

OPTIMIZATION OF PROCESS PARAMETERS AND QUALITY RESULTS USING PLASMA ARC CUTTING IN ALUMINUM ALLOY

Abdul Hamid, Oyong Novareza, Teguh Dwi Widodo
Mechanical Engineering Departement, Brawijaya University
Jl. Mayjen Haryono 167, Malang 65145, Indonesia

Abstract Plasma cutting is a thermal cutting using a plasma arc that is widely used in metal cutting. In the field study, there were several problems including the quality of cutting and the cost of finishing on aluminum metal. To overcome this problem, the researcher applied the parameter process optimization method by combining the Taguchi method and Gray Relational Analysis with the orthogonal array L9 design selection (3^4). The material used is aluminum 5083, the response parameters studied are surface roughness and conicity angle. Then compare the results of the research with the actual field data. The results of the study obtained a combination of optimal parameters 90A, 1800mm/s, 3 bars, and 3mm. Parameter contribution is dominated by cutting current 79.42% followed by cutting speed. The difference between the actual data and the optimal combination has increased. While the finishing time was reduced by 2.16 seconds, and finishing costs were minimized to 25.11 rupiahs per 100 mm².

Key words: aluminium, plasma cutting, quality of cutting, taguchi and grey

1. Introduction

The world of metal fabrication, metal cutting is the initial process step in the fabrication. Cutting in this initial process experienced rapid technological development. Cutting itself is a sharpening of an object using a tool to determine a certain size and accordingly. The principle used in this kind of operation is like turning, dragging, strapping, and cutting, just like other processes are done by machine tools.

Along with developments, research on the optimization of Plasma Arc Cutting (PAC) parameters has grown rapidly in obtaining optimum results. Start research using varied variants based on cutting parameters until the metal is used. The use of the analytical method also varied in line with the development of quality control.

CV Kurnia Abadi CNC Plasma Cutting, Jl. KB. Agung No.3, Karah, Jambaxngan, SBY City, East Java 60232. The CV is engaged in

CNC plasma cutting based metal cutting services in the formation of ornament shapes from steel metal to aluminum. In a field study at CV Kurnia Abadi CNC Plasma Cutting found several problems where often cost finishing leaks, especially cutting aluminum metal in surface smoothing which takes 3.5 seconds every 100 mm². In the case of cutting quality, especially aluminum metal which has a thickness of 10 mm the roughness produced by the cutting process is 21.22 μ m and the conicity angle is 14.710. The quality of the results of cutting heat in metal, the standard surface of the heat cut is divided into several parameters as follows [1].

1. Angle equation and tolerance (u)
2. Average into valleys and surface peaks (Rz5) surface roughness
3. Drag (n) cutting direction
4. Melting upper edge radius (r)
5. Metal melt (dross) at the bottom edge of cutting.

To reach the output parameter standard, it is necessary to set the right input parameters according to cutting requirements. Where setting

* Corresponding author. Email : abdulhamid200292@gmail.com

Published online at <http://Jemis.ub.ac.id>

Copyright ©2019 JTI UB Publishing. All Rights Reserved

Cite this Article As Hamid, A., Novareza, O., & Widodo, T. (2019). OPTIMIZATION OF PROCESS PARAMETERS AND QUALITY RESULTS USING PLASMA ARC CUTTING IN ALUMINUM ALLOY. *Journal of Engineering and Management in Industrial System*, 7(1), p7-14.

Paper Submitted : Dec, 18th 2018

Paper Published : May, 29th 2019

the parameters that affect, among others, current (Ampere), gas pressure (Gas Pressure), Nozzle Type, cutting speed (Feed rate).

Maximizing the amount of metal wasted or MMR (Material Removal Rate) and minimizing surface roughness or SR (Surface Roughness) in cutting EN 31 steel using PAC (Plasma Arc Cutting) using the Taguchi method and the WPCA multi-response method approach. The optimum results of the parameters were tested from gas pressure, current and plasma torch distance with a combination of 7 bars, 200 amperes and 4 mm. By using ANOVA, it can be seen that gas pressure has more significant influence on MMR and SR followed by gas pressure [2].

Optimization of the quality of metal cutting with Experimental Design and Taguchi method that Torch Plasma Distance followed by currents also gives the dominant influence in the formation of kerf, MMR and SR on 316L Stainless Steel metal [8].

