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# Table of Contents

## *INTERNATIONAL CONFERENCE ON ENGINEERING, SCIENCE AND NANOTECHNOLOGY 2016 (ICESNANO 2016)*

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### PRELIMINARY

OpenJanuary 2017

## *Preface: International Conference on Engineering, Science and Nanotechnology 2016 (ICESNANO 2016)*

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OpenJanuary 2017

## *Group Photo: International Conference on Engineering, Science and Nanotechnology 2016 (ICESNANO 2016)*

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## PLENARY AND INVITED PAPERS

OpenJanuary 2017

### *Heat transfer characteristics of various kinds of ground heat exchangers for ground source heat pump system*

[A. Miyara](#), [K. Kariya](#), [Md. H. Ali](#), [S. B. Selamat](#) and [Jalaluddin](#)

AIP Conference Proceedings **1788**, 020001 (2017); <https://doi.org/10.1063/1.4968249>

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### *Study toward high-performance thermally driven air-conditioning systems*

[Takahiko Miyazaki](#), [Jin Miyawaki](#), [Tomonori Ohba](#), [Seong-Ho Yoon](#), [Bidyut Baran Saha](#) and [Shigeru Koyama](#)

AIP Conference Proceedings **1788**, 020002 (2017); <https://doi.org/10.1063/1.4968250>

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## *Transport properties measurement on low GWP alternative refrigerants*

[Keishi Kariya](#), [Mohammad Ariful Islam](#), [Alam Md Jahangir](#), [Hirotaka Ishida](#) and [Akio Miyara](#)

AIP Conference Proceedings **1788**, 020003 (2017); <https://doi.org/10.1063/1.4968251>

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OpenJanuary 2017

## *Generation of high-temperature steam from unused thermal energy by a novel adsorption heat pump*

[Koichi Nakaso](#), [Shotaro Eshima](#) and [Jun Fukai](#)

AIP Conference Proceedings **1788**, 020004 (2017); <https://doi.org/10.1063/1.4968252>

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## *Deposition of p-type wide-gap semiconductor $Cu_xZn_yS$*

[Masaya Ichimura](#)

AIP Conference Proceedings **1788**, 020005 (2017); <https://doi.org/10.1063/1.4968253>

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## CONTRIBUTED ORAL PAPERS

OpenJanuary 2017

## *Performance and driveline analyses of engine capacity in range extender engine hybrid vehicle*

[Achmad Praptijanto](#), [Widodo Budi Santoso](#), [Arifin Nur](#), [Bambang Wahono](#) and [Yanuandri Putrasari](#)

AIP Conference Proceedings **1788**, 030001 (2017); <https://doi.org/10.1063/1.4968254>

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OpenJanuary 2017

## *Numerical investigation of laminar convective heat transfer for TiO<sub>2</sub>/water nanofluids using two-phase mixture model (Eulerian approach)*

[Budi Kristiawan](#), [Budi Santoso](#), [Wibawa Endra Juwana](#), [Raden Mahesa Ramadhan](#) and [Ivan Riandana](#)

AIP Conference Proceedings **1788**, 030002 (2017); <https://doi.org/10.1063/1.4968255>

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## *Improving ion-exchange membrane properties by the role of nanoparticles*

[Danu Ariono](#) and [Khoiruddin](#)

AIP Conference Proceedings **1788**, 030003 (2017); <https://doi.org/10.1063/1.4968256>

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## *Performance of the drag type of Horizontal Axis Water Turbine (HAWT) as effect of depth to width ratio of blade*

Syamsul Hadi, Rio Jevri Apdila, Arif Hidayat Purwono, Eko Prasetya Budiana and Dominicus Danardono Dwi Prija Tjahjana

AIP Conference Proceedings **1788**, 030004 (2017); <https://doi.org/10.1063/1.4968257>

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## *Concentric tube heat exchanger installed by twisted tapes using various wings with alternate axes*

Indri Yaningsih and Agung Tri Wijayanta

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OpenJanuary 2017

## *A modified Newton's method used to solve a steady flow problem based on the shallow water equations*

[Sudi Mungkasi](#) and [Juliani Sihotang](#)

AIP Conference Proceedings **1788**, 030006 (2017); <https://doi.org/10.1063/1.4968259>

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## *Comparison between SVPWM two level in internal and external circle of hexagon*

[Andhika Giyantara](#) and [Mochammad Rameli](#)

AIP Conference Proceedings **1788**, 030007 (2017); <https://doi.org/10.1063/1.4968260>

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## *Experimental study on optimization of curvature blade impeller pump as turbine which functioned as power plant picohydro*

Dwi Aries Himawanto, D. D. D. P. Tjahjana and Hantarum

AIP Conference Proceedings **1788**, 030008 (2017); <https://doi.org/10.1063/1.4968261>

