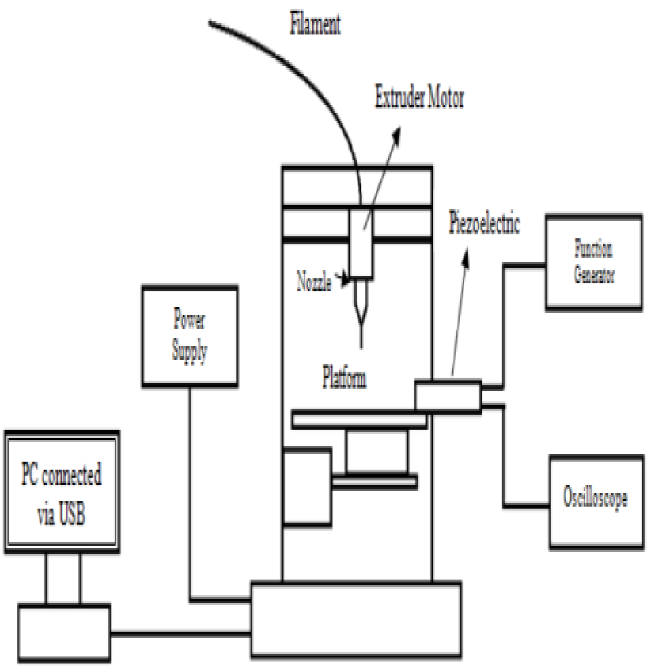


Fig. 1. Experimental setup of ultrasonic-assisted FDM 3D printer [16]

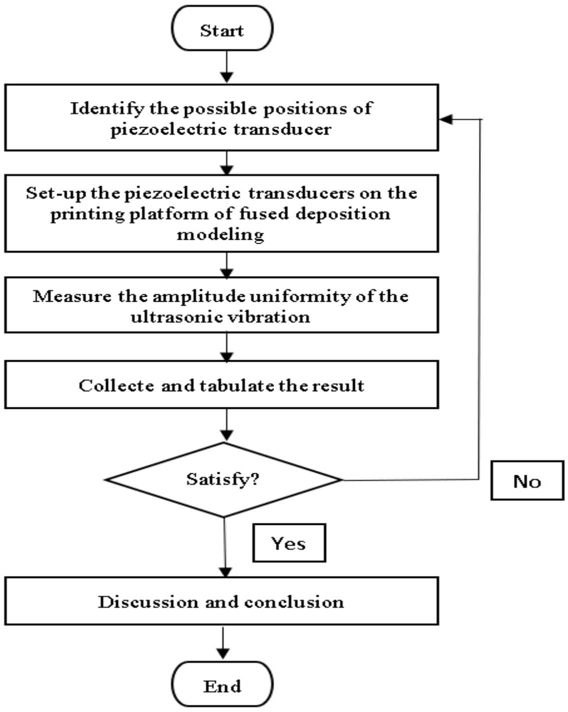


Fig. 2. Step-by-step of studying the amplitude uniformity in ultrasonic assisted fused deposition modeling

B. Piezoelectric Transducer

A piezoelectric transducer was used due to it can generate mechanical vibration through the effect of piezoelectric. Fig. 3 shows the piezoelectric transducer that used to mount on the printing bed of the FDM machine. A piezoelectric transducer can convert the electrical energy to vibration with high frequency. Thus, the vibration with high frequency (≥ 20kHz) was produced by the piezoelectric transducer in a longitudinal direction. The details of the piezoelectric transducer are shown in Table I

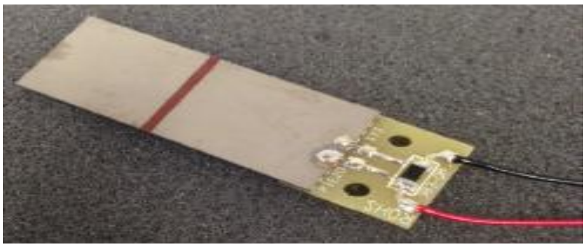


Fig. 3. Piezoelectric transducer (PSI-5A4E)

