Parameter Optimization of Strategies at CNC end Milling Machine Roland Modela MDX - 40R Cam Against Surface Roughness Made Insoles Shoe Orthotic EVA Rubber Foam

P. W. Anggoro[1,2*], B. Bawono[1,2], Andreyas. W[1], J. Jamari[2], A. P. Bayuseno[2]

[1)] Department of Industrial Engineering, Faculty of Industrial Technology, University of Atma Jaya Yogyakarta, Jl. Babarsari 44, 55281 Yogyakarta, Indonesia.

[2)] Department of Mechanical Engineering, University of Diponegoro, Jl. Prof. Soedarto, SH., Tembalang, 50 275 Semarang, Indonesia.

* e-mail: [1)] pauluswisnuaanggoro@ymail.com, [2)] bajubawono@gmail.com

Abstract-- **The Quality Optimizing of surface and processing time insole shoe orthotic (*iso*) that made from EVA rubber foam (*erf*) is highly dependent on the determination of machining strategies on a CNC milling process. This paper aims to obtain optimal parameters of surface roughness and machining time iso products made erf. Data processing by Taguchi Design of Experiments used to obtain the most significant effect on the Toolpath parameters of machining strategies on software Powermill 2015. The effect of the four parameters (spindle speed, feeding, depth of cut, and types of milling cutter) set out in this experiment would give effect significant surface roughness and machining time iso products made erf. Orthogonal array is $L_{12}2^4$, after the output finish analyzed the experimental results. Experimental results showed four of these parameters have a significant influence on the surface roughness approaching iso product N7 (63 µm scale CLA or Ra = 1.6 to 3.00 µm). The *iso* product processing time in this experiment are in accordance with the request of the shoe industry for approximately 1-1.5 hours/pair *iso*. The optimal solution for design Experiment: machining setting is 14,500 rpm, Cutter feed is 2000 mm/min, DoC is 2 mm and type of Cutter is End Mill SECO 93060 With RA =2 µm**

Index Term-- **Insole Shoe Orthotic, EVA rubber foam, Toolpath strategy, Powermill 2015, surface roughness, CNC milling technology.**

INTRODUCTION

Ethylene vinyl acetate (EVA) is rubber foam material that popularly used in the field of shoes and shoe insole [1] [2] because EVA has good mechanical properties, lightweight material, shockproof and pressure, and has a high elasticity. The Iso making procedures as a complementary product to be accurate if you use a shoe made of EVA foam rubber (*erf*). The Insole Shoe Orthotic (*iso)* product manufacturing procedures with CNC machines is to get a kind of product with high quality and high precision. Orthotics are all tools that are added to the human body to stabilize the body, prevent disability, to protect from cuts, or assist the function of the limb. Insoles Shoe Orthotic is a device designed to restore the function of malformed foot.

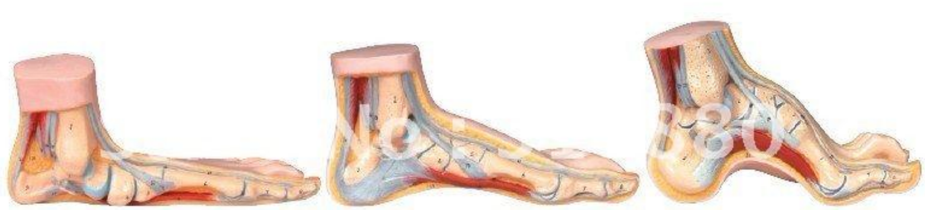

Fig. 1. Forms Pattern Human Foot (a) Flat (b) Normal (c) Arc

Fig. 2. Benefits on foot orthotic can change the position of the foot is malformed

Fig. 3. Applications Orthotic Insole Shoes on Feet Flat

Custom functional foot orthotic is a medical device made from a non-weight bearing mold (plaster cast) or a 3D scan of the foot. The tool is designed to control the alignment and function of the foot and lower leg, to overcome or reduce the pressure that causes injury to the bones, joints, tendons, and ligaments. This tool is often used to restrict movement as excessive pronation (rolling in) and excessive supination (rolling out). The tool is also useful to help users perform various activities such as running, walking, and standing more effectively and efficiently. In addition, it also redistributes the pressure foot on the bottom of the foot to relieve pain in the area of the foot that got the brunt of high pressure or weight on the leg suffering from corn/calluses. A custom orthotic function not only works with the principle of only supporting arch of the foot. Orthotic realign the structure of your foot to prevent misalignment and fatigue bones, muscles, tendons, and ligaments. This tool is often used after surgery to help stop or delay the recurrence of the foot deformity. In addition, it is important to focus that device that must function properly in facilitating the function of the foot. This tool works to improve the efficiency of interaction of biomechanical foot to the ground. Custom orthotic designed with accurate standards, using the latest advances in biomechanics and is made with customized with your feet, based on the biomechanics and morphology of your feet.