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## *Knock detection system to improve petrol engine performance, using microphone sensor*

Agus Sujono, Budi Santoso and Wibawa Endra Juwana

AIP Conference Proceedings **1788**, 030009 (2017); <https://doi.org/10.1063/1.4968262>

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## *Effect of sintering time on the performance of turmeric dye-sensitized solar cells*

Basuki, [R. Lullus Lambang G. Hidajat](#), [Suyitno](#), [Budi Kristiawan](#) and [Rendy Adhi Rachmanto](#)

AIP Conference Proceedings **1788**, 030010 (2017); <https://doi.org/10.1063/1.4968263>

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## *Exergy analysis of a dual-evaporator refrigeration systems*

[Matheus M. Dwinanto](#), [Suhanan](#) and [Prajitno](#)

AIP Conference Proceedings **1788**, 030011 (2017); <https://doi.org/10.1063/1.4968264>

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## *Three-dimensional flow in the vicinity of a circular cylinder mounted to a flat plate at high Reynolds number*

[Galih Bangga](#), [Andri Ashfahani](#), [Erik Sugianto](#), [Devy Sa'adiyah](#), [Tiara Putri](#), [Eva Jost](#) and [Thorsten Lutz](#)

AIP Conference Proceedings **1788**, 030012 (2017); <https://doi.org/10.1063/1.4968265>

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## *Numerical simulation of flow through pipe with magnitude of valve opening as variant at $Re\ 2 \times 10^5$*

[Mahmud](#) and [Wawan Aries Widodo](#)

AIP Conference Proceedings **1788**, 030013 (2017); <https://doi.org/10.1063/1.4968266>

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## *Comparison of wake behind finned cylinders with fin pitch variations in cross-flow*

[Sudirman](#) and [Ruslim](#)

AIP Conference Proceedings **1788**, 030014 (2017); <https://doi.org/10.1063/1.4968267>

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## *Performance analysis of the electric vehicle air conditioner by replacing hydrocarbon refrigerant*

[Budi Santoso](#) and [D. D. D. P. Tjahjana](#)

AIP Conference Proceedings **1788**, 030015 (2017); <https://doi.org/10.1063/1.4968268>

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## *Computational study: The influence of omni-directional guide vane on the flow pattern characteristic around Savonius wind turbine*

[Yoga Arob Wicaksono](#) and [D. D. D. P. Tjahjana](#)

AIP Conference Proceedings **1788**, 030016 (2017); <https://doi.org/10.1063/1.4968269>

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## *Development of briquette fuel from cashew shells and rice husk mixture*

[Eflita Yohana](#), [Arijanto](#), [Ivan Edgar Kalyana](#) and [Andy Lazuardi](#)

AIP Conference Proceedings **1788**, 030017 (2017); <https://doi.org/10.1063/1.4968270>

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## *The study of membrane formation via phase inversion method by cloud point and light scattering experiment*

[Nasrul Arahman](#), [Teuku Maimun](#), [Mukramah](#) and [Syawaliah](#)

AIP Conference Proceedings **1788**, 030018 (2017); <https://doi.org/10.1063/1.4968271>

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*Ternary (liquid + liquid) equilibria of (diethyl carbonate + ethanol or 1-propanol + water) systems at 303.15 K under atmospheric pressure*

[Rizqy Romadhona Ginting](#), [Asalil Mustain](#), [Ignatius Gunardi](#) and [Gede Wibawa](#)

AIP Conference Proceedings **1788**, 030019 (2017); <https://doi.org/10.1063/1.4968272>

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*A numerical study of condensation heat transfer for R-134a in annular flow regime inside horizontal tube*

[Teguh Hady Ariwibowo](#), [Fifi Hesty Solihah](#) and [Bambang Harjanto](#)

AIP Conference Proceedings **1788**, 030020 (2017); <https://doi.org/10.1063/1.4968273>

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## *Mass transfer in stirred tank for phenolic extraction from coal tar*

[Dewi Selvia Fardhyanti](#), [Bahy Wibowo](#) and [Muhammad Rafiqi](#)

AIP Conference Proceedings **1788**, 030021 (2017); <https://doi.org/10.1063/1.4968274>

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## *High crystalline $Cu_2ZnSnS_4$ semiconductor prepared from low toxicity ethanol-based precursors*

[Badrul Munir](#), [Bayu Eko Prastyo](#), [Dwi Marta Nurjaya](#), [Ersan Yudhapratama Muslih](#) and [Sahri Karim Alfauzan](#)

AIP Conference Proceedings **1788**, 030022 (2017); <https://doi.org/10.1063/1.4968275>

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OpenJanuary 2017

## *Experimental evaluation on the use of capillary tube and thermostatic expansion valve with heat recovery hot spot water heater in air source refrigeration system*