Table- I: Specification of piezoelectric transducer

Table- I: Specification of piezoelectric transducer Manufacturer	INC (Piezo System)
Type	Standard quick-mount extension actuator
Weight	2.3g
Max Voltage	±90 V
Deflection	3.6 μm
Max Amplitude	10 μm

However, the position of the piezoelectric transducer that mounted on the printing bed needs to be determined in order to ensure the vibration that transmits over the printing platform was uniformly distributed. If the amplitude of vibration is not uniform, there had different impacts of the ultrasonic vibration effect on the 3D printed specimen.

Retrieval Number: D8037049420/2020©BEIESP
DOI: 10.35940/ijeat.D8037.049420
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

This will cause the variance of the result of the mechanical properties of the specimen produced with the assisting of ultrasonic vibration.

Another important thing that needs to be considered when positioning the piezoelectric transducer is the part of the FDM machine cannot make contact with the piezoelectric transducer while the 3D printing process was carried out. If the piezoelectric transducer collides with the structure of the FDM 3D printer, the wiring and mounting of the piezoelectric transducer may damage. This will affect the signal transmitted by ultrasonic vibration to the printing bed.

C. Amplitude Uniformity

The best position of the piezoelectric transducer for transmitting the vibration thoroughly to the printing platform was determined. A laser scanning vibrometer (LSV) was used to determine the amplitude uniformity of ultrasonic vibration that is transmitted over the printing platform of open-source FDM 3D printer. The setup of the experiment is shown in Fig. 4. The distance between the LSV was fixed at 0.45 m. The tripod supported the LSV and the axis was set at 45 ° throughout the experiment of testing the amplitude of vibration [23].

The function generator was set the frequency at 20 kHz and voltage at 4 V_{pp} (voltage peak-to-peak) which supplied to the piezoelectric transducer to convert to vibration. The data was captured by LSV which was measured at 36 points when the piezoelectric transducer started to transmit the vibration. The positions of the points are indicated in Fig. 5.

The laser of the LSV was focused on the points that marked on the printing platform so that the distribution signal is known to take an accurate result. The amplitude of vibration was measured by repeat three times at each point that was marked on the printing platform and average result was calculated [23]. The frequency range of the LSV was set in the range of 0 kHz to 100 kHz. After the LSV capture the signal, then the data is transmitted to the oscilloscope in order to determine the amplitude of vibration. The rate of sampling and the vertical scale of the oscilloscope was set at 25 MS/s and 20 mV respectively.