In another study using Design Experiment and Anova Analize on Hardox 400 plate. Optimum results of cutting on Hardox 400 plate with a thickness of 12 mm resulted in 421 micron roughness with adjustment of 70 L / m for gas flow rate, with cutting voltage 125 V and cutting speed 2100 mm / minute [6].

In optimizing some cutting parameters in finding the optimization, cutting current, gas pressure and cutting distance are the main choices. Where each of these studies is looking for cutting quality by saving time which can have an effect on production costs. Especially in minimizing cutting process time by maximizing cutting speed cutting time, minimizing the amount of MMR wasted metal and maximizing cutting smoothness (SR).

Cutting Height is the most dominant influence in cutting in determining the Conicity optimization, MRR and SR, while Cutting Current has the most effect in the HAZ width. So that the proper parameter settings can give smaller HAZ results so that the microstructure of the metal is still like a base material according to its use [5].

In achieving good cutting results in accordance with EN ISO 9013 standards, the need for quality improvement in determining parameters in a process. A research towards product design and optimizing production processes is important for increasing product productivity and quality. Quality can be achieved

by optimizing design to minimize costs in obtaining and maintaining the position of world market competition.

Statistical methods have been developed from time to time and are used in various fields, one of them in the field of optimization. One of the most used optimization methods is Taguchi. The Taguchi method is one of the off-line methods of controlling product quality, namely by controlling or improving quality by starting from design to product processing [7]. This method uses an efficient approach using experimental planning to produce a combination or factor level that can be controlled at a small cost but still supplies and meets consumer needs. this Taguchi.

method is used and resolves the one response optimization case. Then for multirespon case analysis is being developed in stages until the present, Gray Relational Analysis for example. The GRA method produces conclusions more efficiently in determining the optimization process for the parameters. Based on the system gray theory. this theory can overcome the lack of incomplete and unclear information. Gray's theory system is to study problems with small samples and little data information. With GRA, the gray relational grade (GRG) value will be obtained to evaluate the responses that are numerous. So that the results of a large number of response optimizations are obtained to be an optimization of one GRG [4].

From some of the descriptions and research above, we can know that the quality of the cut-off surface of aluminum metal using plasma arc cutting has its disadvantages, namely the quality of the cut. So the researchers focused on the optimization of the quality of cutting results based on EN ISO 9013 standard and combined the input settings parameters of gas pressure, current, cutting speed, and cutting distance in improving the optimization results and knowing the contribution of input parameters for each response variable. The advantage of this research is to integrate the Taguchi and GRA methods, making it more efficient than the multi-response optimization method from several previous researchers.

2. Experimental procedure

This research was carried out experimentally using the Taguchi method and gray relational analysts to improve cutting quality and

minimize production costs.

2.1 Research Design

The design of this study uses the Taguchi L-9 Design Method with an orthogonal matrix (3^4) robust design. Then, from the research design, the optimization phase will be carried out simultaneously using the Taguchi-Gray method. The selection of process parameter factors can be seen in table 1 and the experimental design.

Table 1 Selection of Process Parameters

Factor	Unit	Not	Level		
			1	2	3
Current	A	A	80	90	100
	(ampere)				
Feed rate	mm/sec	B	1400	1600	1800
Gas pressure	bar	C	3	4	5
Nozzle	mm	D	2	3	4

After determining the cutting parameters and number of levels then do a combination of experiments with L9 Orthogonal Experiment (3^4) in table 2.

Table 2 Design of the L9 Orthogonal Experiment (3^4)

Ex p	Curre nt	Feed rate	Gas pressu re	nozzl e	Resp ons e
1	A1	B1	C1	D1	
2	A1	B2	C2	D2	
3	A1	B3	C3	D3	
4	A2	B1	C2	D3	
5	A2	B2	C3	D1	
6	A2	B3	C1	D2	
7	A3	B1	C3	D2	
8	A3	B2	C1	D3	
9	A3	B3	C2	D1	

Every experiment measured a value of 2 responses to the value of conicity and surface roughness. The two response values are used as data analysis processing values.

2.3 Work piece

The object studied was the quality of the cutting results of Aluminum 5083 in order to meet the EN ISO 9013 standard by optimizing the kerf width, metal roughness (SR), and surface angle (Conicity). Aluminum 5083 which

will be studied with dimensions of length and width of 50 mm x 40 mm with a thickness of 10mm. The shape of the specimen is shown in Figure 1. Aluminum 5083 is one of the non-ferrous metals where the type of metal that chemically does not have iron or Ferro (Fe). Enter in the category of aluminum metal with magnesium alloy, namely Al-Mg (seri5000). With a metal melting point of 6500C. The preliminary data in the field show that the results of cutting on aluminum have a metal roughness level of 21.22 μm and a conicity angle of 14.710.

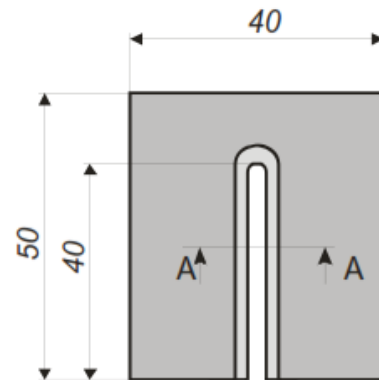


Figure 1 Dimension of *Aluminium*

2.4 Data Processing Stage

The data processing phase is the steps taken to solve the problems in the study:

1. Making an experimental design table, a Signal to Noise (SN Ratio) counter with characteristics of smaller is better, using Minitab 18 software and Microsoft Excel software.
2. Calculating the normalization value of Signal to Noise (SN Ratio)
3. Calculate the deviation sequence value
4. Calculating the delta value and gray relational coefficient on each response using Microsoft Excel
5. Calculate the gray value of relational grade as the outcome data
6. Comparing the actual conditions and after obtaining the optimum combination.
7. Create an ANOVA table and determine the percent contribution of each response.
8. Compare the results of actual data and optimum results.

Table 3 Data collection of result

No	A	B	C	D	Surface roughness (sr)				Conocity (c)			
					d 1	d2	d3	mean	d1	d2	d3	mean
1	80	1400	3	2	22.87	21.9	24.2	22.99	10.23	11.3	13.57	11.7
2	80	1600	4	3	20.01	21.4	22.22	21.21	11.1	10.9	11.6	11.2
3	80	1800	5	4	17.42	17.58	20.23	18.41	9.4	9.78	11.72	10.3
4	90	1800	3	3	13.16	13.56	13.09	13.27	11.23	10.87	12.1	11.4
5	90	1400	4	4	16.27	16.89	15.65	16.27	10.6	10.7	11.1	10.8
6	90	1600	5	2	15.76	15.45	13.82	15.01	11.7	11.7	12	11.8
7	100	1600	3	4	14.53	14.55	15.2	14.76	11.76	12.14	11.8	11.9
8	100	1800	4	2	13.42	13.37	13.23	13.34	12.75	12.98	12.67	12.8
9	100	1400	5	3	15.55	15.23	16.23	15.67	10.9	11.25	11	11.2

9. Make conclusions on the results obtained.

3. Results and Discussion

In this chapter describes data collected and processing data to solve problems on the Industrial.

3.1 Data Collection

The following is a recapitulation of the mean results from retrieving surface roughness data and the large conicity angle on the cutting surface of aluminum metal specimens 5083 in table 3.

3.2 Calculation of Deviation Sequence Value

The value of deviation sequence is the absolute difference between the maximum value of the normalization result of each response value. Deviation sequences are calculated using formulas.

The example of calculating the value for surface roughness response in the first combination is as follows.

$$\Delta_{0,i}(k) = |X_0(k) - X_i^*(k)|$$

$$\Delta_{0,i}(1) = |1 - 0.1.0|$$

$$\Delta_{0,i}(1) = 0$$

The results of calculating the values for each response parameter in each combination can be shown in the following table 4.

Table 4 Calculation Deviation Sequence

Experiment	Parameter proces				Dev – Seq	
	A	B	C	D	sr	c
1	80	1400	3	2	0.000	0.414
2	80	1600	4	3	0.147	0.614
3	80	1800	5	4	0.404	1.000
4	90	1800	3	3	1.000	0.533
5	90	1400	4	4	0.629	0.782
6	90	1600	5	2	0.776	0.374
7	100	1600	3	4	0.806	0.336
8	100	1800	4	2	0.990	0.000
9	100	1400	5	3	0.697	0.614

Table 5 Calculation of *Grey Relational Coefficient* and *Grey Relational Grade*

Experiment	Parameter proses				GRC		Mean GRC /GRG	Rank
	A	B	C	D	sr	c		
1	80	1400	3	2	1.000	0.547	0.774	9
2	80	1600	4	3	0.773	0.449	0.611	7
3	80	1800	5	4	0.553	0.333	0.443	4
4	90	1800	3	3	0.333	0.484	0.409	1
5	90	1400	4	4	0.443	0.390	0.416	2
6	90	1600	5	2	0.392	0.572	0.482	5
7	100	1600	3	4	0.383	0.598	0.491	6
8	100	1800	4	2	0.335	1.000	0.668	8
9	100	1400	5	3	0.418	0.449	0.433	3

3.3 Calculation of Gray Relational Coefficient and Gray Relational Grade

GRC is the relationship between the ideal conditions and the actual conditions of the response parameters from the calculated deviation sequence values. The GRC value is calculated based on the value of each response. The GRC value is calculated with the distinguish coefficient value of 0.5.

The example of calculating the GRC value for the surface roughness response in the first combination is as follows.

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta \Delta_{\max}}{\Delta_{0,i}(k) + \zeta \Delta_{\max}}$$

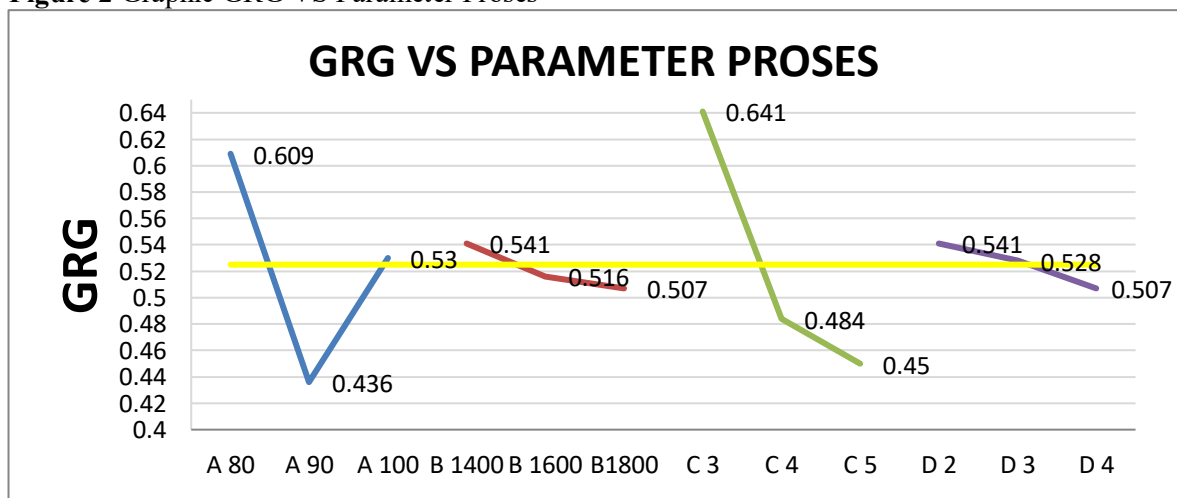
$$\xi_i(1) = \frac{0,000 + 0.5 \times 1,000}{0,000 + 0.5 \times 1,000}$$

$$\xi_i(1) = 1.000$$

After obtaining the GRC value for each response presented in Table 5 an experiment consisting of two responses will be converted into one variable Gray Relational Grade (GRG). The results of the GRG calculation in table 6 will be used to determine the composition of the factors that produce the optimum response based on smaller is better simultaneously.

Data taken from table 5 in the average GRG column is the sum of the GRC values of SR and Conicity. The GRG value and GRC is same value, but GRG is average and GRC is spesification every parameter. Figure 2 GRG vs Parameter.

Figure 2 Graphic GRG VS Parameter Proses



From the results of the Gray Relational Grade calculation shown in table 6, it can be concluded that the one with the optimal value is the lowest GRG experimental value shown in experiment 4 with parameter settings A1, B3, C1, and D2. After obtaining the optimum combination of process parameters, the next step is a confirmation experiment which obtained the roughness and conicity values.

Table 6. Result of experiment confirmation

Parameters	Surface Roughness	conocity
GRC	13.13	11.22

3.4 Percent Contribution

Variance analysis (ANOVA) was used to determine process parameters that had a significant influence on the response and the magnitude of the contribution of factors to the response.

If the error free degree is 0, then it cannot calculate the value of the number of error squares so that the average error square cannot be calculated and it also results in the calculation of the calculated F value. So polling needs to be held (merging several factors into error).

Polling up is done by eliminating the factors that have a small number of squares of non-significant factors which are then combined into a number of squared errors. Taguchi recommends that this incorporation procedure be carried out until the error free degree approaches half of the total degrees of observation [7]. The least number of squares of significant factors is factor D.

ANOVA calculation is obtained in the following table.

Table 7 Anova Grey Rerational Grade

Factor	DF	Seq SS	Adj MS	F- Value
A	2	75.7464	37.8732	*
B	2	0.7509	0.3754	*
C	2	16.5925	8.2962	*
D	2	0.6145	0.3072	*
Error	0	*	*	
Total	8	93.7042		

Table 8 After data ANOVA Polling Up

F	D F	Seq SS	Contrib ution	Adj MS	F- Val ue
A	2	0.003471	79.42%	0.001736	7.76
B	2	0.000480	11.03%	0.000239	1.01
C			Polling		
D			Polling		
Err	4	0.000419	9.28%	0.000201	
Ttl	8	0.004370	100.00 %		

After polling up can be seen in table 8, with the value of F table $(0.05, 2, 5) = 5,31$, it is found that $F_{\text{count}} > F_{\text{table}}$ so that these parameters have a significant effect that is on the strong current factor.

And for the calculation of the contribution size for both responses, the current strength has a contribution of 79.42% and followed by a cutting speed of 11.03%.

3.5 Comparison of Results of Initial Data and Optimum Combination Results

Comparison of metal roughness and conicity in actual conditions obtained data of 17.67 μm and 14,710, while the optimum condition values obtained were 13.13 μm and 11,220. In table 9 is a comparison of actual conditions and optimum combinations.

Table 9 Comparison of early versus optimum conditions

Respon	Early condi tion	Optimum condition	Diffe rent	Percen tage
Surface Roughn ess	17,67	13,13	4,54	25,69%
conicity	14.71	11,22	3,49	23,72%

Based on data processing using the Taguchi and GRA methods compared to the actual data, it was found that the cutting quality improvement was achieved by decreasing metal roughness by 25.69% and conicity by 23.72%. The actual high condition is caused by setting a large cutting current parameter and setting a cutting speed that is too slow, the gas pressure is too large, and the cutting distance is too close. So the nominal metal roughness is high and the conocity value increases.

3.6 Comparison of Time (t) and Cost (c) Cut Surface Finishing between Actual Data and Optimum Combination

According to the Law regarding working hours, working hours are the time to do work, can be carried out during the day and / or night. Working hours for workers in the private sector are regulated in Act No. 13 of 2003 concerning Manpower, specifically articles 77 through article 85. Article 77 paragraph 1, Law No.13 / 2003 requires every employer to implement provisions on working hours. The provisions of this working hour are set in 2 systems as mentioned above, namely:

1. 7 hours of work in 1 day or 40 hours of work in 1 week for 6 working days in 1 week; or
2. 8 hours of work in 1 day or 40 hours of work in 1 week for 5 working days in 1 week.

If working hours in a week are 40 hours, then in the calculation of the time of 1 month there are 160 hours of work.

While the UMR (Regional Minimum Wage) of the city of Surabaya is Rp. 3,871,052.61 for 1 month or 160 working hours, so if calculated in seconds, the total cost paid by the company to the operator in the following equation.

$$\begin{aligned} \text{Cost/t} &= \frac{\text{UMR (rupiahs)}}{\text{total time in one month (hour)}} \\ &= \frac{\text{UMR (rupiahs)}}{160 \times 60 \text{ menit} \times 60 \text{ detik}} \\ &= \frac{3.871.052,61}{160 \text{ jam} \times 3600 \text{ detik}} \\ &= \frac{\text{Rp } 12,09}{\text{detik}} \end{aligned}$$

Operator costs in one second are Rp. 12.00

Based on field data taken at CV Kurnia Abadi CNC Plasma Cutting, after confirmation of the experimental specimens, the process is cut, then the next process is refining the cut surface. Data for refining the results of cutting specimens in table 11.

Table 11. Timing of Finishing Specimens of Minimum and Optimum Combinations.

Parameter respon	Optimum Combination	Surface Area
Sr (µmm)	13.13	1000 mm x 50 mm = 500 mm ²
Conicity (°)	11.22	
Time Finishing	6,7 seconds	

In refining the specimen finishing process, the time taken is 6.7 seconds for optimum combination per 500 mm². So that the time needed to refine the surface area is 100 mm² in

this calculation.

Number of parts per 100 mm² = 500 mm²: 100 mm² = 5

$$\begin{aligned} t_1 &= \frac{\text{time finishing}}{5} \\ &= \frac{6.7 \text{ seconds}}{5} \\ &= 1,34 \text{ seconds} \end{aligned}$$

t₁ = Is time needed to smooth the surface area of the optimum combination specimen every 100 mm²

Cost calculation smoothes surface specimens cut the initial condition response before optimization and the optimum combination is obtained from multiplying the amount of time needed to smooth every 100 mm² and operator costs every second. Then the data is compared and analyzed in table 12.

Table 12 Comparison of Operator Costs Per 1 Second in Smoothing 100 mm² Aluminum

Parameter respon	Early condition	Optimum combination	Difference
Waktu	3,5 seconds	1,34 seconds	2,16 seconds
Biaya	Rp 42,31	Rp 16,20	Rp 26,11

Difference in the reduction of time from the actual data and the optimum combination shows that there is a process of decreasing the working time of 2.16 seconds in table 5.18. So that the cost that can be minimized by the manufacturer in smoothing the cut surface per 100 mm² of aluminum is Rp. 25.11 and finishing time is 2.16 seconds.

4. Conclusion

The combination of treatment parameters for cutting CNC plasma cutting on aluminum 5083 metal uses the taguchi and GRA method on the variable surface roughness response and conicity obtained by cutting current settings of 90 A, cutting speed of 1800 mm / s, gas pressure of 3 bars, and cutting distance by 3mm. after conducting a confirmation experiment it was found that the surface roughness was 13.13µm and the conicity angle was 11,220. The contribution that influences the variable surface roughness response and conicity, the contribution of the cutting current factor is 79.42% followed by the cutting speed of 11.03%. Comparison of the optimal conditions and the optimum increase in

the target response value increased by 28.12% and the amount of conicity was 23.72%. While finishing finishing time is 2.16 seconds, and finishing costs can be minimized to 25.11 rupiah per 100 mm².

[8] Vivek, S. 2011. *Analysis of Process Parameters of Plasma Arc Cutting Using Design of Experiment*. Departement of Mechanical Engineering, National Institute of Technology Rourkela.

References

- [1] ISO 9013, 2013. *Thermal cutting – Classification of thermal cuts – Geometrical product specification and quality tolerances*. www.iso.ch.
- [2] Kumar, Milan dkk. 2014. *Optimisation of MRR and Surface Roughness in PAC of EN 32 Steel Using Weighted Principal Component Analysis*. Departement of Mechanical Engineering, Jadavpur University, Kolkata, India.
- [3] Kulvinder .dkk. 2013. *Optimization of plasma arc cutting by applying Taguchi Method*. International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463 Vol. 2 Issue 7.
- [4] Lin, J. L. dan Lin, C. L. (2002), “*The Use of Orthogonal Array with Grey Relational Analysis to Optimize the Electrical Discharge Machining Process with Multiple Performance Characteristics*,” International Journal of Machine Tools and Manufacture, Vol 42, hal. 237–244.
- [5] Salonitis, K.dkk. 2012. *Experimental Investigation of the Plasma Arc Cutting Process* . Procidia CIRP 3. US. Pp 287 – 292.
- [6] Subbarao, C dkk. 2013. *Investigation Analysis of Plasma arc cutting Parameters on the Unevenness surface of Hardox-400 material*. Department of Mechanical Engineering, Vardhaman college of engineering, 501218, A.P., India.
- [7] Soejanto, Irwan, 2009. *Desain Eksperimen dengan Metode Taguchi* . Graha Ilmu. Yogyakarta.