Azridjal Aziz, [Rahmat Iman Mainil](#), [Afdhal Kurniawan Mainil](#) and [Eko Saputra](#)

AIP Conference Proceedings **1788**, 030023 (2017); <https://doi.org/10.1063/1.4968276>

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OpenJanuary 2017

## *Effect of water temperature and air stream velocity on performance of direct evaporative air cooler for thermal comfort*

Azridjal Aziz, [Rahmat Iman Mainil](#), [Afdhal Kurniawan Mainil](#) and [Hendra Listiono](#)

AIP Conference Proceedings **1788**, 030024 (2017); <https://doi.org/10.1063/1.4968277>

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## *Effect of concave rectangular winglet vortex generator on convection coefficient of heat transfer*

Syaiful, Gladys Sugiri, Maria F. Soetanto and Myung-whan Bae

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## *Wind energy potential assessment to estimate performance of selected wind turbine in northern coastal region of Semarang-Indonesia*

B. S. Premono, D. D. D. P. Tjahjana and S. Hadi

AIP Conference Proceedings **1788**, 030026 (2017); <https://doi.org/10.1063/1.4968279>

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OpenJanuary 2017

## *Numerical study of 3D brine flow across ice can to analyze heat transfer characteristics*

Arrad Ghani Safitra and Prabowo

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## *Thermal analysis of disc brakes using finite element method*

Jaenudin, J. Jamari and M. Tauvqirrahman

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OpenJanuary 2017

## *Bifunctional catalyst of graphite-encapsulated iron compound nanoparticle for magnetic carbon nanotubes growth by chemical vapor deposition*

Teguh Endah Saraswati, Oktaviana Dewi Indah Prasiwi, Abu Masykur and Miftahul Anwar

AIP Conference Proceedings **1788**, 030029 (2017); <https://doi.org/10.1063/1.4968282>

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## *Effect of annealing temperature of titanium dioxide thin films on structural and electrical properties*

A. S. Bakri, M. Z. Sahdan, F. Adriyanto, N. A. Raship, N. D. M. Said, S. A. Abdullah and M. S. Rahim

AIP Conference Proceedings **1788**, 030030 (2017); <https://doi.org/10.1063/1.4968283>

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OpenJanuary 2017

## *Effect of electrode and weld current on the physical and mechanical properties of cast iron welding*

M. Chamim, [Triyono](#) and [Kuncoro Diharjo](#)

AIP Conference Proceedings **1788**, 030031 (2017); <https://doi.org/10.1063/1.4968284>

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OpenJanuary 2017

## *Performance prediction of serpentine type compact magnetorheological brake prototype*

Ubaidillah, [A. Wibowo](#), [D. Adiputra](#), [D. D. D. P. Tjahjana](#), [M. A. A. Rahman](#) and [S. A. Mazlan](#)

AIP Conference Proceedings **1788**, 030032 (2017); <https://doi.org/10.1063/1.4968285>

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OpenJanuary 2017

## *Degradation activation energy determination of PEG 4000-quartz composites using dynamic mechanical analyzer (DMA) measurements*

[Teuku Andi Fadly](#), [Nur Aini Fauziah](#), [Allif Rosyidy](#), [Mashuri](#) and [Suminar Pratapa](#)

AIP Conference Proceedings **1788**, 030033 (2017); <https://doi.org/10.1063/1.4968286>

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OpenJanuary 2017

## *Fins effectiveness and efficiency with position function of rhombus sectional area in unsteady condition*

[Tito Dwi Nugroho](#) and [P. K. Purwadi](#)

AIP Conference Proceedings **1788**, 030034 (2017); <https://doi.org/10.1063/1.4968287>

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OpenJanuary 2017

## *The effect of thermal cycles during aluminum casting on the intermetallic layer formation at the interface of steel crucible*

Dedy Hernady, Triyono and Nurul Muhayat

AIP Conference Proceedings **1788**, 030035 (2017); <https://doi.org/10.1063/1.4968288>

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## *Rheological properties of a reclaimed waste tire rubber through high-pressure high-temperature sintering*

Ubaidillah, N. A. Yunus, S. A. A. Aziz, N. A. A. Wahab and S. A. Mazlan

AIP Conference Proceedings **1788**, 030036 (2017); <https://doi.org/10.1063/1.4968289>

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# *Combination of ternary $Fe_3O_4/TiO_2/CuO$ nanocomposites and nanographene platelets: High performance photo and sonocatalysis*

[Ardiansyah Taufik](#) and [Rosari Saleh](#)

AIP Conference Proceedings **1788**, 030037 (2017); <https://doi.org/10.1063/1.4968290>

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# *Gear distortion analysis due to heat treatment process*