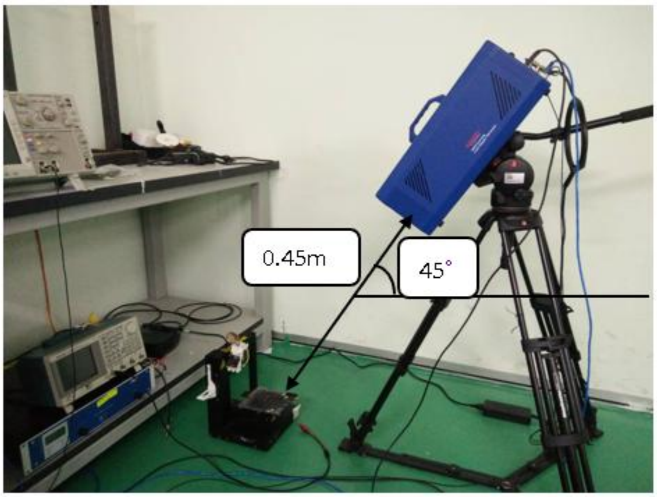


Fig. 4. Setup of Laser Scanning Vibrometer

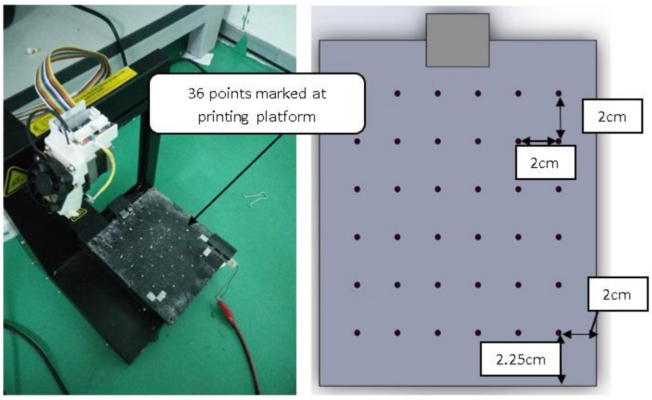


Fig. 5. The 36 points marked on the surface of the printing platform

III. RESULTS AND DISCUSSION

For the testing of uniformity of the amplitude of vibration, there were five different positions of the piezoelectric transducer tested. The five positions were P1, P2, P3, P4 and P5, which are shown in Fig. 6, Fig. 7, Fig. 8, Fig. 9 and Fig. 10 respectively. The five positions were selected due to the transducers were safely mounted on the printing bed without striking with the structure of the 3D printer or blocking the movement of 3D printing bed. This can ensure that the transducer consistently transmits the vibration and avoid any damage caused to the transducer.

After the five different positions were determined, the amplitude of the vibration was measured at the 36 points that marked on the printing platform. In this way, the five different positions and number of piezoelectric transducers were compared to find out the best uniformity of the amplitude of vibration. The FDM printer was in starting mode when the amplitude measurement was carried out.