This device is intended to control the joint motion to the right, to facilitate and improve the movement in certain joints while limiting the other joint, with the overall goal is to prepare the legs for optimal alignment and function during each phase of the cycle. Optimal alignment of the foot which will also help align with the state of the lower extremities and pelvis.

When the foot rests on a custom orthotic that has been designed and manufactured with precision and precision, the load will be supported by a gentle and consistent so that the position of the foot will be redirected to the correct position or the position of the legs become better and convenient for users who are walking, running, and standing. Weight on the leg to be reduced due to more efficient *iso* support, pain due to muscle tension and pressure point was reduced, and the development of the deformity can be prevented, reduced or even stopped.

To produce custom orthotic requires a very thorough process and determine which users get quality *iso* is the best option for treating conditions of the foot. As well as a wide variety of other goods, there is a well-made orthotic some are not in accordance with the characteristics of the user. Orthotic ability to relieve pain in the foot orthotic users depending on the quality. Orthotic quality depends on three main steps, namely

Taguchi experimental design is a powerful method used to achieve high quality at lower no experimentation. This provides a better setting than the traditional experimental design time consuming because a large number of trials and most of the time are not worthy [2],[3],[5],[6],[7],[8]. Taguchi method reduces the sensitivity of the quality characteristics for various noise factor of the unknown. In this study, the relationship between the machining parameter strategy to surface roughness and working time *iso* products made from EVA foam rubber.

MATERIAL & METHODS

Erf with dimensions of 250 x 95 x 23 mm was used in this experiment. This material hardness determined ranged from 35-40 HRC. This material can be used in healthcare solutions such as: orthopedic shoes, insoles, exercise mats, orthotic support [4]. The specification of these materials include: density 55-65 kg/m^3, nominal sheet size (trimmed) 2000 x 1000 mm, nominal thickness (split) 3-36 mm, hardness after 2 second read 25-30 degrees, tensile strength 800kPa , tear strength 4.5kN/m.

The chemical composition of EVA foam rubber can be displayed in the following table:

Table I
The chemical composition of rubber EVA Foam [11]

Material	Properties		Source
Ethylene Vinyl acetate (EVA)	Melt flow index (g/10 min)	2.00	PIL Madras
	Density (g/cm^3)	0.937	
	Vicat Softening Point (^{o}C)	59	
	Vinyl acetate (wt%)	18	
	Viscosity (g/cm^3)	0.170	

The dimensions and shape of this product is targeted close to or similar to the results of scanning the foot of a normal person.

Fig.4. The 3D solid ISO EVA rubber foam

This experiment is done to produce a pair of shoes orthotic insole using reverse engineering technology on CNC machines Rolland Modela MDX 40R. Stages of experimental manufacturing system may be presented in the figure below:

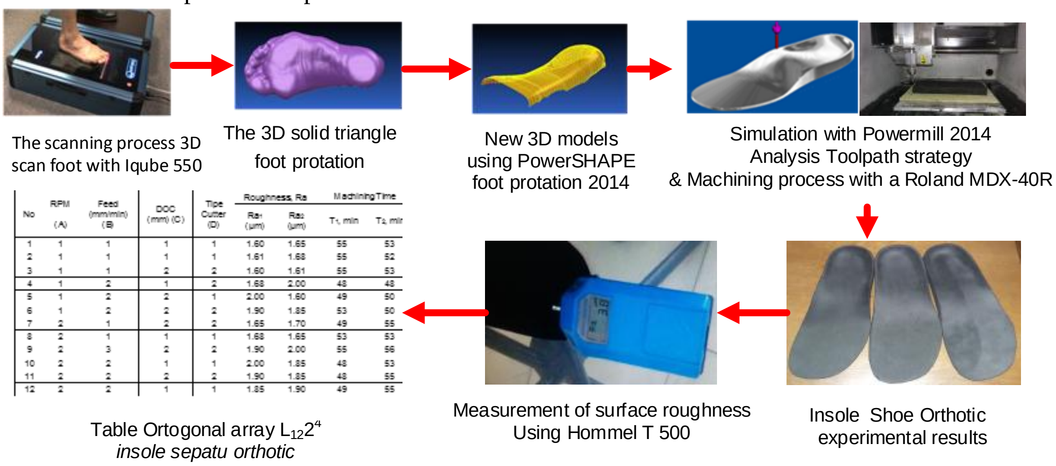

Fig. 5. Stages Taguchi experimental manufacturing system

The initial phase conducted by researchers is the process of brainstorming with some engineer CNC tooling, CNC machining, material rubber, and businessmen shoes (PT. WIMO and CV. DAF) to get the parameters that influence significantly the process of CNC milling with material EVA rubber foam. Based on the results obtained brainstorming four most influential parameters in the manufacturing process of this orthotic shoe insole products, namely: Spindle speed (rpm), Feeding rate (mm /min) Depth of cut (mm), and Type milling cutter used. These four parameters are set according to the results of discussions with engineers from the shoe industry that wants time CNC machining process in the machine ranged from 1.5-2.5 hours for a pair of orthotic shoe insole with surface roughness ranges approaching N7 (63 µm scale CLA or Ra = 1.6 to 3.00 µm) [6]. Each parameter set two levels that can be described in the following table:

Table II
Parameters machining and levels

No	Factor	Level 1	Level 2
1	Speed (rpm)	15,000	14,500
2	Feed (mm/min)	1,750	2,000
3	Depth of Cut (mm)	2.0	3.0
4	Type of Cutter	Endmill MEH 0604	Endmill SECO 93060 F

According to the table II above, the orthogonal array on the Taguchi method is used to determine the optimum process parameters on the machining process of *iso* erf with the response the data set is surface roughness and machining time product.

Orthogonal Array The selection of orthogonal array depends on the calculation of total degrees of freedom. The number of comparisons made between levels to better determine the condition called degrees of freedom. There are four process parameters considered for surgery on the processing and each parameter is on two levels, the level of total degree of freedom is 2. Orthogonal array chosen must have a degree of freedom is greater than or equal to the process parameters. This paper uses orthogonal array $L_{12}2^4$ larger than the total degrees of freedom of process parameters. Taguchi Orthogonal Array provides a better combination of walking and reduce the number of experimental runs, thus making experiments feasible. The combination of process parameters using the $L_{12}2^4$ are given in Table 3 below.

SN Ratio $$S/N = -10 \log \left[\frac{1}{n} \left(y_1^2 + y_2^2 \ldots y_n^2 \right) \right] \quad (1)$$

$$\mu = \frac{\sum_{i=1}^{N} X_i}{N} \quad (2)$$

$$Mq_A = \frac{SA}{v_A} \tag{3}$$

Sum of Squares for Treatments, $\boldsymbol{SSR} = n_S \sum_{i=1}^{k} \left(\bar{y}_i - \bar{\bar{y}}\right)^2$ is the "Between Group" variation, where the *k* "groups" or populations are represented by their sample means. If the sample means differ substantially then SST will be large.

Sum of Squares for Error, $\boldsymbol{SSE} = \sum_{i=1}^{k} \sum_{j=1}^{n_S} \left(y_{ij} - \bar{y}_i\right)^2$ is the "Within Group" variation and represents the random or sample-to-sample variation

Total Sum of Squares, $\boldsymbol{SST} = \sum_{i=1}^{k} \sum_{j=1}^{n_S} \left(y_{ij} - \bar{\bar{y}}\right)^2$ is the total variation in the values

Table III
Data Orthogonal array $L_{12}2^4$ of Experiment

No	RPM (A)	Feed (mm/min) (B)	DOC (mm) (C)	Type Cutter (D)	Roughness, Ra		Machining Time	
					Ra_1 (µm)	Ra_2 (µm)	T_1, min	T_2, min
1	1	1	1	1	1.60	1.65	55	53
2	1	1	1	1	1.61	1.68	55	52
3	1	1	2	2	1.60	1.61	55	53
4	1	2	1	2	1.68	2.00	48	48
5	1	2	2	1	2.00	1.60	49	50
6	1	2	2	2	1.90	1.85	53	50
7	2	1	2	2	1.65	1.70	49	55
8	2	1	1	1	1.68	1.65	53	53
9	2	3	2	2	1.90	2.00	55	56
10	2	2	1	1	2.00	1.85	48	53
11	2	2	2	2	1.90	1.85	48	55
12	2	2	1	1	1.85	1.90	49	55