[Natalino F. D. S. Guterres](#), [Rusnaldy](#) and [Achmad Widodo](#)

AIP Conference Proceedings **1788**, 030038 (2017); <https://doi.org/10.1063/1.4968291>

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*Microstructure and mechanical properties of micro-SiC<sub>p</sub> particles reinforced magnesium matrix composites with semi-solid stir casting method*

[E. I. Bhifttime](#) and [J. B. Belo](#)

AIP Conference Proceedings **1788**, 030039 (2017); <https://doi.org/10.1063/1.4968292>

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*Effect of wt.% SiC<sub>p</sub> and TiB on the mechanical properties in SiC<sub>p</sub>/AZ81A magnesium matrix composite by the method semi solid stir casting*

[E. I. Bhifttime](#), [Natalino F. D. S. Guterres](#) and [R. Atmaja](#)

AIP Conference Proceedings **1788**, 030040 (2017); <https://doi.org/10.1063/1.4968293>

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## *Study the effect of active carbon modified using HNO<sub>3</sub> for carbon electrodes in capacitive deionization system*

Ernes Josias Blegur and Endarko

AIP Conference Proceedings **1788**, 030041 (2017); <https://doi.org/10.1063/1.4968294>

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OpenJanuary 2017

## *Ultrasonic irradiation-driven sonocatalytic degradation of methylene blue by ternary Fe<sub>3</sub>O<sub>4</sub>/ZnO/NGP nanocomposites*

Faurul Fitri Harno, Ardiansyah Taufik and Rosari Saleh

AIP Conference Proceedings **1788**, 030042 (2017); <https://doi.org/10.1063/1.4968295>

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## *Mechanical behaviour of biophotocomposite materials: An experimentally validated micromechanics model for tensile strength*

[Joko Triyono](#), [Alva Edy Tontowi](#), [Widowati Siswomihardjo](#) and [Rochmadi](#)

AIP Conference Proceedings **1788**, 030043 (2017); <https://doi.org/10.1063/1.4968296>

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## *Effect of anneal temperature on fluorine doped tin oxide (FTO) nanostructured fabricated using hydrothermal method*

[M. K. Ahmad](#), [N. A. Marzuki](#), [C. F. Soon](#), [N. Nafarizal](#), [R. Sanudin](#), [A. B. Suriani](#), [A. Mohamed](#), [M. Shimomura](#), [K. Murakami](#), [M. H. Mamat](#) and [M. F. Malek](#)

AIP Conference Proceedings **1788**, 030044 (2017); <https://doi.org/10.1063/1.4968297>

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Rizka Nurlaila, [Musyarofah](#), [Nibras Fuadi Muwwaqor](#), [Triwikantoro](#), [Anton Kuswoyo](#) and [Suminar Pratapa](#)

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[Hendry Tju](#), [Ardiansyah Taufik](#) and [Rosari Saleh](#)

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Yopi Y. Tanoto, Juliana Anggono, Ian H. Siahaan, and Wesley Budiman

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# The Effect of Orientation Difference in Fused Deposition Modeling of ABS Polymer on the Processing Time, Dimension Accuracy, and Strength

Yopi Y. Tanoto<sup>1,a)</sup>, Juliana Anggono<sup>1</sup>, Ian H. Siahaan<sup>1</sup> and Wesley Budiman<sup>1</sup>

<sup>1</sup>*Mechanical Engineering Department – Petra Christian University, Surabaya 60236, Indonesia*

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**Abstract.** There are several parameters that must be set before manufacturing a product using 3D printing. These parameters include the orientation deposition of that product, type of material, form fill, fill density, and other parameters. The finished product of 3D printing has some responses that can be observed, measured, and tested. Some of those responses are the processing time, the dimensions of the end product, its surface roughness and the mechanical properties, i.e. its yield strength, ultimate tensile strength, and impact resistance. This research was conducted to study the relationship between process parameters of 3D printing machine using a technology of fused deposition modeling (FDM) and the generated responses. The material used was ABS plastic that was commonly used in the industry. Understanding the relationship between the parameters and the responses thus the resulting product can be manufactured to meet the user needs. Three different orientations in depositing the ABS polymer named XY (first orientation), YX (second orientation), and ZX (third orientation) were studied. Processing time, dimensional accuracy, and the product strength were the responses that were measured and tested. The study reports that the printing process with third orientation was the fastest printing process with the processing time 2432 seconds followed by orientation 1 and 2 with a processing time of 2688 and 2780 seconds respectively. Dimension accuracy was also measured from the width and the length of gauge area of tensile test specimens printed in comparison with the dimensions required by ASTM 638-02. It was found that the smallest difference was in thickness dimension, i.e. 0.1 mm thicker in printed sample using second orientation than as required by the standard. The smallest thickness deviation from the standard was measured in width dimension of a sample printed using first orientation (0.13 mm). As with the length dimension, the closest dimension to the standard was resulted from the third orientation product, i.e. 0.2 mm. Tensile test done on all the specimens produced with those three orientations shows that the highest tensile strength was obtained in sample from second orientation deposition, i.e. 7.66 MPa followed by the first and third orientations products, i.e. 6.8 MPa and 3.31 MPa, respectively.

