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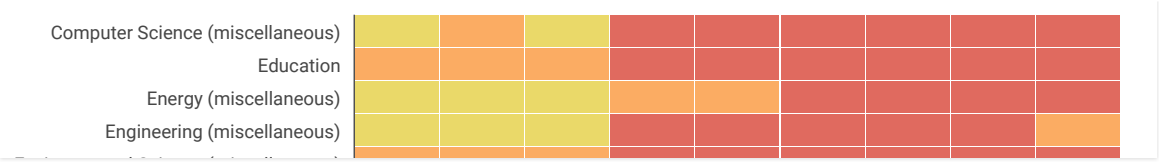

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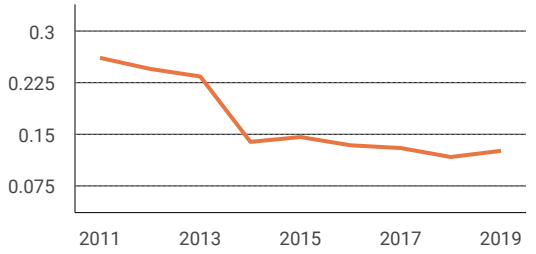

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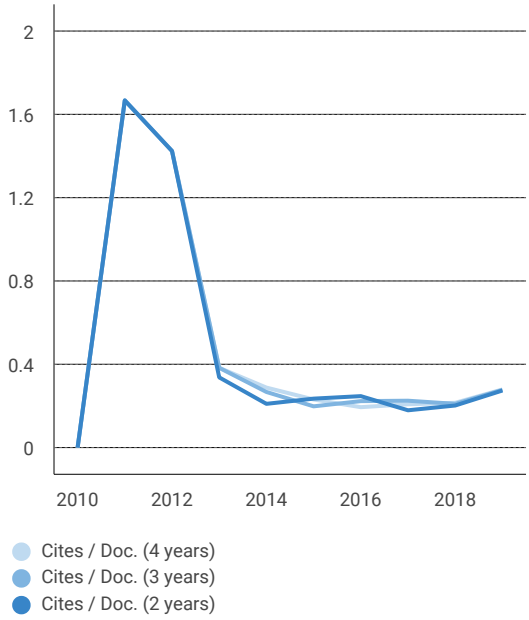

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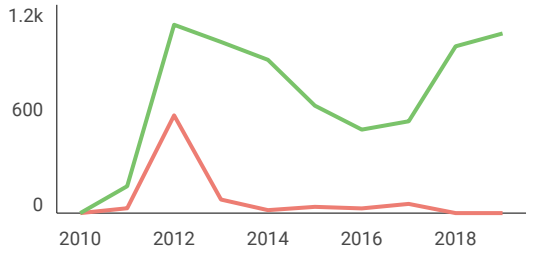

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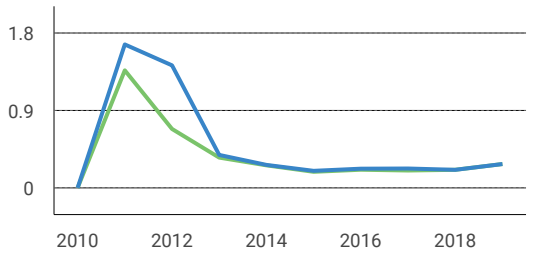

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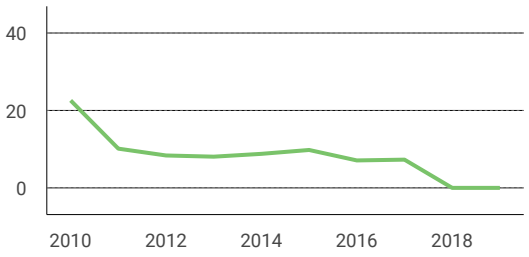

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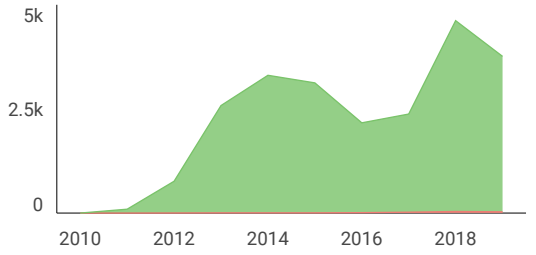

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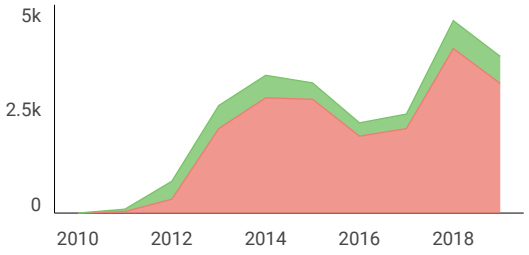

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A SPECIAL SECTION

RESEARCH ARTICLES

OPTIMIZATION OF THE PARAMETERS OF THE MANUFACTURING PROCESS OF THE PRODUCT ISO_DIABETES FOR PATIENTS WITH HIGH RISK CLASSES

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Abstract
Reverse innovative design (RID) on the insole shoe orthotic for diabetics (*iso_diabetes*) was able to speed up the design and manufacturing of products with the quality of the surface requested appropriate patients. The accuracy of the scanning results with 3D CAD insole that conforms with the shape and contour of the patient's foot will certainly make things easier in the process of manufacturing in CNC machines. Problems encountered in this paper is to determine the design of the *iso_diabetes* the most optimal process of experimentation with doing manufacturing in CNC machine Rolland Modela MDX 40R. The strategy finishing *raster machining* 45^0 and *step & shallow machining* in CAM Powermill 2016 applied to get a pair of *iso_diabetes* from each patient. Two diabetic patients designated as research subject . Lay out experiment with orthogonal array L_8 4.2^3 set on this paper to get *iso_diabetes* type optimal based on the values of surface roughness (Ra) and processing time the (Ta) obtained.
Experimental results show that the design of the *iso_diabetes* type 0.75 mm is the most optimal design with surface roughness approaches 0.0069 mm and time machining around 4.20 hours for both patient.

Keywords: *toolpath strategy, raster finishing* 45^0*, step & shallow, PowerMill 2016 surface rougness, iso_diabetes.*

INTRODUCTION

Reverse innovative design (RID) is a new method in reverse engineering by Xiuzi Ye (2008). This method was applied in the industry to avoid repeating the process in CNC machining or Rapid Prototyping as a result have not been optimal design of new products designed in addition to also reduce the additional costs for the process of trial & error in the next process. To get the new design is optimal, this method requires an engineer to do the optimization design using Computer Aided Engineering (CAE) such as Abaqus, Ansys, mold flow and others. Through the analysis of FEA will be obtained from a minimum stress distribution design we make so that an optimal new designs will be obtained. The RID had already developed by some researchers such as: Xiuzi Ye, et.all.(2008), Anggoro P.W.,et.all.(2016) and Xia Z. (2014) and managed to get the new product, optimum precision and through several stages. These stages include: scanning physical objects, 3D mesh generation to 3D CAD objects, optimization new design with CAE and after the new design of the optimum is obtained by using the technology of manufacturing phase subtractive machining with CNC machines or adaptive manufacturing with a rapid prototyping machine.
Research on application of RID in *iso_diabetes* by Anggoro PW.,et.all.(2016) managed to get six new design type insole shoe orthotic that fits the contour of the surface of the soles of the feet of diabetic patients. Six type design builds upon wide tolerance of differences range from 0.0 – 2.0 mm and the results can be presented on Figure 1 and Figure 2.

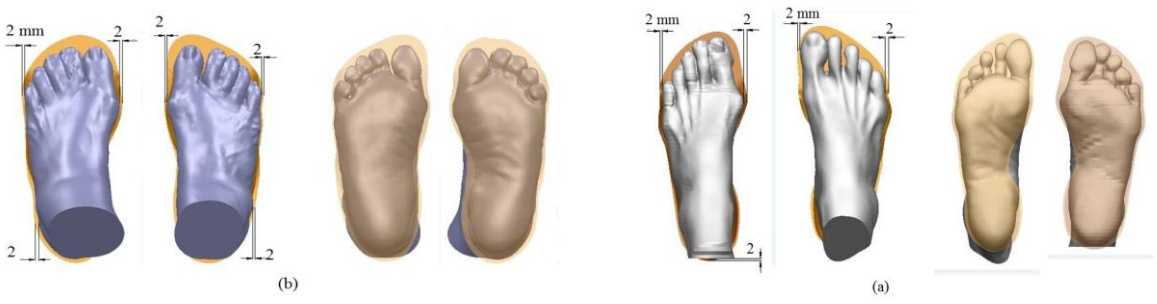


Figure-1. Top and bottom view width tolerance 2 mm *iso_diabetes*: (a) patient 1, (b) patient 2

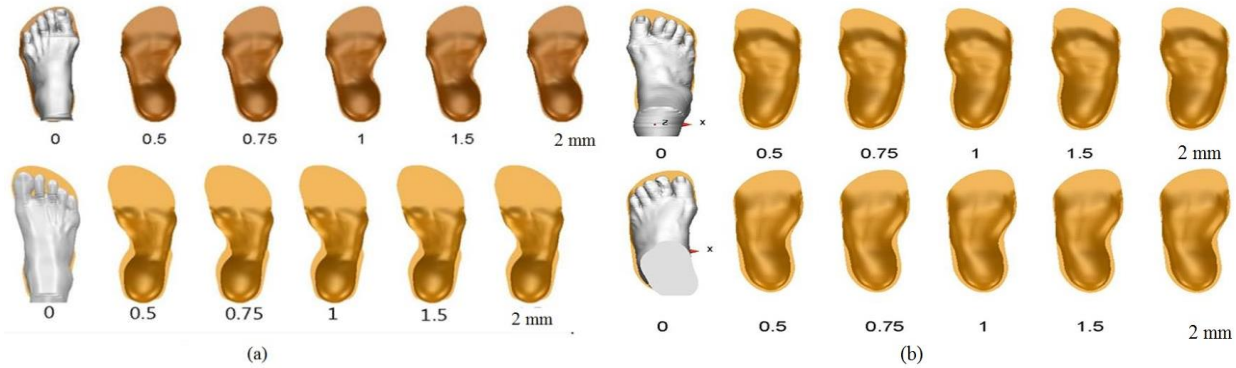


Figure-2. Variation 3D model of *iso_diabetes* based on the width tolerance: (a) patient 1, (b) patient 2.

Foot disorders experienced by patients diabetics as in Figure 3 often are usually closely associated with abnormal plantar pressure distribution by Holewsky JJ ,et.all (1989), Hodge MC,et.all(1999), Bawono B.,et.all (2016), and Anggoro PW.,et.all(2016). This causes the foot sickness or experiencing the illness syndrome due to wearing inappropriate footwear insole and precision. The perfect solution to overcome this is done by creating the appropriate orthotic insole shoes with soles contour the problematic people. FEA (Finite Element Analysis) being done of the researchers Bawono B.,et.all (2016), and Anggoro PW.,et.all(2016to get the new optimal design of *iso_diabetes* simply based on the smallest *von misses stress* which occurs when the imposition varying held in the simulation. However to determine the optimal design of new still felt quite yet because only the suspect based on the influence of varied material against the imposition of *iso_diabetes* used. However to determine exactly where the new design the optimal manufacturing process optimization to be done by combining Taguchi experimental design on the creation of *iso_diabetes* in CNC machines by digitally material EVA rubber foam. Up to this time had never found a researcher doing optimization manufacturing with CNC machines on rubber material particularly material EVA rubber foam.

Taguchi methods experimental design is a method of manufacturing a significant selection on a treatment that really considered influential direct response is measured. Some of the treatments are not significant in Taguchi will be directly reduced. Reduction treatment is intended to get the response data is actually valid reason other than economical. A complete analysis of ANOVA and poolling up strategy on this method will quickly determine which treatment will be obtained on factors and their interactions between factors that influence significantly to response measures taken as well as the output optimum.

Deformities can be classified as "significant" or "non significant". Deformities is related to the mechanical alignment of the food with the heel, toe and ball aspects of a normal shoe. If the foot does not line up within these shoe parameters there will be potential friction, shear and pressure implication and the deformity will be "significant" by William M (2005). An example of significant deformities is shown in Figure 1,

Figure-3 . Swollen foot for diabetes patient on the sign of the red circle

The manufacture of foot orthoses, is related to the function of individual well-being that examine feet. The material choices are supportive function, stabilization or accommodation of deformities, relief of plantar pressure, excessive reduction of pressure and shear, and the possible limitation of the rage of motion by William M (2005) and Luigi U,et.all (2012). Example of foot orthoses are shown in Figure 4.

Figure-4. Example of foot orthoses

High Speed Machining (HSM) is a relative new technology in recent years in manufacturing industry for process of mold and dies, spare part and other products made from rubber. The process implementation, HSM can lower production costs of making part with the level of accuracy and surface quality. HSM in the process is also used to work on material in industrial rubber shoes. *HSM* can be defined as the process of machining by use of cutting speed, RPM, feed rates are high

compared to the conventional method. HSM allows material removal rates, reduce the pressure at the time of cutting, reducing lead times and increase precision machining results. HSM can be done on CNC machines that have a minimum of 10,000 rpm spindle rotation. Research on parameter optimization of machining on a CNC machine HSM with Taguchi experimental design methods mostly use metal or plastic material as the object being worked on. However the research rarely discusses the optimization of machining parameters on CNC using materials rubber especially EVA rubber. In this paper, manufacturing optimization will be performed using CNC machine type HSM to gain new design *iso_diabetes* optimal. CNC machine that used was Rolland modela MDX 40R which has maximum spindle rotation up to 17,000 rpm. Two machining strategy that has been obtained in previous studies by Anggoro PW., et.all (2016) are compared to see the influence that occur at each treatment.

The purpose of this research is to get product from *iso_diabetes* that is designed as shown in Figure 2 along with the parameters of machining strategy is optimal in CNC machines. The end result of this study it is expected that the product *iso_diabetes* really fit and fit to the shape and contour of the feet of the patient. Optimization of manufacturing with the orthogonal array on paper is expected to provide a more in-depth analysis of surface quality and processing time *iso_diabetes* for the engineer mainly prostethic and orthotic laboratory of parties who are still using conventional technology.

METHODOLOGY

The most important factor in the design process and manufacturing *iso_diabetes* is a 3D solid CAD models, EVA rubber quality machining results and products on CNC machines. The quality of the surface roughness of *iso_diabetes* also very determined from machining parameters selection in software Computer Aided Manufacture (CAM). The selection of the optimum machining strategy in this paper using a CAM PowerMill2016, which in this software there are two finishing strategies are used, namely: *raster finishing* 45^0 and raster finishing 90^0 by PW.Anggoro, et.all (2016) .

Iso_diabetes that will be done later in the research should meet the demand of Orthotic & Prostethic Rehabilitation Centers, Jakarta and the Artificial Foot Center Kuspito, Tasikmadu, Karanganyar, Surakarta. The desired surface roughness is 0.008 mm with maximum time 4–6 hours for each pair.

Eva rubber specimen

Eva rubber foam with dimensions 250 x 95 x 23 mm thick are used in this experiment. The hardness of the material is determined based on the results of the test with of Shore Hardness Tester Asker CL-150 range 35-50 HRC. This material can be used in healthcare solutions such as: orthopedic shoes, insoles, exercise mats, orthotic support [9]. The specifications of this material according to E.T. Nurit (2006): density 55–65 kg/m^3, nominal size 2000 x 1000 mm nominal thickness (split) 3–36 mm, hardness read after 2s is 25-30 grade, tensile strength 800kPa, tear strength 4.5 kN/m.

3D model *iso_diabetes*

3D model *iso_diabetes* that be processed as an object of research is as shown in Figure 5.

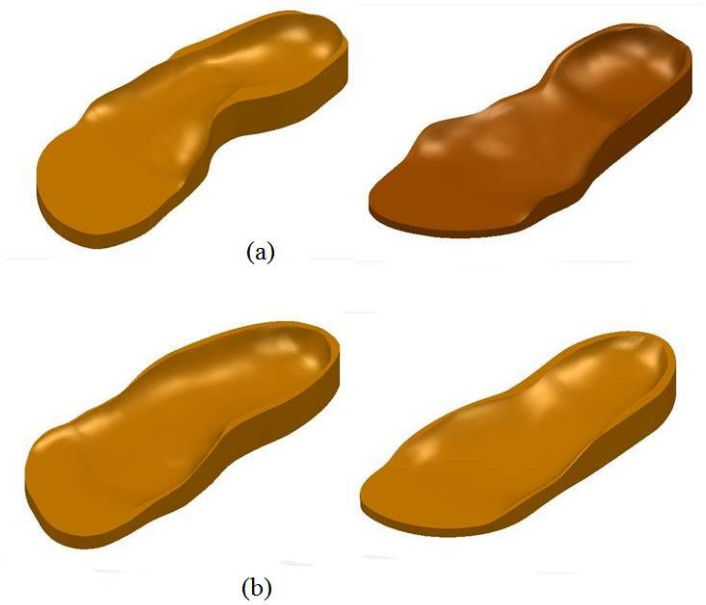
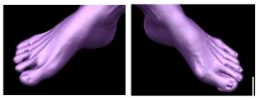


Figure-5. 3D solid *iso_diabetes* : (a) patient 1, (b) patient 2.

Patient Data

Two diabetics we select as an object that will do the scanning process with the Handyscan 700™ and the results there on table 1.

Table-1. Patient data

No	Name	Old year	male/female	weight Kg	Risk classes	Figure foot	3D Scann foot
1	Sulastri	57	female	50	High		
2	Agnes Siti saliwatun	75	female	72	High		

Tooling & CNC machine

In this paper, research is carried out using a machine CNC Rolland Modela MDX – 40, as well as using the tool cut with a 6 mm diameter type EndMill cutter and BallNose cutter. Cutter used was obtained from SECO, with specification 93060F for EndMill cutter and JS533060D1B. 0Z3-NXT to BallNose cutter. Specification of the cutter can be seen in Figure 6.

Figure-6. Tooling experiment

Orthogonal array

To get a significant relationship between surface roughness and time desired machining parameters against, it will be done the making process of orthogonal array.Early stage conducted by the researchers is brainstormed with some engineer CNC tooling, CNC machines, rubber material, and orthotic laboratory & prostethic. The purpose of this stage is to get any parameters which influence significantly on CNC milling process with EVA rubber foam materials for product *iso_diabetes*. Based on the results of the brainstorming obtained four of the most influential parameters, namely: spindle speed (rpm), feeding (mm/tooth), step over (mm), and toolpath strategy that is used. The fourth parameter is assigned in accordance with the results of the discussion with the engineer of the shoe industry wanted time machining processes on CNC machines range from a maximum of between 4 – 6 hours for a pair of *iso_diabetes* with surface roughness ranges approaching N7 (63 µm scale C.L. A or Ra = 3.00 – 102,000 µm). Each parameter set two levels which can be presented in Table 2.

Table-2. The parameters of machining and levels

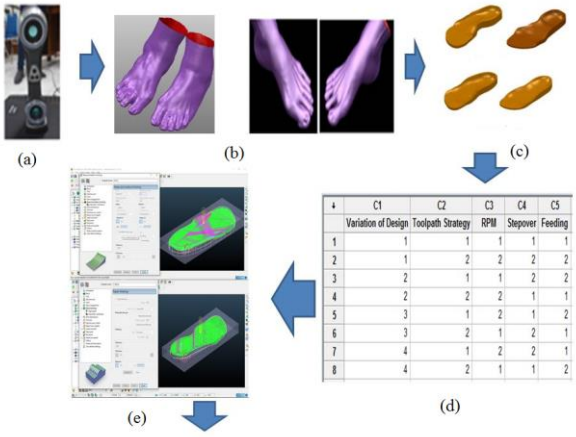
Factor	Level experiment			
Toolpath	Raster 45^0		Raster 90^0	
RPM	14,000		15,000	
StepOver	0.2		0.3	
Fedding	800		900	
Type Iso_diabet	0.5	0.75	1.0	1.5

Type *iso_diabetes* 0.0 is not discussed in this paper because it's already covered in previous studies Bawono B.,et.all (2016) so that the given tolerance variation on *iso_diabetes* in this paper starts from 0.5–1.5 mm as shown in table 2.

Based on table 2 would do the manufacturing layout orthogonal arrays to determine the parameters of the process of machining *iso_diabetes* optimal. Response data will be measured in the experiments of this surface roughness (Ra) and machining time (T_m) by comparing the variation of *iso_diabetes* with limitations of Ra = 0.008 mm and T_m = maximum of 4–6 hours/pair.

By using Software Minitab 13 and enter the parameters of machining with level set on Table 1, then the chosen orthogonal array $L_8 4.2^4$, with the number of treatment by as much as eight times where the factor type *iso_diabetes* set four levels while the other four factors of each of the two levels. In order to make a valid response data is obtained then any treatment process experiment will be done twice, so that the total amount of data that will be generated response is as much as 16 response data. The response to this form of data: the value of surface roughness, machining time and 16 pairs of *iso_diabetes.* Based on orthogonal array $L_8 4.2^4$, then carried out the process of experimentation based on the treatment that

has been set using the machine Rolland modella MDX 40R and EVA rubber material. Stages of the process of experimentation can be presented on Taguchi Figure 7 below.



	C1	C2	C3	C4	C5
	Variation of Design	Toolpath Strategy	RPM	Stepover	Feeding
1	1	1	1	1	1
2	1	2	2	2	2
3	2	1	1	2	2
4	2	2	2	1	1
5	3	1	2	1	2
6	3	2	1	2	1
7	4	1	2	2	1
8	4	2	1	1	2

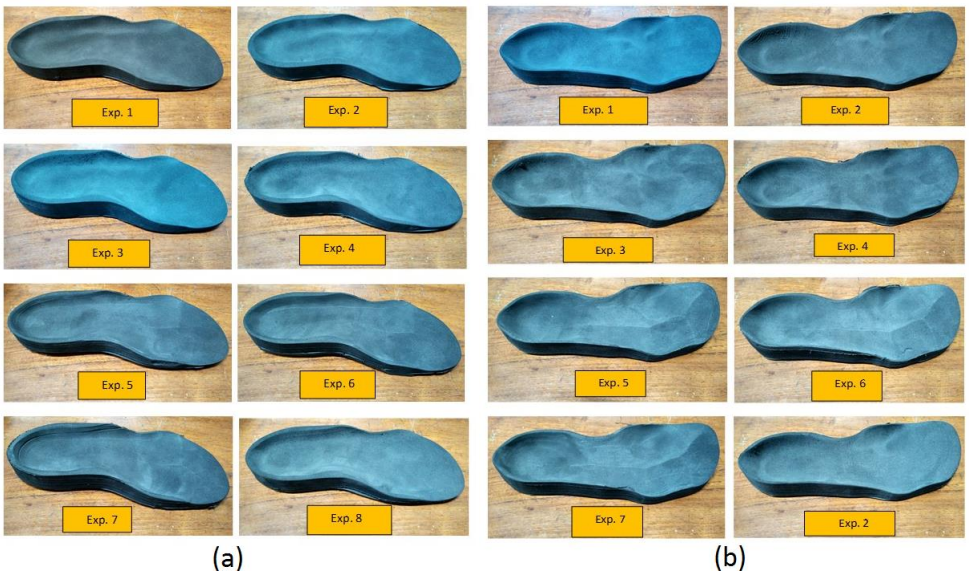
Variation of Design	Toolpath Strategy	RPM	Stepover	Feeding	Ta(PowerMill)	Ta(Machining)	Ra(PowerMill)	Ra(Machining)
1	1	1	1	1	02.04.53	03.06.18	0,0033	0,0059
1	2	2	2	2	01.24.55	02.26.20	0,0075	0,0070
2	1	1	2	2	01.23.35	02.25.00	0,0075	0,0069
2	2	2	1	1	02.07.06	03.08.31	0,0033	0,0056
3	1	2	1	2	01.53.35	02.55.00	0,0033	0,0057
3	2	1	2	1	01.32.38	02.34.03	0,0075	0,0067
4	1	2	2	1	01.31.08	02.32.33	0,0075	0,0067
4	2	1	1	2	01.55.33	02.56.58	0,0033	0,0054

(i)

Figure-7. Methodology stages optimization of manufacturing *iso_diabetes*: (a) the Handyscan 700™, (b) 3D mesh output, and (c) 3D solid models for two patient, (d) Blank Orthogonal array $L_8 4.2^4$ (e) optimize and simulation on toolpath strategy PowerMill2016, (f) manufacturing *iso_diabetes* made EVA rubber foam with CNC Rolland Modella MDX 40R (g) out put *iso_diabetes*, (h) measuring surface roughness of *iso_diabetes* with MarSurf PS 1, (i) the output tresponse experiment data

The final output of this paper is *iso_diabetes* a number of 16 pairs for both patients that results can be presented in Figure 8. Based on Figure 8, experiment 1 up to 8 output shows the result of machining *iso_diabetes* appropriate treatment at Figure 7. i.

Machining process will be get machining time Ta (simulated and actual) and the level of Roughness (Ra) is simulated and actual. With a variety of value Ta and Ra would result Ta and Ra Optimal



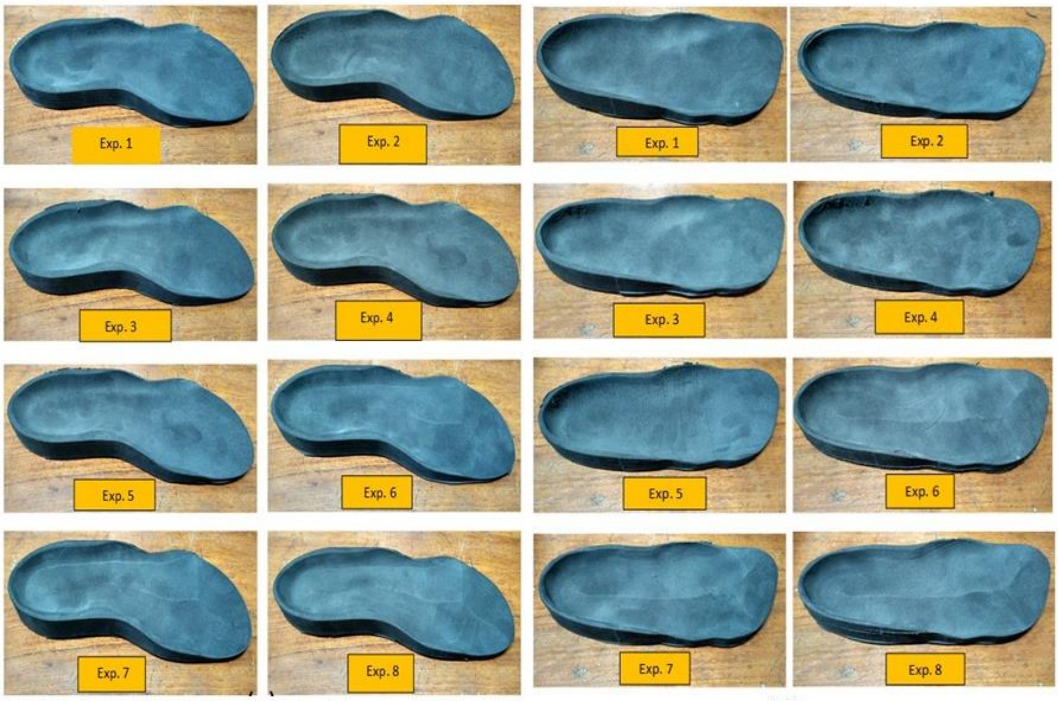


Figure-8. *Iso_diabet* with various width tolerance: (a) the left foot patient 1, (b) the right foot patient 1, (c) left foot patient 2, (d) the right foot patient 2

RESULT & DISCUSSION

Based on Figure 1 and 2, granting wide tolerance ranging 0.5-2.0 mm provide 12 new design *iso_diabetes* for both patients. At first glance when seen from the view up the surface of the *iso_diabetes* is already appropriate contour with precision and soles of the feet of the patient. The granting of very small tolerance width do researchers to avoid too lax when patients walk will use *iso_diabetes.*

EVA rubber Material used in this paper has a hardness shore range between 30-50 HRC. To maximize the working machines CNC Rolland Modela MDX 40R roughing process then in the depth of the cut are selected very high range 3.0-5.0 mm with the use of round spindle machines ranging from 13,000-15,000 rpm. Although EVA rubber material can be described as the soft material, but in the process of experimentation showed the reverse where often chip EVA rubber that was chipped by incision milling cutter is trapped or twisted on the axis of cutter and finally the process was stopped. As the cause of absence coolant machine CNC Rolland Modela MDX – 40, material is very easy to melt when machining process done. Result of discharge that occurs by EVA rubber foam on cutter, then rupture results from consumption by the cutter is not wasted, but rather follow the rotation of the *cutter* and the resulting process of machining must be stopped. Determination to clean it enough to squirt *WD–40* on the cutter. This aims to cool the cutter quickly so when the cutter began slashing EVA rubber foam, this material does not melt quickly.

Cutter used is the cutter to work on a special EVA rubber foam on the insole shoe orthotic. Machining of shoe orthotic insole is done based on the results obtained from the mix level method Taguchi. L_8 is an orthogonal array used in the study. The parameters used in the research is the toolpath strategy, spindle speed, feeding, stepover, and the type of *iso_diabetes* .

SN Ratio

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

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

$$Mq_A = \frac{SA}{v_A} \quad (3)$$

$$\boldsymbol{SSR} = n_S \sum_{i=1}^{k} \left(\bar{y}_i - \bar{\bar{y}}\right)^2 \quad (4)$$

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

Table 3. SN Ratio For L_8 4.2^4

No Experiment	Patient (A)	Toolpath Strategy (B)	Spindle Speed (C)	Feeding (D)	Step over (E)	Ra (Power Mill), mm	Ra (Machining), mm	SN Ratio
1	1	1	1	1	1	0.0033	0.0049	2.481486
2	1	1	2	2	2	0.0075	0.0059	2.124939
3	1	1	3	3	3	0.0134	0.0150	**1.872895**
4	1	2	1	1	2	0.0075	0.0091	2.124939
5	1	2	2	2	3	0.0134	0.0150	1.872895
6	1	2	3	3	1	0.0033	0.0049	2.481486
7	1	3	1	2	1	0.0033	0.0049	2.481486
8	1	3	2	3	2	0.0075	0.0091	2.124939
9	1	3	3	1	3	0.0134	0.0150	1.872895
10	2	1	1	3	3	0.0134	0.0148	1.872895
11	2	1	2	1	1	0.0033	0.0047	2.481486
12	2	1	3	2	2	0.0075	0.0061	2.124939
13	2	2	1	2	3	0.0134	0.0148	**1.872895**
14	2	2	2	3	1	0.0033	0.0047	2.481486
15	2	2	3	1	2	0.0075	0.0089	2.124939
16	2	3	1	3	2	0.0075	0.0089	2.124939
17	2	3	2	1	3	0.0134	0.0148	1.872895
18	2	3	3	2	1	0.0033	0.0047	2.481486

After the analysis of Taguchi orthogonal arrays on $L_8 4.2^4$, then the optimal results can be presented in table 3 in experiment 3 and 13

Table 4. Optimum Design for *iso_diabetes* based Sq and % rho

Source	Sq	dof (v)	Mq	F-ratio	Sq'	rho %
A	20.23	2	39.111	3.234	42.766	8.962
B	80.01	2	154.686	12.791	169.140	35.447
C	90.45	2	174.870	14.460	191.210	40.072
D	15.23	2	29.445	2.435	32.196	6.747
E	10.23	2	19.778	1.635	21.626	4.532
e					20.23	4.240
St	216.15	16	417.890		477.168	100
Mean	43.23					

Based on table 3 above is obtained that for patients 1 Ta optimal machining is 3:58:20 with Ra=0.0061 mm. Optimal design for the patient 2 is Ta optimal machining is 4:12:00 and Ra of 0.0069 mm.
Based on the results of Table 4 above were obtained from 5 factors that used in this research, factors that mostly influence is factor B 35.47% and the factor C (40.07%). The result of evidence suggests that the factor B (toolpath strategy) and C (spindle speed) are both influential amounted to 75.51 % of all the existing factor.
These conditions based on orthogonal array $L_8 4.2^4$ exists on machining parameters for patients 1 & and 2 were on treatment to three i.e. toolpath strategy raster finishing 45^0 CNC machine spindle, round at 14,000 RPM, step over 0.2 mm and 900 mm/feeding. It is this condition type *iso_diabetes* the most optimal can be obtained during the in width of 0.75 mm tolerance.

CONCLUSION

Manufacturing Optimization method Taguchi orthogonal arrays on $L_8 4.2^4$ managed to get parameters of machining *iso_diabetes* optimal i.e. the second treatment. The parameters obtained with the *new iso_diabetes product* for patients 1 and 2 there is on type 0.75 mm.
In General researchers managed to meet the demand laboratoium orthotic prostethic and less than 4 5. hours and Ra is less than 0.008 mm. The results of this experiment can be used as input for laboratory or industrial shoe insole that's still conventional switching to RID technology based subtractive manufacturing with CNC machines.
Further research will be conducted more in-depth about the optimization process of manufacturing on the other foot disorders patients such as: proteanus, high heel, flat feet, diabetes scale so high that must be amputated.
Research on optimization of manufacturing with EVA rubber materials with different characteristics also needs to be done to anticipate the large number of types and type EVA rubber on the market.

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