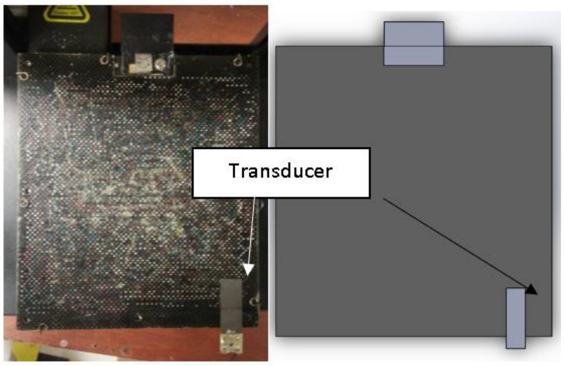


Fig. 6. P1

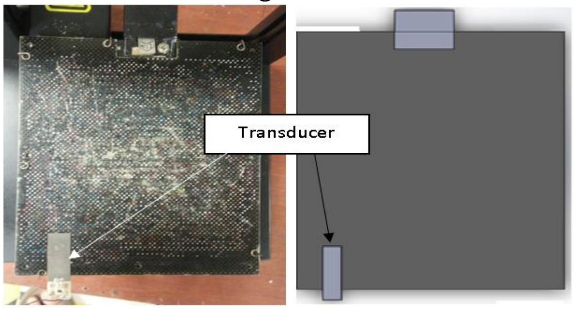


Fig. 7. P2

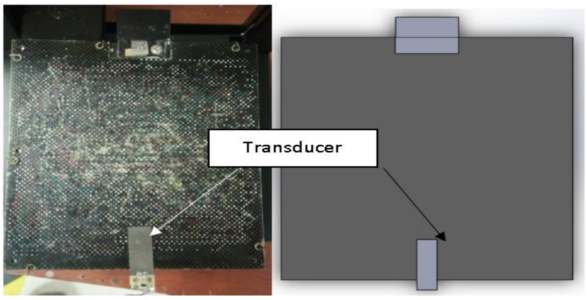


Fig. 8. P3

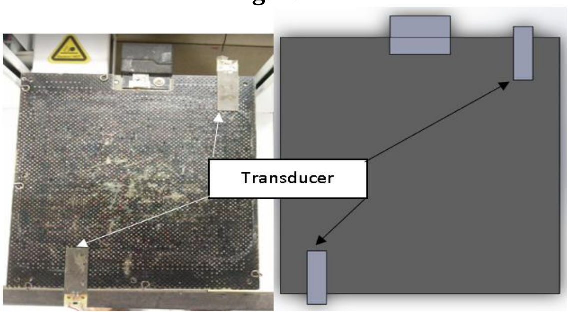


Fig. 9. P4

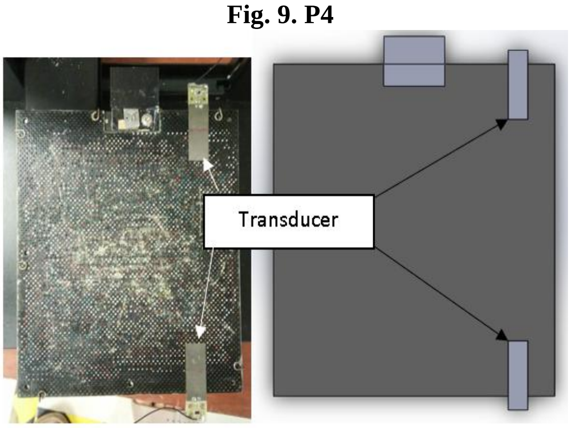
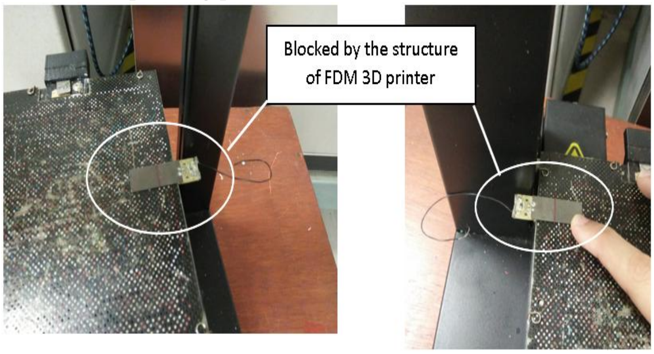


Fig. 10. P5

However, there are some places that the piezoelectric transducer cannot be mounted on the printing platform, which is at the right side and left side of the printing platform (refer to Fig. 11). If the piezoelectric transducer was mounted on the left (Fig. 11 (a)) and right side (Fig. 11 (b)) of the printing platform, the transducer will strike the structure of the FDM printer and cause damage to the transducer. Hence, the piezoelectric transducer was not mounted on the left and right sides of the printing platform.



(a) (b)

Fig. 11. Transducer at struck the structure of FDM 3D printer if mounted the left and right side of the platform (a) Transducer placed at the right side (b) Transducer placed at the left side

The measurement was repeated three times at each point to get the average result of the amplitude of vibration for each position and number of piezoelectric transducers. All of the results were tabulated and recorded to make a comparison between the five different positions. Table II shows the results of the average value and standard deviation of the amplitude of vibration for Position 1 to Position 5.

Table- II: Average and standard deviation of the amplitude of Position 1 to Position 5

Position	Average of **Table- II: Average and standard deviation of the amplitude of Position 1 to Position 5** Amplitude (mV)	Standard Deviation
Position 1	0.01987	0.00362
Position 2	0.02003	0.00402
Position 3	0.00896	0.00307
Position 4	0.01750	0.00078
Position 5	0.01112	0.00220

The average amplitude of ultrasonic vibration was various at different positions and numbers of the piezoelectric transducer show similar findings with the study of the effect of multiple piezoelectric transducers on FDM to improve part surface finish. The study shows that different number of piezoelectric transducer will affect the surface roughness of 3D printed part [22]. From the box plot that showed in Fig. 12, Position 1 and Position 2 had a higher average value of the amplitude of vibration which is 0.01987 mV and 0.02003 mV respectively. However, Position 1 and Position 2 have a high variance which is 0.00362 and 0.00402 respectively, which shows that the uniformity of the amplitude of vibration is not good. This is due to the attenuation of ultrasonic vibration. Vibration tends to be attenuated when it travels through a medium. The intensity of ultrasonic vibration was decreased due to the vibration energy was diverged, scattered, dissipated or absorbed [18]- [20].