## INTRODUCTION

Product cost, quality, and time to market are the three effectiveness criteria for the design process [1]. The development of the technology of rapid prototyping (RP) which uses 3D printing technology makes the design or the product development process become faster. RP is a technique that can be used to create a data computer aided design (CAD) into 3D objects with additive manufacturing or 3D printing technology [2]. There are many types of RP technologies, such as stereolithography, fused deposition modeling, laminated object manufacturing, selective laser sintering, etc. From the various types of technologies, RP is the most commonly used in fused deposition modeling (FDM). In FDM, a filament extruded through a heated die [3].

Studies about the influence of 3D printing process parameters especially FDM technology has been done by several researchers. Lubis and Sutanto had studied on the type of material and the orientation of the object in FDM with PLA and ABS as the materials and used vertical and horizontal orientations. In their research, the observed responses evaluated were processing time, deviation of dimensions, and surface conditions of specimens/products. They reported that the fastest processing time was the horizontal orientation, i.e. 53 minutes (3180 seconds). Horizontal orientation was also reported to have a smoother surface than a vertical orientation. Horizontal

orientation on PLA had a small deviation dimension compared with the ABS [4]. Other research groups like Galeta *et al.* studied the effect of printing process parameters on the production process of 3D printing products [5]. Factors studied were the orientation of the object, layer thickness, and the type of infiltrant. Lužanin, *et al.* studied the effect of layer thickness, deposition angle, and the infill shape on the deflection force at FDM [6].

A research work about parameters that are affecting the mechanical properties in FDM 3D printing product is also important because FDM is the most common 3D printer that can be used from the household to the industrial scale. Today the product of 3D printing is not only as a prototype but also as an end product. From previous research, it was found that the differences of orientations are affecting the processing time and quality, but the vertical (third) orientation and tensile strength response were not observed. Therefore, this research was carried out to investigate the effect of object orientation during FDM process on the processing time, dimensional accuracy, and the tensile strength of the products.

## EXPERIMENTAL METHOD

### Preparation of Material, Setting and Printing Process

Materials used in this research was 1 kg BFB (Bits from Bytes) ABS polymer filament. In 3D printing process, ABS is a popular plastic that has been used to make all sorts of home goods and toys [7]. 3D engine printer used was BFB 3D Touch Double (Fig. 1). FDM printing process produced three specimens for each orientation (Fig. 2). The dimensions of the specimens were determined in accordance with ASTM D638-02 [8]. Specimens drawing was created using CAD software. The CAD files were saved in .stl format which then was imported into 3D Printing software, namely AXON v2. Axon software is processed the model specimen printing process according to the parameters input (Fig. 3). During the printing, the processing time was recorded using a stopwatch. The starting time was recorded when an extruder began the printing process (extruder began to extrude the material), and the recording ended when the extruder finished the printing process.

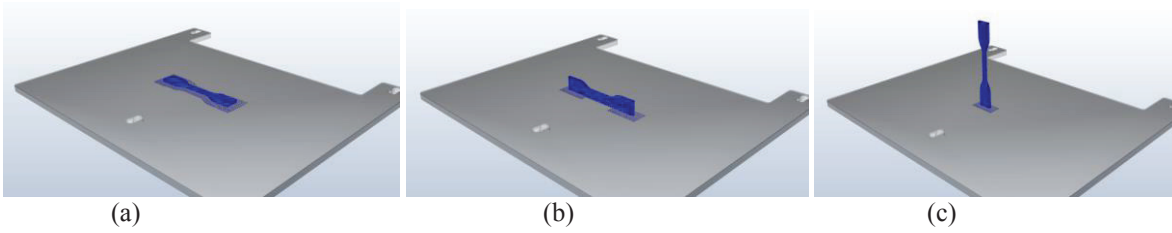
Layer thickness means the thickness of each layer printed. The thinner the layer the smoother the surface will be. However, the thicker the layer will make the printing time faster.

### Specimen Characterization

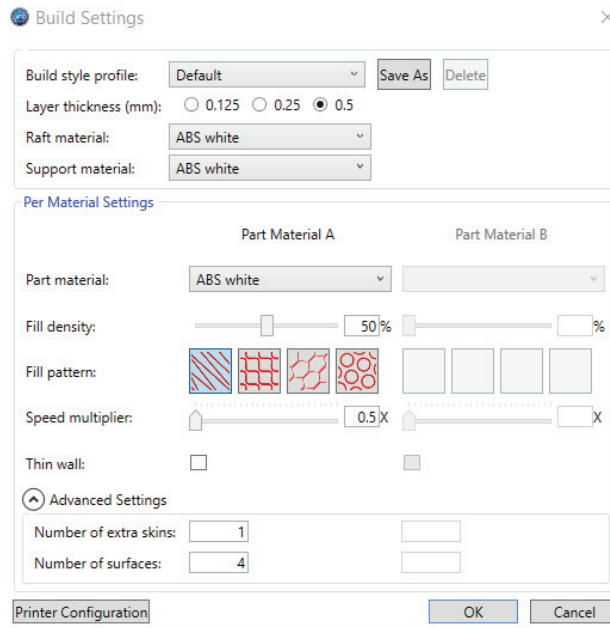
Characteristics of the printed specimens that were measured and tested were the dimensional accuracy of all specimens produced with different deposition orientations and their tensile strength. Specimen dimensions, namely the length, width, and thickness were measured using a caliper with an accuracy of 0.05 mm. Before performing the tensile test, all specimens were prepared by grinding their surface with the silicon carbide paper with a surface finish surface using grade 1500. Tensile test machine used was Autograph AG 10TE Shimadzu with a capacity of 10 kN.



FIGURE 1. BFB Touch Double Printer Machine and Material



**FIGURE 2.** (a) First orientation (b) Second Orientation (c) Third Orientation



**FIGURE 3.** AXON Built Setting Interface

## RESULTS AND DISCUSSION

### Influence of Object Orientation on Dimensional Accuracy

Dimensional accuracy was obtained by comparing the measured dimensions (thickness, length, and width) of all printed tensile test specimens with the standard tensile test specimens required by ASTM D638-02. The measurement of all dimensions can be seen in Fig. 4. Specimen length that was closest to the standard was found in the third orientation specimen, i.e. 115.2 mm or there was a difference of 0.2 mm. The largest difference occurred in the second orientation specimen, i.e. 0.9 mm. As with the width measurement, the closest width compared to the standard was found in the first orientation product, i.e. 6.1 mm or having a deviation of 0.1 mm. The biggest difference occurred in the second orientation product that was measured as 0.6 mm. In the thickness measurement, second orientation had the closest thickness as required by ASTM 638-02 (4.1 mm); while the largest difference occurred with first orientation product, i.e. 0.5 mm.

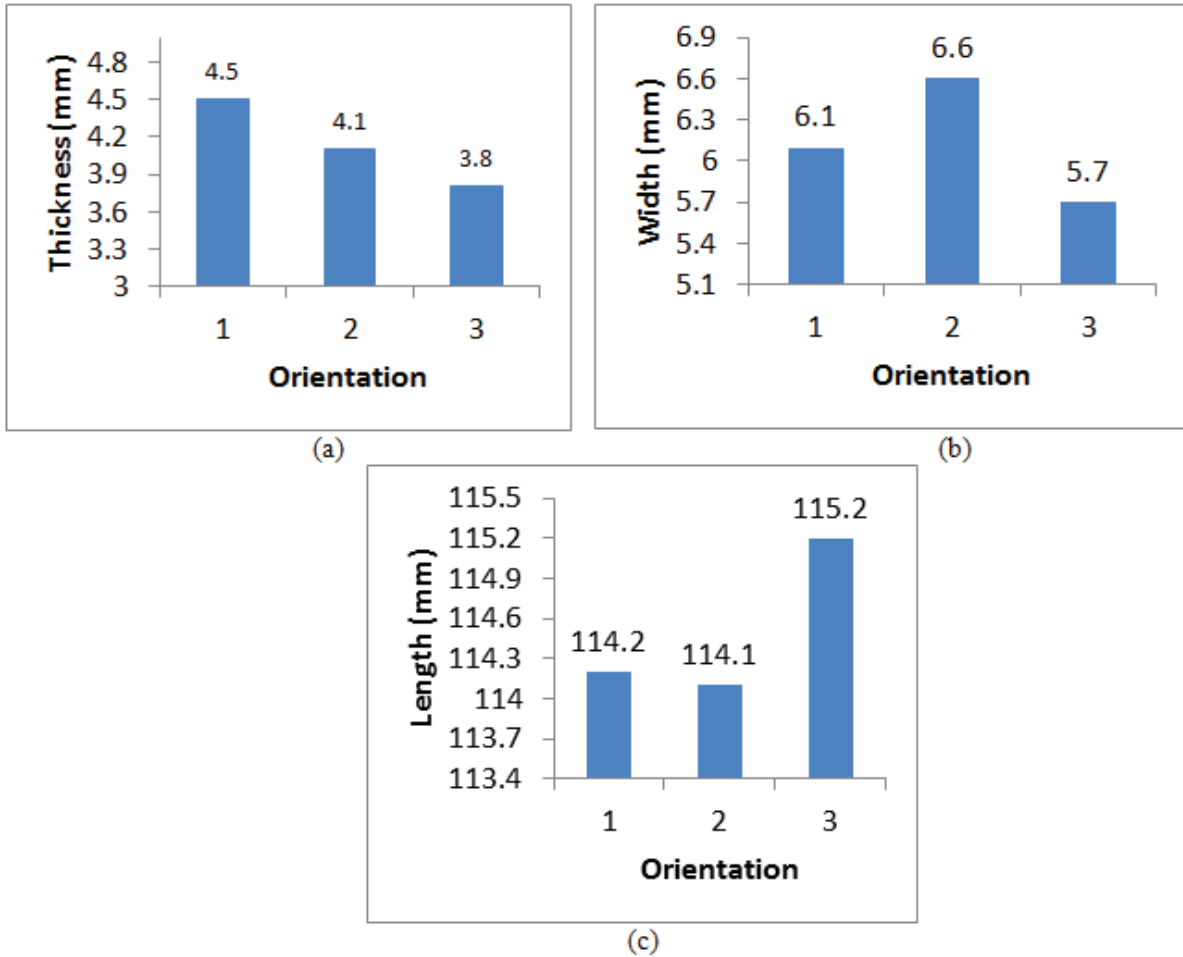


FIGURE 4. Specimen dimensions printed in a different orientation (a) thickness (b) width and (c) length.

### Influence of Object Orientation On Processing Time

Figure 5 shows the processing time recorded using a stopwatch. The processing time on the first orientation was measured as 2688 seconds. In this orientation, the raft was the widest compared to the other two orientations. The processing time in the second orientation was 2780 seconds. The second orientation took the longest processing time, i.e., 92 seconds longer than the first orientation and 348 seconds longer from the third orientation (the fastest was required 2432 seconds). That longer time required due to it needed support to create the object. In the third orientation, support was not necessary as the object and the raft were the smallest. Rafts in all orientations and support in second orientation can be seen in Fig. 6. This result is analogous with the previous research that first orientation has a faster time than second orientation [4].

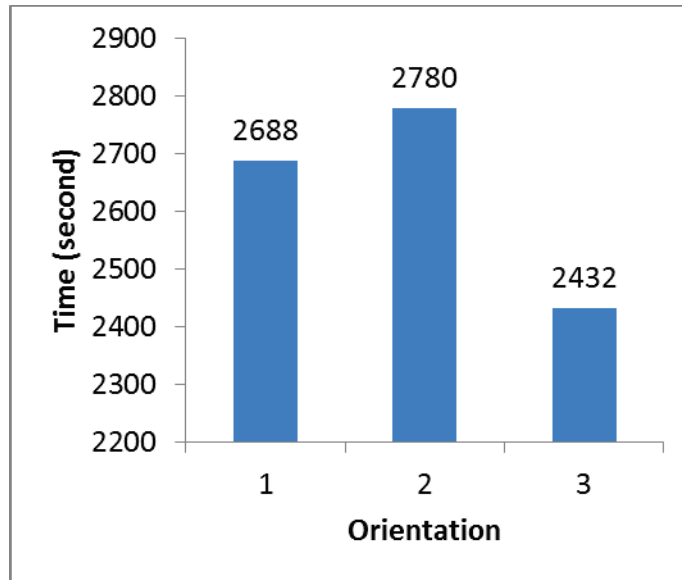


FIGURE 5. Processing Time Needed In Different Orientation

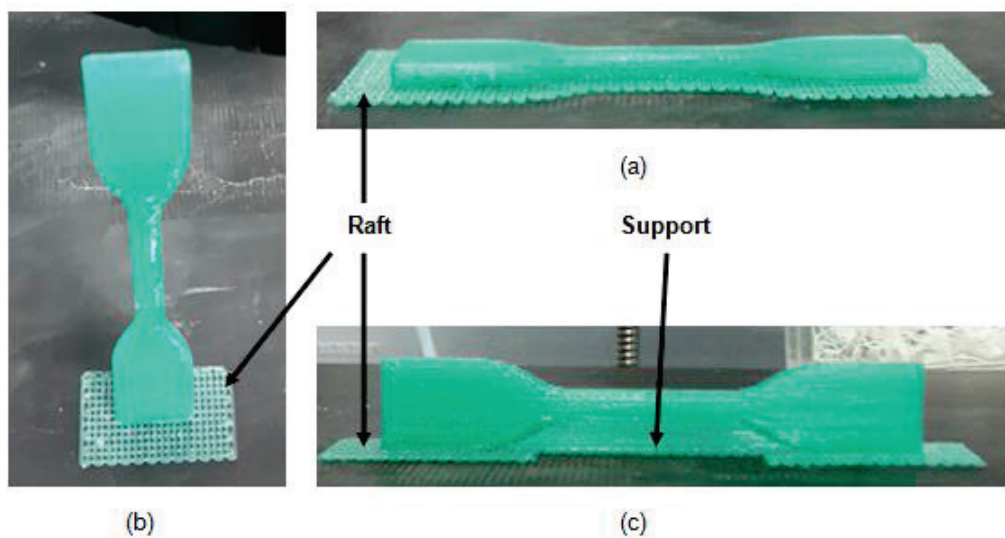


FIGURE 6. Raft and Support in Specimen at (a) First Orientation (b) Third Orientation (c) Second Orientation

### Influence of Object Orientation on Tensile Strength

Tensile strength obtained from products of each orientation can be seen in Fig. 7. It shows that the second orientation was an orientation with the highest tensile strength, i.e. 7.66 MPa. Third orientation has a lowest tensile strength with an average of 3.31 MPa. This orientation produced layer patterns of ABS that were perpendicular to the tensile force, therefore, caused the bonds between layers were easily separated than the other two orientations. Second orientation has the highest tensile strength because it had more layers (12 layers) that were parallel to the tensile force. First orientation only had 8 layers. The more layers, they can hold better. Figure 8 illustrates the tensile force working on the cross section of gage area of the tensile test specimen.

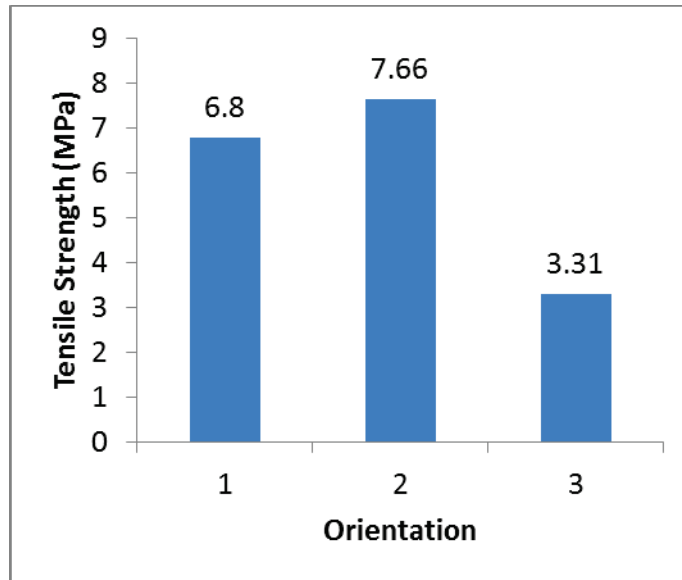


FIGURE 7. Tensile Strength Obtained with Different Orientation

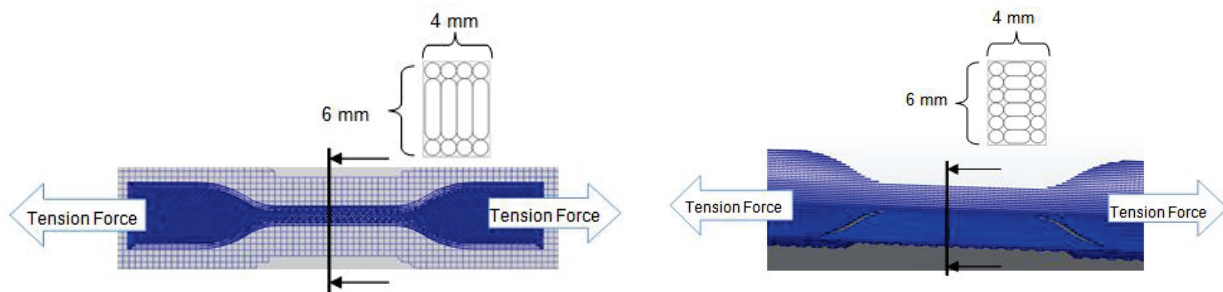


FIGURE 8. Illustration of gage section under a tensile load (a) first orientation (b) second orientation.

## CONCLUSION

From the experiments and tests performed, it can be concluded that the third orientation has the fastest processing time, i.e., 2432 seconds because during the printing process, support was not needed and it only used the smallest raft. In dimensional accuracy, each orientation has the smallest difference in dimension of its own in comparison to the required dimension by ASTM D638-02. The highest tensile strength was identified with the product printed with a second orientation (7.66 MPa), and the third orientation product has the smallest tensile strength, i.e. 3.31 MPa. For the application, the operator can set the orientation based on the required response, for example, for faster processing time, third orientation should be set.

## ACKNOWLEDGEMENTS

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