Table IV
Analysis of S/N Ratio for $L_{12}2^4$ of Experiment

No.	Level				Average		S/N Ratio, Ra	S/N Ratio, T
	A	B	C	D	Ra, μm	Machining Time (min)		
1	1	1	1	1	1.63	54.00	-5.979	-36.4098
2	1	1	1	1	1.65	53.50	-6.086	-36.3303
3	1	1	2	2	1.61	54.00	-5.87	-36.4098
4	1	2	1	2	1.84	48.00	-7.079	-35.3857
5	1	2	2	1	1.80	49.50	-6.902	-35.6533
6	1	2	2	2	1.88	51.50	-7.221	-35.9995
7	2	1	2	2	1.68	52.00	-6.242	-36.0906
8	2	1	1	1	1.67	53.00	-6.189	-36.2464
9	2	3	2	2	1.95	55.50	-7.564	-36.647
10	2	2	1	1	1.93	50.50	-7.454	-35.8338
11	2	2	2	2	1.88	51.50	-7.221	-36.0104
12	2	2	1	1	1.88	52.00	-7.221	-36.0906

Table IV
ANOVA for $L_{12}2^4$ of Experiment

Source	Sq	dof (v)	Mq	F-ratio	Sq'	rho %
A	90.74	2	45.37	76,06	75.74	3.54
B	180.01	2	90.49	151,70	160.01	17.1
C	134.87	2	67.05	123,26	125.27	42.95
D	94.12	2	42.06	05,11	88.12	33.29
E	57.23	10	59,65	1,00	55.23	3.12
St	253.80	10	336.25		225.24	100

From the calculation and analysis of data at four factors, which are considered the most influential factors on the quality of the machining process models based on the pooling up *iso* is the spindle feed, DoC, and Type Cutter.
For the selection of the setting levels each factor, selected value level corresponding to the data common practice in the field. The table 5 and 6 below is setting level of each factor:
Based on the tables 5 and 6 can be seen the value of the data analysis at each level selected. The value chosen based on practical experience that has often done in the field at the time of the machining process.
For the selection of the best setting at each level of the factor is:

a) RPM selected is level 2 or 14,500 for a finer surface quality due
b) Cutter feed used is at level 2 is 2000 mm/min to get the finer quality results
c) This is due to a finer surface quality. Depth of Cut (DoC) is selected at level 1 or 2 mm for the smaller DoC product quality more fined.

Setting Type Cutter also influenced by the type of material and size of the cutter being used. Selected level 2 for the use of cutter type 1 (Endmill MEH) to produce chips that are formed will stick to the cutter, with the quality of the product is less smooth surface. The use of cutter type 2 (Endmill SECO) to produce chips that are formed will be removed directly from the cutter, more refined product surface quality

Tablel V
Setting Level Analysis for Roughness

Faktor	**A**	**B**	**C**	**D**
Level 1	1.82	8.23	10.58	10.85
Level 2	1.72	13.1	10.78	10.52

Tablel VI
Setting Level Analysis Machining Time

Faktor	**A**	**B**	**C**	**D**
Level 1	54	53.9	44.9	60
Level 2	52	51.2	64.8	44.79

RESULTS AND DISCUSSION

From Table 5 and 6 it can be seen in total scores on each level of the selected factor. The weights are calculated based on the number selected at each factor divided by the total number selected in each factor and factor level. Factors and levels of factors used in this experiment can be seen in table 2

The factor levels that have been determined to do the analysis:

a. Feed rate: Based on the brainstorming process, the feed rate that used in the experiment are three levels in sequence for level 1 and level 2 is 1,750 and 2,000 mm/min. Feed rate have on those values is as designed raw material hardness and type of material used cutter. Raw material that used is erf.
b. Spindle Speed: is the speed of the cutter rotation per minute. CNC machine Roland MDX modela 40R has a minimum limit per minute cutter rotation speed is 5,000 rpm, and the maximum limit is 15,000 rpm. Based brainstorming spindle speed value of the questionnaire used in this study were selected according to the results of brainstorming on questionnaires. Value spindle speed is used is, 14,500 rpm and 15,000 rpm.
c. Step Down: Step down is the movement of the cutter feeds the vertical direction (z-axis). Step down this value is adjusted by the diameter cutter, cutter material, and the raw materials that used in machining. Based on the results of the brainstorming researchers determined level setting step down by 2 and 3 mm.

Selection of Orthogonal Array Design: The selection orthogonal array design to be adapted to a number of factors and total factor level value predetermined based on the results of the brainstorming process. From the results of the brainstorming process obtained a number of factors as much as 4 factors and the number of levels a factor of 2 levels. Based on availability Taguchi orthogonal array design there is the factor number 4 and number 2 level factor level values obtained orthogonal array design $L_{12}2^4$

Taguchi orthogonal array of design variations $L_{12}2^4$ obtained treatment should be performed on each of the experiments. The treatment variations can be seen in Table 4.

According to the table it can be seen the value of the data processing at each level selected. The value chosen based on practical experience that has often done in the field at the time of the machining process.

For the selection of the best setting from table 5, 6 at each level of the factor is:

a. RPM selected is level 2, is 14,500 for a finer surface quality due
b. Cutter feed used is at level 2 is 2000 mm / tooth for finer quality results
c. This is due to a finer surface quality. Depth of Cut (DoC) is selected at level 1 or 2 mm for the smaller DoC product quality is more refined.
d. Setting Type Cutter also influenced by the type of material and size of the cutter being used. Selected level 2 for the use of cutter type 1 (Endmill MEH) to produce chips that are formed will stick to the cutter, with the quality of the product is less smooth surface. The use of cutter type 2 (Endmill SECO) to produce chips that are formed will be removed directly from the cutter, more refined product surface quality

From the results of pooling up done finds that the contribution to the source or a significant factor from highest to lowest is the percent contribution factor C 42.95%, which means these factors significantly affect the machining process by 42.95% out of 100%, factor D with 33.29% percent of the contribution, which means these factors significantly affect the machining process by 33.29% out of 100%, and factor B with the percent contribution of 17.10% which means that these factors significantly affect the machining process by 17, 10% out of 100% with error 3.12%

CONCLUSION

Based on experiments on the behavior of the wear iso Erf

a. There are four parameters that have chosen major engine rotation (rpm), Feeding Speed (mm /min), DoC (Depth of Cut) mm, and Type Cutter
b. ANOVA analysis showed that the Depth of Cut (26.432%) and Type Cutter (15.877%) had a major influence on surface roughness iso. The interaction effect parameter has a significant effect on the surface roughness
c. The optimal solution for design Experiment: machining setting is 14,500 rpm, Cutter feed is 2000 mm/min, DoC is 2 mm and type of Cutter is End Mill SECO 93060 With RA =2 µm

REFERENCES

[1] E.T. Nurit, W.Ety, H. F. Yifat and G. Amit; Bio-Med. Mater. Eng, 16 (2006), 289-299
[2] Yi-Ren Jeng, De-Shin Liu, Hong-Tzong Yau; "Designing Experimental Methods to Predict the Expansion Ratio of EVA Foam Material and Using Finite Element Simulation to Estimate the Shoe Expansion Shape"; *Material Transaction*, Vol. 53, N0. 9 (2012) pp. 1685-1688
[3] Thakur Paramjit M, R.Rajesh, "Optimal Selection of process parameters in CNC end milling of Al 7075-T6 aluminum alloy

using a Taguchi-Fuzzy approach", *Procedia Materials Science*, 5 (2014) pp 2493-2502

[4] Metro Foam Products, metrofoam.com.au

[5] V.Mugendiran, A.Gnanavelbabu, R.Ramadoss; "Parameter Optimization for Surface Roughness and Wall Thickness on AA5052 Aluminium Alloy by Incremental Forming Using Response Surface Methodology", *Procedia Engineering* 97 (2014) pp 1991-2002

[6] Kuttolamadom, M.A., Hamzehlouia, S. and Laine Mears, M. (2010) Effect of Machining Feed on Surface Roughness in Cutting 6061 Aluminum, *International Center for Automotive Research*, Clemson University, South Carolina, United State of America, 2010-01-0218.

[7] Gunay, M., Kacal, A. and Turgut, Y. (2011) Optimization of Machining in Milling of Ti-6Al-4V Alloy using Taguchi method. *e-Journal of New World Sciences Academy*, 6, Article No. 1A0165.

[8] Jatin, P.S. (2013) Effect of Machining Parameters on Output Characteristics of CNC Milling Using Taguchi Optimization Technique. *IJEBEA* 13-335, 2013.