From the box plot, it shows that Position 4 had the lowest variance (0.00078). Its average amplitude is 0.0175 mV which is 12.6311 % lower than the average amplitude of Position 2 (highest average of amplitude). Position 3 had an average amplitude at 0.00896 mV with a standard deviation of 0.00307. Furthermore, Position 5 had an average amplitude of 0.01112 with a standard deviation of 0.00220.

Based on the results of the vibration amplitude, Position 4 had the lowest standard deviation and its average amplitude was slightly lower than the highest average of amplitude (Position 2). Thus, Position 4 was chosen as the best position for placing the piezoelectric transducer so that it can reduce the difference of the ultrasonic vibration effect on different areas of 3D printed specimens. In this way, the results of mechanical properties testing can get a consistent result and reduce the variance between each result.

Retrieval Number: D8037049420/2020©BEIESP
DOI: 10.35940/ijeat.D8037.049420
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

IV. CONCLUSION

In conclusion, position 4 was the best position for transmitting the ultrasonic vibration to the printing platform to assist the FDM 3D printing process. From the results, it shows that by mounting two piezoelectric transducers at position 4, it improved the uniformity of ultrasonic vibration as it had the lowest standard deviation which is about 0.00078. The other positions and numbers of piezoelectric transducer were not chosen as the best position due to high standard deviation of average amplitude if compared with position 4. By using the position 4 in the ultrasonic-assisted FDM printing process, it proofs the effect of ultrasonic vibration applied uniformly while the printing process commences and it impact the mechanical properties of the 3D printed specimen. A uniform ultrasonic vibration can ensure that all of the area of the 3D printed specimen is ultrasonic strengthened uniformly. Hence, it reduces the variation of the testing result and to get more accurate results of the mechanical properties of the 3D printed specimen.

ACKNOWLEDGMENT

Thanks, UTeM Zamalah, for financial support and to those who have much helped and assisted in finishing this study.

