PRODUCTION & MANUFACTURING | RESEARCH ARTICLE

Virtual design and machining of core and cavity for fabrication of dining plate tableware with Kawung batik pattern

P.W. Anggoro¹*, M.B. Krishnyayuda¹, T. Yuniarto¹, B. Bawono¹, Y. Suharyanti¹, S. Felasari², D.B. Setyohadi³, O.K.W. Widyanarka⁴ and A.P. Bayuseno⁵

Abstract: Batik Kawung is one of the most popular batik patterns in Indonesia. This pattern can be displayed as an attractive and artistic ornament of ceramic plate products. This ornament can increase the selling value and storytelling of the product. Computer-based virtual design and manufacturing (VDM) technology is used to produce Kawung batik patterns that can be affixed to ceramic surfaces. The wrapping method in PowerShape is used to paste this pattern. The stages of

ABOUT THE AUTHORS

P.W. Anggoro obtained a doctoral degree from Universitas Diponegoro, Indonesia and Lecture at Department of Industrial Engineering, Universitas Atma Jaya Yogyakarta, Indonesia. His research interest focus on Reverse Innovative Design with additive and subtractive manufacturing technology especially on the orthotic, prosthetic and ceramic product design.

M.B. Krishnyayuda, received a sudent BS degree in engineering from the Universitas Atma Jaya Yogyakarta.

T. Yuniarto obtained a master’s degree from Universitas Gadjah Mada, Indonesia.

B. Bawono obtained a doctoral degree from Universitas Diponegoro, Indonesia.

Y. Suharyanti obtained a doctoral degree from Universitas Gadjah Mada, Yogyakarta, Indonesia.

S. Felasari obtained a doctoral degree Architecture from University of Sheffield, United Kingdom.

Djoko Budiyanto Setyohadi is a professor in the system information of the Department of Universitas Atma Jaya Yogyakarta.

O.K.W. Widyanarka received Bachelor of Engineering from Universitas Atma Jaya Yogyakarta and have a good experience in design and fabrication ceramic product for some industry ceramic local in Indonesia (PT Doulton Indonesia, PT Nuanza Porcelain Indonesia and Naruna Ceramic Studio).

Athanasius P. Bayuseno is a professor in material science and engineering and a Senior Lecturer in the Mechanical Engineering Department of Universitas Diponegoro, Indonesia.

PUBLIC INTEREST STATEMENT

Batik Kawung is one of the most popular batik motifs in Indonesia and depicts the original character of Indonesian culture from the sugar palm fruit and Rhynchophorus. This motif can be displayed as an attractive and artistic ornament when affixed to the surface of a ceramic plate product. The appearance of this batik ornament can increase the selling value and storytelling of the ceramic product. The practical solution to get this product ornament is not using handmade technology as is usually done by Naruna Keramik Studio, but using the application of computer-aided reverse engineering system (CARE System) technology. In this study, virtual design and manufacturing (VDM) technology based on ArtCAM Pro 2015 artistic software, Autodesk PowerShape, and PowerMill were used to generate kawung batik motifs from .JPG format into 2.5D model images with .STL format. With the help of Autodesk PowerShape software, the motif is attached to the surface of a simple plate to become a plate with the Kawung batik pattern using the wrapping method. This study also explains the design stages of the dining set plate print with the Batik Kawung motif. To get an overview of this patterned plate mold manufacturing simulation, a virtual machining stage was also carried out using computer-aided manufacturing PowerMill software. The final result shows that the resulting virtual machining simulation shows that the resulting product is precise, precise, accurate, and can be directly processed in real manufacturing on a CNC router machine.
designing a ceramic plate from the beginning of the Kawung pattern to form the core & cavity of the Kawung patterned plate into a 3D image and a virtual cutting milling motion simulation on a CNC machine using PowerMill software. The final result shows that the virtual machining simulation produces plate molds that are precise, accurate, and can be directly manufactured on a CNC router machine. The simulation time of a pair of plate molds is 234 hours 21 minutes 53 seconds, while the actual machining time is about 343 hours.

**Subjects:** Industrial Engineering & Manufacturing; Manufacturing & Processing; Mechanical Engineering; Manufacturing Engineering

**Keywords:** Kawung Batik pattern; ornament; virtual design and machining; ArtCAM Pro; ceramic plate

1. **Introduction**

The design paradox is a problem that plagues a traditional product development process that is normally carried out sequentially (Chang, 2015a; Ullman, 1992). The dichotomy or contradiction between both the design engineer’s technical experience and the amount of factors to be considered (flexibility) all across the product life cycle is referred to as this. Major design practices are commonly decided early in the design process when the product is still a work in progress. As a result, engineering adjustments are routinely sought in later stages of product development to remedy decisions (Ullman, 1992), as product design grows and becomes better understood.

In e-Design, system designers create a solid model of a process innovation concept utilizing CAD tools (Figure 1). Simulations for quality performance, precision, and manufacture can be carried out using the product physical model presented in CAD. Engineering specialties and competence are used to manage design and development tasks and the cross-functional group. Simulation models can be derived using correct simplifying assumptions based on a centralized computer-aided design prototype. However, for faster simulation model modifications, a one-way geometry that directs alterations from CAD models to simulation models must be built (Chang, 2015b, 2015c; Chang et al., 1998).

![Figure 1. The e-Design paradigm (Chang, 2015a).](image)

The ceramic kitchenware sector has long been thought to be mainly craft-based. In the Indonesian ceramic industry, computers are largely used for word processing, databases, records, payments, warehousing, and process monitoring. The ceramics industry in Indonesia still applies little computer technology in designing due to constraints of the technology and cost. Along with
the development, some industries are increasingly interested in using computer technology. However, the business’s adoption of computer-based design technologies for the designing stage of new product innovation.

Before functional prototype and production, it is extremely desirable to verify the manufacturability of individual parts and the entire assembly in product development (Anggoro et al., 2018; Anggoro, Bowono et al., 2019; Anggoro et al., 2021; Anggoro, Wibowo et al., 2019; Chang, 2015b, 2015c). It is critical to address precision machining difficulties throughout the design phase, and virtual manufacturing devices and system tools are useful in doing so. The use of simulation-based technologies to assist engineers in defining, replicating, and visualizing the production process and development in a computerized environment is known as virtual manufacturing. The fabrication can be established and confirmed design phase utilizing virtual manufacturing. Virtual manufacturing is a vast topic that covers a wide range of issues. On virtual manufacture machining procedures such as drilling, turning, and milling, particularly, namely virtual machining (VM).

Designers can use virtual machining to plan machining operations, produce toolpaths (Anggoro et al., 2018, 2021; Chang, 2015c; Fergiawan, Anggoro, Ismail et al., 2021), monitor and simulate processing steps, and estimate manufacturing time. Furthermore, the resulting toolpath can be transformed into CNC codes (M-codes and G-codes) to machine functioning parts, as well as a die or mold for manufacturing. The toolpath is often created in a CL (cutting location) file format, which is then transformed to CNC codes using post-processors.

In recent years, the use of computers and other forms of automation in the ceramic tableware industry has increased (Chua, Gay, Hoheisel et al., 1997c; Homer & Skaar, 1991; McLaughlin, 1988a, 1988b). In particular, the application of CAD/CAM to ceramic production is feasible for manufacturing sanitary ware, tableware and technical ceramics (Clayton, 1986; Dickin, 1993; Wormald, 1993). In Indonesia, the use of this technology has been proven to be able to increase the development of new designs on ceramic products as described by (Anggoro et al., 2018, 2021; Fergiawan et al., 2019). However, both of them still tend to develop new designs for ceramic products in the form of plain, precise and accurate, but there are no detailed relief patterns that can be displayed on the surface of the ceramic products produced (plates, teapot sets, and jewellery). Patterns with
detailed, elegant patterns and ornaments with telling stories are still rarely found in virtual design and machining (VDM) application research, so they need to be discussed in this paper.

This study examines in detail the stages of making dinner plates with ornaments from the Kawung batik pattern with the help of visual design and machining. The distinguishing structure of batik in terms of patterns, patterns and ornaments is also included in the output of elaborate and precise decorative themes. The findings of this study are intended to contribute to the production of ceramic tableware dining sets with the theme Batik Kawung which is one of Indonesia’s national heritage from thousands and even millions of types and variations of Indonesian Batik.

2. Material and methods
In this study, one of the Kawung batik patterns (Figure 2) was chosen by researchers and the Naruna Keramik Studio because it has a strong telling story value about Indonesian Batik patterns as one of the cultural heritage of the Indonesian nation.
As a result of the discussion group forum with Naruna Ceramic Studio, there are three types of dining tableware plate designs made in this paper, namely plates with diameters of 270, 220, and 180 mm. The resulting design drawing is in the form of a 3D model of a ceramic plate with a Kawung pattern and a print of the top and bottom plates which will be done virtually on a CNC machine (see, Figure 3).

At the same time, the process of making sketch drawings from pieces of plates in the form of 2D models using pencils and drawing paper was also carried out. The goal is as initial input for engineers to create an initial 3D plate model in Autodesk PowerShape CAD software by combining wireframe, workplace, continuous arc into a surface plate with surface revolution operations on the Z-axis until a plate model is formed in 3 dimensions (see, Figure 4).

The generation of photo files in .jpg format (Figure 2) into 2D vector images and 2.5D Kawung pattern models is done using the ArtCAM 2015 R2 software (see, Figure 5).

With the wrapping operation available in the PowerShape software, the output of the plate design (Figure 4) and the Batik Kawung ornament in a 2.5D solid model image with .STL format (Figure 6) is then pasted until a plate is formed and the print is decorated with its patterned ornaments as in Figure 2.

The four stages of research in this paper were carried out by researchers to obtain the design and optimization of the optimal machining strategy selection with virtual design and machining based on CAD-CAM. The stages of the research flowchart are presented in Figure 7.
3. Result and discussion

3.1. Story telling Batik Kawung

Batik is a culture that has long developed and is known by the people of Indonesia. Batik has been known since the Majapahit era and the spread of Islam. Batik was initially only made limited by the palace. By courtier, batik was then taken out of the palace and developed to this day. Indonesian Batik has been officially confirmed as a world cultural heritage by UNESCO on 2 October 2009 (In a press release from the Ministry of Culture and Tourism in Jakarta on Friday, 2 October 2009). This recognition helped boost the popularity of batik and people’s awareness to feel they have batik. Indonesian Batik patterns are many and varied, such as a damaged machete, Garuda batik, palace batik, machete batik, barong and Kawung damaged machete batik. Kawung batik is the most widely used because this batik pattern is simple, but has a high philosophical value (Figures 2 and 8).

The selection of the Kawung batik pattern was based on a request from the customer of Naruna Ceramic Studio himself who wanted the dinner set tableware plate product to have a relief texture that depicts the noble culture of the Indonesian nation in general and Javanese culture in particular. The texture pattern that must be displayed later can give a deep impression for tourists and foreign consumers in using this product later.

This relief texture is one type of ancient batik pattern that emerged and developed in Ngayogyakarta Hadiningrat in the 13th century and was created by the Sultan of Mataram at that time. Kawung itself, being the pattern taken from the kolang-kaling fruit from the palm tree, other sources also say that the Kawung batik pattern is associated with the Kawungwung animal.
The philosophy contained in the palm tree from the top (the tip of the leaf) to the roots can be used so that it is very beneficial for human life, it implies that humans are useful for everyone in the life of society, nation, and state. Some history books, Kawung batik patterns are only reserved for noble families or palace officials. The geometric patterns on this batik in Javanese traditional philosophy have a special meaning that reflects the existence of a single point of power in the universe. With the start of product development based on culture and supported by the above conditions, there will be a significant collaboration between Kawung pattern batik and ceramics to strengthen competitiveness and improve positioning in the face of MAE for the national ceramic industry (Anggoro, Yuniarto et al., 2019; Yao, 2017). Batik patterns prioritize floral aspects compared to fauna, and the use of batik patterns as ornaments affixed to ceramic products has also been successfully carried out by previous researchers (Abdullahi & Rashid, 2013, 2015; Anggoro, Yuniarto et al., 2019; Chua, Gay, Hoheisel et al., 1997b, 1997c; Renzi, 2009; Zhang et al., 2018).

Figure 9. Wrapping process dinner set tableware of plate with Kawung batik pattern.

Figure 10. Virtual design core & cavity dinner set tableware plate with Autodesk powershape 2019i.
Figures 2 and 8 show examples of Kawung batik that pattern models that derived from 2 typical plant and animal forms in Indonesia that are similar to palm sugar fruit (kolang-kaling), and Oryctes rhinoceros (Kawangwung beetle) which is in the form of pronunciation into Kawung

3.2. Virtual Design patterned ceramic plate with computer-aided design (CAD)
The design dinner set tableware designed in this paper consists of 3 types of sizes, each with a diameter of 270 mm; 220 mm, and 180 mm. The three of them are a set of dinner plates that have a pattern with the Kawung ornament pattern presented in Figure 3(a). To get the design of the three plates, the researchers carried out three stages of the virtual design generation process with CAD software, namely: generation of the 2.5D solid Kawung model, surface revolution plate, and wrapping process on the plate.
The generation of photo file data in the .jpg format into a 2D vector image of the Kawung pattern is shown in Figure 5. Meanwhile, the steps for generating Kawung model items that are imported into a CAD file can be seen in Figure 8. The Kawung pattern was drawn when the engineer drew a polyline from the middle of the media. Draw and create a vector oval on the guidelines. Vector triangle Drawn with the polygons tool and give a radius to the edges of the triangle with the fillet tool. After the oval and Kawung triangle vectors are formed, copy and rotate them 4 times to become a 2D Kawung pattern vector. Next, create stars and fill in the number of points as much as 8 and rotate the image by 250 until a star image has been filled and placed in the middle of the Kawung pattern.

The output at this stage is the Batik Kawung pattern in .stl format which will be imported into the PowerSHAPE software for the process of pasting the pattern on the surface of the plate (Figure 8).

The next step is to paste the Kawung pattern in .stl format onto the surface of the plate (Figure 4). This pasting operation uses the wrapping operation feature in Autodesk PowerShape CAD software. The stages of design generation using wrapping operations can be presented in Figure 9. The output of image generation in the wrapping process is in the form of a 3D design model dining set tableware with batik Kawung pattern with three different types of dimensions, namely plate diameters of 270 mm, 220 mm, and 180 mm (see, Figure 3(a)). Meanwhile, the proceed to the stage of generating plate mold designs can be shown in Figure 10. This is done because later in the ceramic industry the fabrication process will be clay plate products obtained from core & cavity plate molds (see, Figure 3(b)). Virtual machining (VM) has been successfully carried out by (Anggoro et al., 2018; Anggoro, Bawono et al., 2019; Anggoro et al., 2021; Chang, 2015a, 2015b, 2015c). The process of making core & cavity molds by virtual design using CAD software can be presented in Figure 10.

The core & cavity design in Figure 10 is conceptually the mold design development for the ceramic industry, it is feasible to be forwarded to virtual machining with CAM software before being processed to a CNC machine. This result is also following and has been carried out successfully by previous researchers (Anggoro et al., 2021; Anggoro, Yuniarto et al., 2019; Fergiawan, Anggoro, Anthony et al., 2021; Fergiawan et al., 2019).

### 3.3. Virtual Machining patterned ceramic plates with computer-aided manufacturing (CAM)

By using the PowerMill CAM software, Figure 3(b) each performs a virtual machining step which can be presented in Figure 11 and Figure 12. In this study, we discussed the subject of virtual machining of manufacture dinner set tableware plate with ornament batik Kawung; including NC part programming, virtual machining simulations, commercially available simulation software, as well as a case study and tutorial examples. In addition, we briefly addressed the practical aspects of CNC machining, including jigs and fixtures, and cutters and machining parameters.

The machining process for the three types of dinner set tableware plate designs is divided into two parts, namely the upper plate mold (cavity) and the lower plate mold (core). Autodesk PowerMill Virtual Machining Software [Anggoro, et al 2015; 2018, 2021] is used in this study to create a machining program at CNC Milling until the toolpath simulation process stage. While the Mach3 post-processor is used to create NC Code for CNC Milling machines as has also been done by previous researchers [PK Fergiawan, 2019]. This is done by researchers because the type of CNC machine that will be used in the manufacturing process is a CNC router machine with the post-processor.

The programming of the machining process begins with importing a printed 3D model in P3Model format into the Autodesk PowerMill software (Figure 11 and Figure 12). Setting the size of the workpiece is determined here based on the size of the model with an added thickness of 3.00 mm
in height to anticipate the flatness of the surface of the gypsum material is a plate mold material. In this study, the workplace is placed at the intersection of the diagonals of the workpiece surface so that it becomes the main coordinate reference and makes it easier for the CNC operator to set up the installation of cutting tools. The choice of cutting tools is adjusted to the availability of CNC machines, namely EndMill 6 mm, Ballnosed 2 mm, and Ballnosed 0.5 mm for three types of work (roughing, semi-finishing, and finishing processes). Because the model being worked on (Figure 3(b)) does not have a contour that is too steep, the cutting tool overhang setting is only a few millimetres above the flute length of the milling cutter. In the initial setting conditions, the position of the cutting tools is 20 mm above the work plane, rapid movement is limited to a height of 15 mm above the work plane, and begins to rotate at a height of 10 mm above the workplace. The spindle speed available in the machine is 5000 rpm, while the feed speed varies for semi-finishing 250 mm/minutes, and for finishing only 200 mm/minutes (see, Figure 11 and Figure 12).

The Virtual Machining process for the upper plate pattern master machining consists of 7 toolpath steps, namely:

1. Roughing the entire surface using the Model Area Clearance strategy with an EndMill 6 mm cutting tool. This process took 12 hours 53 minutes 25 seconds.

2. The process of finishing the flat surface outside the plate profile using the Optimized Constant Z Finishing toolpath strategy with the cutting tool still 6 mm Endmill. This process takes 1 hour 55 minutes 37 seconds.

3. The process of finishing flat on the inside of the plate using the Spiral finishing strategy with a 6 mm EndMill cutting tool. The toolpath technique of walking in a circle along the flat surface of the center of the plate is very helpful for the evenness of the surface. This process took 21 minutes 42 seconds. The Spiral finishing strategy is especially suitable for flat surfaces with circular shapes.

Figure 13. Comparison visual of core and cavity of dining plate tableware with pattern Batik Kawung: (a) 3D CAD model design; (b) output virtual machining simulation.
(4) The finishing process for locking the mold uses the Optimized Constant Z Finishing strategy with Ballnosed Tool cutting 2 mm. The shape of the mold lock in the form of a circle with a curved contour of a radius requires that the finishing process be carried out with a cutting tool that has a tip that is also less than the radius of the contour to be worked on. Ideally slightly below the contour radius of the model, but here the largest available is Ballnosed 2 mm. This process took 2 hours 41 minutes 6 seconds.

(5) The semi-finishing process on the ornaments uses a Steep and Shallow Finishing strategy with a Ballnosed 2 mm cutting tool. This process bridges the previous roughing process using a 6 mm Endmill cutting tool to the finishing process using a small diameter cutting tool, namely Ballnosed 0.5 mm. This means that the Ballnosed cutting tool is 0.5 mm so that it does not work too hard for feeding. There is a decreasing contour, it is necessary to set it so that the step down is the same as the step over, the choice of this strategy is what distinguishes the Optimized Constant Z Finishing strategy. This process took 10 hours 56 minutes 25 seconds.

(6) The finishing process on the outer edge of the plate ornament uses the Steep and Shallow Finishing strategy with a Ballnosed 2 mm cutting tool. This process takes 3 hours 3 minutes 4 seconds.

Figure 14. Dining plate tableware printed products with Batik Kawung pattern: (a) process machining on CNC router; (b) core & cavity plate from CNC machine; (c) master mold ceramic base on plaster technique; (d) biscuit clay product plate before process kiln; (e) one set dining plate tableware with pattern Batik Kawung; (f) variation colour of dining plate tableware.
The finishing process for the ornament uses the Optimized Constant Z Finishing strategy with a Ballnosed cutting toll of 0.5 mm. This process took 91 hours 33 minutes 5 seconds.

While the master machining process for the bottom plate mold pattern only consists of 5 toolpath steps, namely:

1. Roughing the entire surface using the Model Area Clearance strategy with an EndMill 6 mm cutting tool. This process took 26 hours 51 minutes 7 seconds.
2. The process of finishing the flat surface outside the plate profile using the Optimized Constant Z Finishing toolpath strategy with the cutting tool still 6 mm Endmill. This process takes 1 hour 58 minutes 17 seconds.
3. Process curved parts and mold locks using Optimized Constant Z Finishing strategy with Ballnosed cutting tool 2 mm. In this process, the two parts can be combined into one. This process took 19 hours 23 minutes 37 seconds.
4. The semi-finishing process for the ornament uses the Optimized Constant Z Finishing strategy with a Ballnosed cutting tool 2 mm. This process bridges the previous roughing process using a 6 mm Endmill cutting tool to the finishing process using a small diameter cutting tool, namely Ballnosed 0.5 mm. This means that the Ballnosed cutting tool is 0.5 mm so that it does not work too hard for feeding. took 4 hours 5 minutes 45 seconds.
5. Finishing process of the ornament using Optimized Constant Z Finishing strategy with Ballnosed cutting tool 0.5 mm. This process took 58 hours 38 minutes 43 seconds.

For the master machining process for the upper plate mold pattern, the machining time is 123 hours 24 minutes 24 seconds and for the lower plate pattern master machining process it takes 110 hours 57 minutes 29 seconds. So that the processing time for a pair of molds takes 234 hours 21 minutes 53 seconds. The visual results of virtual machining simulations with CAD drawings have the same precision and fit (See, Figure 13). In general, the Model Area Clearance and Optimized Constant Z Finishing machining strategies are very practical, effective and efficient to get optimal machining results in Virtual Machining with Autodesk PowerMill and these two strategies have also been successfully carried out by previous researchers in the process of working on Miranda Kerr Tea ceramic molds. Pot set and Insole Ankle Foot Orthotic [7.8, 9, 11]. This proves that these two types of machining strategies can be applied very well in real on a CNC machine (Figure 14).

After the real machining process is carried out on the CNC router machine (see, Figure 14(a and b)) and the fabrication process is carried out in the local ceramic industry, the final result of the product dining plate tableware with Kawung batik pattern shown at Figure 14(c) to Figure 14(f) can be seen that the ornaments produced from the virtual design and machining can be presented properly and perfectly. This is because, in the design process, CAD engineers and researchers made changes to the design of the groove on the ornament according to the dimensions of the ball nose cutter milling used in CNC machines. This is very important so that complex and complicated ornament details can be formed properly and when the clay plate model is made, the desired Kawung Batik ornament pattern will be formed as has been done by (Anggoro, Yuniarto et al., 2019; Chua, Gay, Hoheisel et al., 1997b; Fergiwan et al., 2019; Zhang et al., 2018).

Table 1 shows the optimal Parameter to produce Dining plate tableware printed products with Kawung Batik pattern. This optimal value is obtained from the results of research and experiments.
Table 1. Optimal parameter dining plate tableware

| No | Parameter                     | Type/Value            |
|----|-------------------------------|-----------------------|
| 1  | Machine                       | CNC machines router   |
| 2  | Cutter endmill 6 mm           | Roughing process      |
| 3  | Cutter Ballnosed 2 mm         | semi-finishing process|
| 4  | Cutter Ballnosed 0.5 mm       | Finishing process     |
| 5  | Position of the cutting tools | 20 mm above the work plane |
| 6  | Spindle speed                 | 5000 rpm              |
| 7  | Feed speed semi-finishing     | 250 mm/minutes        |
| 8  | Feed speed semi-finishing     | 200 mm/minutes        |

4. Conclusion
Virtual machining and design are very effective and make a big contribution to design engineers and the ceramic studio industry to develop precise, accurate and fast patterned ceramic product designs. The results of the design and optimization of the machining toolpath strategy obtained in this paper can be directly applied by the ceramic industry into a dinner set tableware plate product with the Kawung Indonesian batik pattern.

The appropriate and sustainable use of virtual machining technology in this paper can show design and manufacturing engineers to be more confident and competent in using virtual machining simulation tools to overcome product manufacturing capabilities and obtain reasonable machining time estimates to support custom ceramic products designs on demand by customers and industry competition in the industry 4.0 era.

In future research, we will provide a more in-depth and comprehensive understanding of the manufacturing process on CNC router machines in the form of initial NC-code data created from virtual simulation machining to the plate fabrication stage in the local ceramic industry in Indonesia.

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Author details
P.W. Anggoro1
E-mail: p.wisnuanggoro@gmail.com
ORCID ID: http://orcid.org/0000-0002-5956-0796
M.B. Krishnayuda1
T. Yuniarto1
B. Bawono1
Y. Suharyanti1
S. Felasari2
D.B. Setyohadi3
O.K.W. Widyantarika4
A.P. Bayuseno4

1 Department of Industrial Engineering, Universitas Atma Jaya Yogyakarta, Jl. Babarsari No. 44, Sleman, Yogyakarta, 55281, Indonesia.
2 Department of Architecture Engineering, Universitas Atma Jaya Yogyakarta, Jl. Babarsari No. 44, Sleman, Yogyakarta, 55281, Indonesia.
3 Department of Informatic, Universitas Atma Jaya Yogyakarta, Jl. Babarsari No. 44, Sleman, Yogyakarta, 55281, Indonesia.
4 Division New Product Research & Development, Naruna Ceramic Studio, Salatiga, Indonesia.
5 Department of Mechanical Engineering, Universitas Diponegoro, Jl. Prof Sucharto, Tembalang, Semarang, 50275, Indonesia.

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Page 13 of 15