REFERENCES

1. C. K. Basavaraj and M. Vishwas, "Studies on Effect of Fused Deposition Modelling Process Parameters on Ultimate Tensile Strength and Dimensional Accuracy of Nylon," IOP Conf. Ser. Mater. Sci. Eng., vol. 149, no. 1, 2016, doi: 10.1088/1757-899X/149/1/012035.
2. O. Dandgaval and P. Bichkar, "Rapid Prototyping Technology -Study Of Fused Deposition Modelling Technique," Int. J. Mech. Prod. Eng., vol. 4, no. 44, pp. 2320–2092, 2016.
3. N. S. Santhanabharathi and S. Venkatramanan, "Effect of FDM Process Parameters in ABS Plastic Material," International Journal on Mechanical and Production Engineering, vol. 3, no. 1. pp. 14–23, 2017.
4. C. P. Sampaio, R. Spinosa, J. Vicentin, D. Tsukahara, J. Silva, S. Borghi & F. Rostirolla. (2013). "3D printing in graphic design education." 10.1201/b15961-7.
5. H. Chen, X. Yang, L. Chen, Y. Wang, and Y. Sun, "Application of FDM three-dimensional printing technology in the digital manufacture of custom edentulous mandible trays," Scientific Reports, vol. 6. 2016, doi: 10.1038/srep19207.
6. S. H. Kochesfahani, "Improving PLA-based material for FDM 3D-Printers using minerals (principles and method development)," Annual Technical Conference - ANTEC, Conference Proceedings. pp. 1598–1614, 2016.
7. F. Galantucci, Luigi & Bodi, Ilo & Kacani, J. & Lavecchia, "Analysis of dimensional performance for a 3D open-source printer based on fused deposition modeling technique." Procedia CIRP, pp. 82–87, 2015.
8. N.-H. Tran, V.-N. Nguyen, A.-V. Ngo, and V.-C. Nguyen, "Study on the Effect of Fused Deposition Modeling (FDM) Process Parameters on the Printed Part Quality," Int. Journal of Engineering Research and Application, vol. 7, no. 2. pp. 71–77, 2017, doi: 10.9790/9622-0712027177.
9. J.-Y. H. and P. M. F. Le Bourhis, O. Kerbrat, L. Dembinski, "Predictive model for environmental assessment in additive manufacturing process," Procedia CIRP, vol. 15, pp. 26–31, 2014.
10. R. R. Ma, J. T. Belter, and A. M. Dollar, "Hybrid Deposition Manufacturing: Design Strategies for Multimaterial Mechanisms Via Three- Dimensional Printing and Material Deposition," Journal of Mechanisms and Robotics, vol. 7, no. 2. pp. 1–10, 2015, doi: 10.1115/1.4029400.
11. F. Lederle, F. Meyer, G.-P. Brunotte, C. Kaldun, and E. G. Hübner, "Improved mechanical properties of 3D-printed parts by fused deposition modeling processed under the exclusion of oxygen," Prog. Addit. Manuf., vol. 1, no. 1–2, pp. 3–7, 2016, doi: 10.1007/s40964-016-0010-y.
12. S. Maidin, J. H. U. Wong, A. S. Mohamed, and S. B. Mohamed, "Effect of vacuum assisted fused deposition modeling on 3D printed ABS microstructure," International Journal of Applied Engineering Research, vol. 12, no. 15. pp. 4877–4881, 2017.
13. S. Maidin, and M. K. Muhamad, "Ultrasonic Assisted Fuse Deposition Modeling to Improve Parts Surface Finish," Australian Journal of Basic and Applied Sciences, vol. 9, no. 9, pp. 105–108, 2015.
14. G. Li, J. Zhao, J. Jiang, H. Jiang, W. Wu, and M. Tang, "Ultrasonic strengthening improves tensile mechanical performance of fused deposition modeling 3D printing," Int. J. Adv. Manuf. Technol., vol. 96, no. 5–8, pp. 2747–2755, 2018, doi: 10.1007/s00170-018-1789-0.
15. A. Tofangchi, P. Han, J. Izquierdo, A. Iyengar, and K. Hsu, "Effect of Ultrasonic Vibration on Interlayer Adhesion in Fused Filament Fabrication 3D Printed ABS," Polymers (Basel)., vol. 11, no. 2, p. 315, 2019, doi: 10.3390/polym11020315.
16. S. Maidin, M. K. Muhamad, and E. Pei, "Feasibility study of ultrasonic frequency application on fdm to improve parts surface finish," J. Teknol., vol. 77, no. 32, pp. 27–35, 2015, doi: 10.11113/jt.v77.6983.
17. A. C. and L. N. L. de L. J. Pujana, A. Rivero, "Analysis of ultrasonic-assisted drilling of Ti6Al4V," Int. J. Mach. Tools Manuf., vol. 46, no. 6, pp. 500–508, 2009.
18. R. Li, Q. Q. Ni, H. Xia, and T. Natsuki, "Analysis of individual attenuation components of ultrasonic waves in composite material considering frequency dependence," Compos. Part B Eng., vol. 140, pp. 232–240, 2018, doi: 10.1016/j.compositesb.2016.03.045.
19. D. M. Hiller and G. I. Grabb, "Groundborne vibration caused by mechanised construction works," *Noise Vib. Worldw*., vol. 32, no. 1, pp. 9–14, 2001, doi: 10.1260/0957456011498218.
20. M. C. Ziskin, "Fundamental physics of ultrasound and its propagation in tissue.," Radiographics, vol. 13, no. 3, pp. 705–709, 1993, doi: 10.1148/radiographics.13.3.8316679.
21. R. J. Friel and R. A. Harris, "Ultrasonic additive manufacturing A hybrid production process for novel functional products," Procedia CIRP, vol. 6, no. 1, pp. 35–40, 2013, doi: 10.1016/j.procir.2013.03.004.
22. S. Maidin, A. S. Mohamed, S. B. Mohamed, J. H. U. Wong and S. Sivarao, "Effect of Multiple Piezoelectric Transducer on Fused Deposition Modeling to Improve Parts Surface Finish," Journal of Advanced Manufacturing Technology, vol 12, no. 1(2), pp. 101-116.
23. T. Kitamura and K. Ohtani, "Non-contact measurement of facial surface vibration patterns during singing by scanning laser Doppler vibrometer," Front. Psychol., vol. 6, no. NOV, pp. 1–8, 2015, doi: 10.3389/fpsyg.2015.01682.

AUTHORS PROFILE

Assoc. Prof. Dr. Shajahan received the B. Eng. (Hons) degree in Manufacturing Systems Engineering from Portsmouth University, United Kingdom in 1997. M.Sc. degrees in Manufacturing Systems Engineering from the Warwick University, United Kingdom, in 2000 and the Doctor of Philosophy in Design for Additive Manufacturing from Loughborough University, United Kingdom in 2008. From 2003 to present, he was a lecturer for Universiti Teknikal Malaysia Melaka. Teaching, supervision, consultancy and Publication related to Manufacturing Engineering of undergraduate and postgraduate program. His research interests include ultrasonic-assisted Fused Deposition Modeling, vacuum assisted Fused Deposition Modeling, optimizing the parameter of 3D printing process for better surface finish and dimensional accuracy and others.

Ting Kung Hieng was born in Sibu, Sarawak, Malaysia in 1995. He received the B. Eng. degree in Manufacturing Engineering from Universiti Teknikal Malaysia Melaka (UTeM), Melaka, Malaysia, in 2015 and graduated in 2019. He is currently pursuing the M.Sc. degree in manufacturing engineering at Universiti Teknikal Malaysia Melaka (UTeM), Melaka, Malaysia. Research interest includes the investigation of mechanical properties of recycled and virgin Acrylonitrile Butadiene Styrene (ABS) for Fused Deposition Modeling, investigation of surface roughness for recycled ABS printed specimen, optimizing the parameter for FDM 3D

printing process and improving the mechanical properties of recycled ABS by using ultrasonic vibration.

Assoc. Prof. Ir. Dr. Mohd Rizal Alkahari is a Deputy Director at Center for Strategy, Quality and Risk Management and an Associate Professor at Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Malaysia. He received his B.Eng from International Islamic University Malaysia (IIUM) and MSc in Manufacturing System Engineering (with Distinction) from the University of Warwick, UK. He then received his Ph.D from Kanazawa University, Japan. His main research interest is on 3D printing / additive manufacturing (AM) particularly related to selective laser sintering/selective laser melting (SLS/SLM), fused deposition modeling (FDM) and wire arc additive manufacturing (WAAM).

Dr. Zulkeflee bin Abdullah received the B. Eng. (Hons) degree in Mechanical Engineering from University of Western Ontario, United Kingdom in 1998. M.Sc. degrees in Advanced Manufacturing Technology from the Universiti Teknologi Malaysia, Malaysia, in 2003 and the Doctor of Philosophy in Engineering Design Empirical Studies, Mechanical Engineering from The University of Melbourne, Australia in 2015. He is a lecturer for Universiti Teknikal Malaysia Melaka. Teaching, supervision and Publication related to product design and additive manufacturing. His research interests include Additive Manufacturing, Fused Deposition Modeling, shockwave guard, slitting sheet metal machine, analysis and improvement product and process design using DFA house methodology and improving Malaysian engineering graduate ability to read and interpret engineering drawings.

Retrieval Number: D8037049420/2020©BEIESP
DOI: 10.35940/ijeat.D8037.049420
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication