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INNOVATION TOOL USING TAGUCHI-METHODS FOR DEVELOPMENT OF A NEW PRODUCT WITH OPTIMUM CONDITION

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Abstract. As a development with short-term and lower cost are strongly required in 21st century. Therefore the innovation tool using Taguchi-methods for development of a new product with optimum condition was developed and evaluated. There are two trials in the innovation tool using Taguchi-methods. First trial investigates rough fuctions regarding all levers of all control factors, then important control factors and meaningless control factors are sorted. Second trial decides the optimum combination of the control factors by more detail trial using only important control factors. The optimum condition for polishing a minute die was investigated for evaluating this innovation tool in the experiment. It is concluded from the result that (1) Innovation tool using the Taguchi-methods was useful for development with short-term and lower cost, and (2) This tool could quickly and exactly decide the optimum polishing condition.

1 INTRODUCTION

Recently a developments with short-term and lower cost are strongly required for shorten products life cycle. Therefore FEM simulation is used for predicting the result of design process instead of doing experiments. On the other hand, Taguchi-methods [1], [2], [3], [4], [5] is also used for deciding optimum process conditions. However these methods are not enough to develop a new product with short time, lower cost, high quality and high accuracy.
In this study, the innovation tool using Taguchi-methods for development of a new product with optimum condition was developed and evaluated. The Taguchi-methods has several properties; the selected optimum combination for the control factors has very high robustness, influences for the each level of the control factors were shown by the each SN ratio and Sensitivity with decibel unit. Therefore the Taguchi-methods was used for the innvovation tool. In this research, there are two trials using the innovation tool; the first trial investigates rough fuctions regarding all levers of all control factors, and important control factors and meaningless control factors were sorted by using the results of the first trial. Second trial decides the optimum combination of the control factors by more detail trial using only important control factors. The optimum condition for polishing a minute die was investigated

for evaluating this innovation tool in the experiment. This new method will be more proper than the conventional Taguchi-methods [6] or other methods [7], [8] for searching the optimum condition.

2 EXPLANATION OF TAGUCHI-METHODS

Flow chart regarding explanation of the Taguchi-methods for products is shown in Figure 1. Taguchi-methods is used to decide optimum processing conditions with narrow dispersion for robust design. Control factors are equal to the design factors (See the control factors in Table 1). Noise factors are occurred for the error of function on the product (See the noise factors in Table1). Most designer can understand that the final functions of the developed product are strongly influenced for the each lever of each control factor under several noise factors. All combinations using all control factors are compressed by an orthogonal table (See the orthogonal array in Table 2). Then the experiment or the CAE analysis with influence of noise factors is performed by the orthogonal table. At last, the average and the standard deviation regarding all combinations using all parameters are calculated for the SN ratio and Sensitivity.

Then most of users write the effective figure of the control factors and zealously search the combination of the control factors for large SN ratio. A product using the combination isn't nearly influenced by noise factors. Specifically decision of optimum combination using the parameters for high robustness was completely finished.

Properties regarding the Taguchi-methods were that the selected optimum combination for the control factors has very high robustness, and influences for the each level of the control factors were shown by the each SN ratio and Sensitivity with decibel unit. Therefore most designers can selected the optimum lever of each control factor by checking the effective figure of the control factors for both SN ratio and Sensitivity.

The control and the noise factors are shown in Table 1. These factors are important factors in the Taguchi-methods. Each factor has several levels. The control factors are equal to the design factors. Noise factors relate to the error of function with regard to the product.

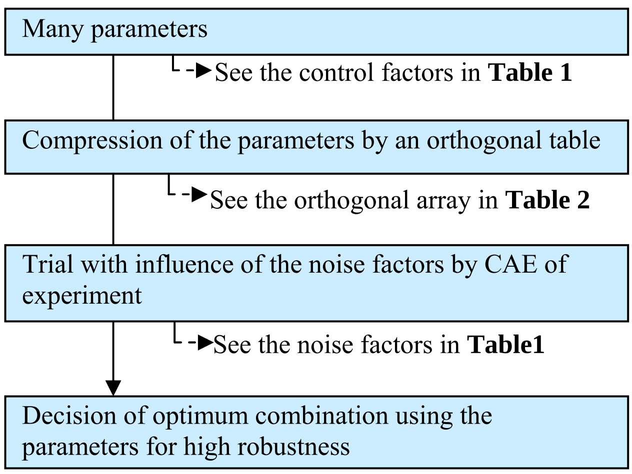


Figure 1 : Flow-chart of the Taguchi-methods

Table 1: Control factors and noise factors in the Taguchi-methods

Control factors				
Name	A	B	C	D
Levels	A_1	B_1	C_1	D_1
	A_2	B_2	C_2	D_2
	A_3	B_3	C_3	D_3
Noise factors				
Name	N			
Levels	N_1	N_2	N_3	

Table 2 : Orthogonal array, SN ratio and sensitivity in the Taguchi-methods

Trial No.	Control factors				Result with noise factors			SN ratio (db)	Sensitivity (db)
	A	B	C	D	N_1	N_2	N_3		
1	A_1	B_1	C_1	D_1	2.7	2.6	2.4	24.5	8.2
2	A_1	B_2	C_2	D_2	2.3	2.2	2.0	23.0	6.7
3	A_1	B_3	C_3	D_3	2.1	1.9	2.0	26.0	6.0
4	A_2	B_1	C_2	D_3	3.3	3.1	3.0	26.2	9.9
5	A_2	B_2	C_3	D_1	4.6	4.4	4.5	33.1	13.1
6	A_2	B_3	C_1	D_2	3.3	3.3	3.0	25.3	10.1
7	A_3	B_1	C_3	D_2	2.1	2.3	2.4	23.4	7.1
8	A_3	B_2	C_1	D_3	3.1	3.2	3.1	34.7	9.9
9	A_3	B_3	C_2	D_1	4.7	5.1	4.9	27.8	13.8

The total of all combinations using all control factors is 81 (=3^4) kinds (Table 1); however, these combinations are compressed to 9 kinds in the orthogonal table (Table 2). The influence of the noise factors is investigated 3 times for each combination of the control factors. Therefore the number of trial in this case is 27 (= 9 kinds × 3 times). SN ratio and sensitivity are calculated by equations (1) and (2).

$$SN\ ratio\ (db) = 10\log(\mu^2 / \sigma^2) \tag{1}$$

$$Sensitivity\ (db) = 10\log\mu^2 \tag{2}$$

Where μ is average of the evaluation value, and σ is standard deviation of the evaluation value in the results of trial. The evaluation value is the final properties or the final functions. Then most of users write the effective figure (Figure 2) of the control factors and search the combination of the control factors for the largest SN ratio. At that time, a product using the combination is not nearly influenced by noise factors. These effective figures are used for decision of optimum combination using several parameters in design of a product with high

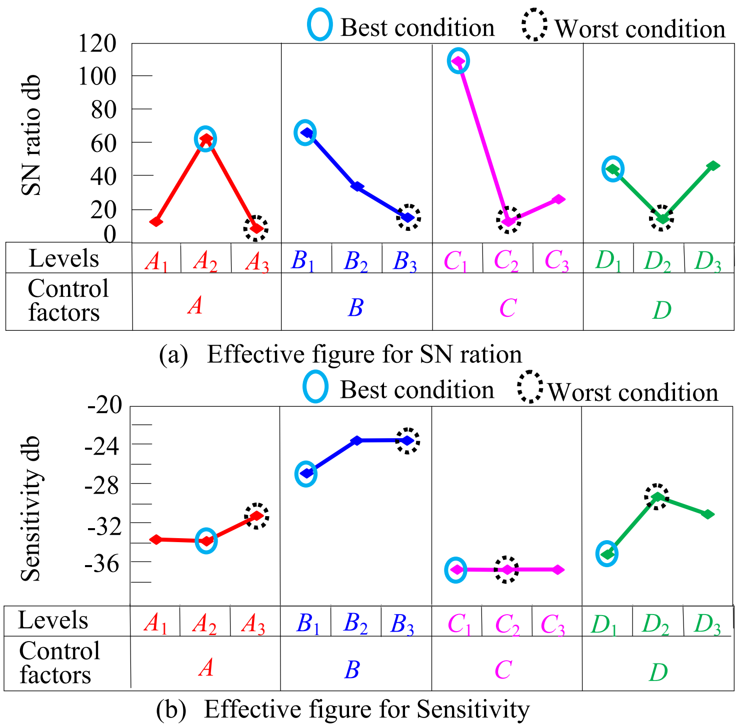


Figure 2 : Relationship between SN ratio or Sensitivity and each lever of each control factor (In the case, the best condition was supposed at the smallest final function possible)

robustness. When the SN ratio becomes large, the distribution of the final functions becomes small and the product has high robustness.

Finally, the average and the standard deviation regarding all combinations using all parameters are calculated by the SN ratio and Sensitivity with respect to the 9 kinds. The addition theorem in the Taguchi-methods is used to calculate the results for all combinations. For example, when m is a control factor and n is the level for the factor, the SN ratio SN_{mn} and Sensitivity S_{mn} for the control factor m and the level n are calculated by the addition theorem. Moreover the SN ratio $SN_{\mathrm{a4 \cdot b2 \cdot c1 \cdot d3 \cdot e2 \cdot f1 \cdot g2}}$ and the Sensitivity $S_{\mathrm{a4 \cdot b2 \cdot c1 \cdot d3 \cdot e2 \cdot f1 \cdot g2}}$ for a4, b2, c1, d3, e2, f1, g2 using control factors (a, b, c, d, e, f, and g) and levels (1, 2, 3, 4, 5 and 6) are calculated by equations (3) and (4), respectively.

$$SN_{\mathrm{a4 \cdot b2 \cdot c1 \cdot d3 \cdot e2 \cdot f1 \cdot g2}} = SN_{\mathrm{a4}} + SN_{\mathrm{b2}} + SN_{\mathrm{c1}} + SN_{\mathrm{d3}} + SN_{\mathrm{e2}} + SN_{\mathrm{f1}} + SN_{\mathrm{g2}} - (7-1)\ SN_{\mathrm{ave}} \tag{3}$$

$$S_{\mathrm{a4 \cdot b2 \cdot c1 \cdot d3 \cdot e2 \cdot f1 \cdot g2}} = S_{\mathrm{a4}} + S_{\mathrm{b2}} + S_{\mathrm{c1}} + S_{\mathrm{d3}} + S_{\mathrm{e2}} + S_{\mathrm{f1}} + S_{\mathrm{g2}} - (7-1)\ S_{\mathrm{ave}} \tag{4}$$

Where SN_{ave} and S_{ave} are averages of all SN ratios and Sensitivities, respectively. SN ratios and Sensitivities of the final properties or the final functions for all combinations of all control factors are quickly estimated before the trials.

3 INNOVATION TOOL USING TAGUCHI-METHODS

There are several strong points in the Taguchi-methods. Trial combinations are compressed to small size by using the orthogonal table, then the Taguchi-methods can estimate the final results for all combinations. Therefore the development with high quality is quickly performed.

Everyone can check influences for all levers on all control factors in the effective figure (Figure 2). SN ratio is used for robustness of the final properties or the final functions, and Sensitivity is used for evaluation regarding the final properties or the final functions. The final properties or the final functions have the several influences of the noise factors. Therefore the trial using the Taguchi-methods can arrive at the results with high robustness.

Flow-chart of the innovation tool using the Taguchi-methods is shown in Figure 3. The tool consists of two trials using the Taguchi-methods; these are “First trial for selection of the several important parameters” and “Second trial for decision of the optimum condition”. In the First trial, all levers of all control factors in your laboratory should try for the final properties or the final functions. This trial is for picking out the important parameters and for throwing away the meaningless parameters. If difference of influence on the each level regarding a control factor in the effective figure of “the Sensitive” is very little, the control factor is judged to the meaningless parameter. And when SN ratio is very small, the level of the control factor is judged to low robustness. Only important parameters selected in the First trial are used in the Second trial. In this trial, each important parameter are checked in more detail. If the important parameters require the larger or smaller level of a control factor for optimum condition, the new equipment for the larger or smaller level of a control factor is supplied in here. And if the important parameters require the level with high precision of a control factor for optimum condition, the new equipment with high precision is also then supplied in here. This second trial becomes the final trial, because optimum condition is decided by the second trial using Innovation Tool using Taguchi-methods with the best condition in the laboratory.

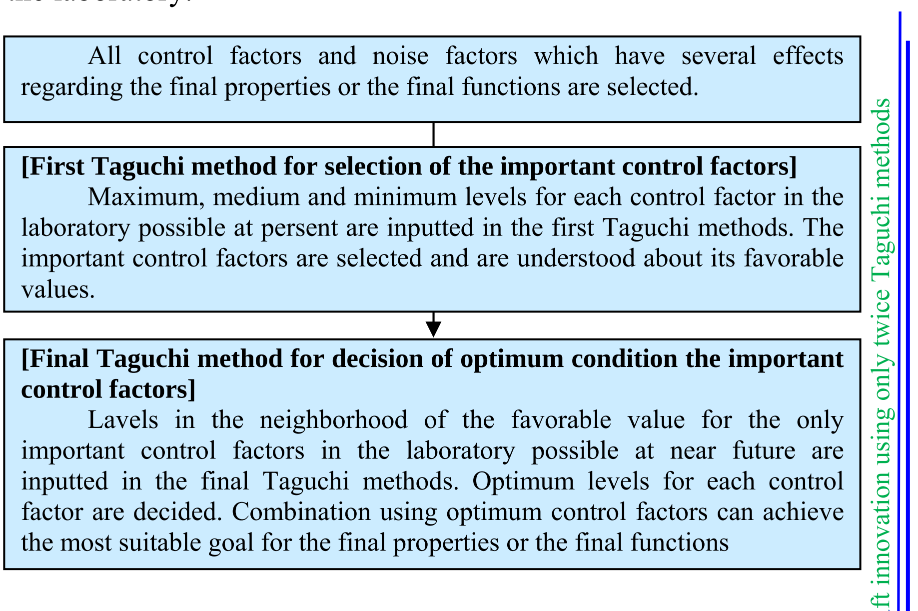


Figure 3 : Flow-chart of the innovation tool using the Taguchi-methods

4 EVALUATION USING THE POLISHING TOOL

4.1 First trial for selection of the several important parameters regarding the polishing tool

Optimum polishing condition is investigated for evalguchi-methods. Polishing tool and polishing procedure are shown in Figures 4 and 5, respectively[9]. This poliuation of the Innovation Tool using Tashing tool consists of the pipe and the ball head with diamond grains. Base material of the ball head is epoxy resin. Slurry consists of water, a polymer and diamond grains. The polishing tool is installed on the spindle of CNC milling machine, is rotating and moving in three dimensional directions by NC control. Several diamond grains in the polishing head and in the slurry can cut on the work piece. The polishing trace becomes very shallow because of soft ball head. However surface roughness of the work piece becomes

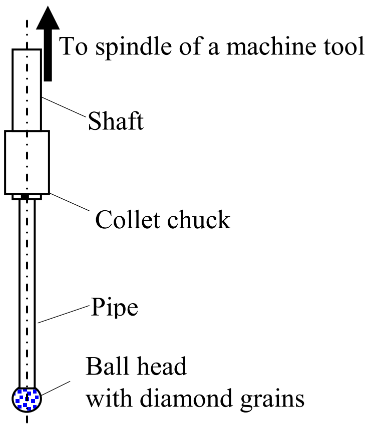


Figure 4: Schematic view of the polishing tool

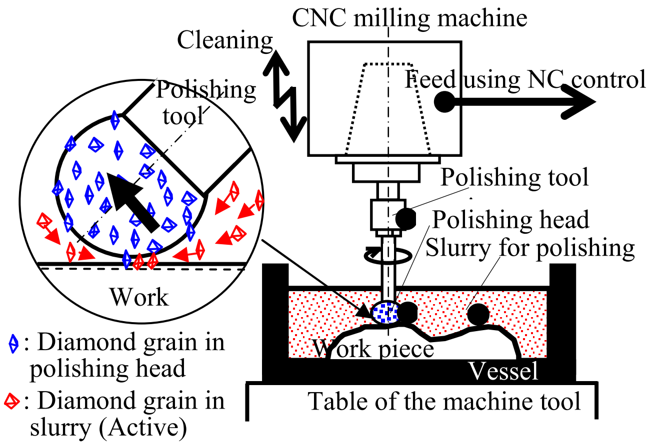


Figure 5: Schematic view of polishing (Principle)

Table 3: Control factors and noise factors for the polishing in the First trial

Control factors					
Name	*Spindle speed* min^{-1}	*Feed speed* mm/min	*Polishing pressure* MPa	*Polishing pitch* mm	*Room Temp.* ℃
Levels	300	0.5	60	0.030	20
	2400	1.0	120	0.045	25
	8000	5.0	180	0.060	30
Noise factors					
Name	*Measuring position*				*Point 1*, *Point 2*, *Point 3*, *Point 4*, *Point 5*, 5×5mm
Levels	*Point 1*	*Point 2*	*Point 3*	*Point 4*	*Point 5*

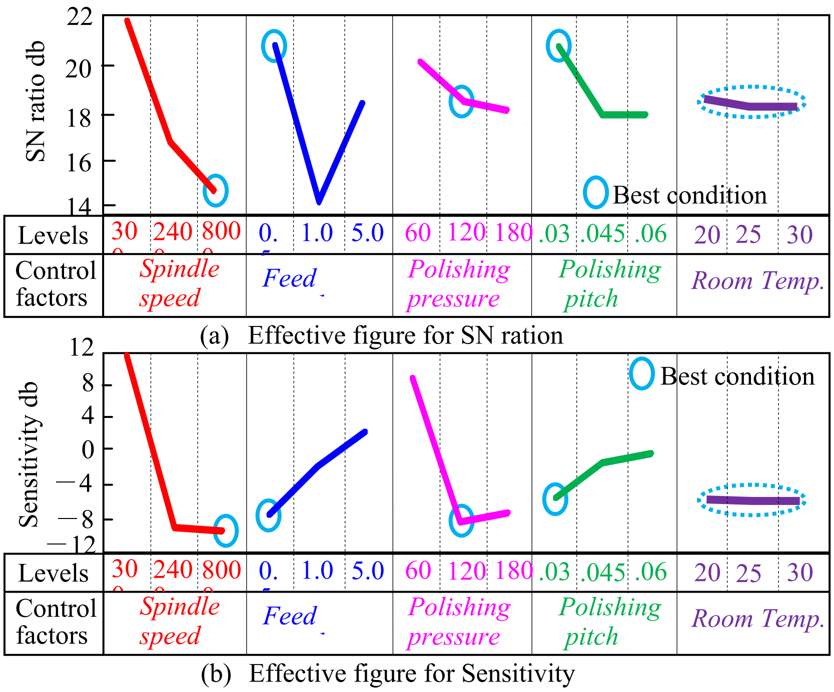


Figure 6 : Relationship between SN ratio or Sensitivity and each lever of each control factor in the First trial

very small because of shallow trace. After all, the polishing tool can polish to mirror-like surface. Particularly the ball head of the polishing tool has small diameter which is smaller than 1 mm. Therefore the polishing tool can polish a minute die.

Control and noise factors for the first trial are shown in Table 3. Control factors are several polishing conditions. These control factors are experimental parameters as thoroughly as possible I could in my laboratory, and the levels of the each control factor are maxmum, minimum and middle values. Namely we can try all possibility for picking out the important parameters and for throwing away the meaningless parameters. Several measuring points are used for the noise factor. Surface roughness after polishing is used for the final function.

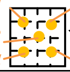
The effective figures for SN ratio and Sensitivity in the First trial are shown in Figure 6. Spindle speed, feed speed, polishing pressure and polishing pitch were selected for the important parameters by the effective figure, and the room temperature was thrown away from the control factors because of the little differences on influence of the each level regarding the room temperature in the effective figure of Sensitive. Optimum condition is that spindle speed was 8000 min^{-1}, feed speed was 0.5 mm/min, polishing pressure was 120 MPa and polishing pitch was 0.03 mm in the First trial. Therefore these control factors are investigated in more detail in the next final trial.

4.2 Second trial for decision of the optimum condition regarding polishing tool

Control and noise factors for the second trial are shown in Table 4. The only important parameters in the first trial are used for the control factors in the second trial. These control

Table 4: Control factors and noise factors for the polishing in the Second trial

Control factors				
Name	*Spindle speed* min^{-1}	*Feed speed* mm/min	*Polishing pressure* MPa	*Polishing pitch* mm
Levels	8000	0.3	100	0.015
	9000	0.5	120	0.020
	10000	0.7	140	0.030

Noise factors						
Name	*Measuring position*					 *Point 1* *Point 2* *Point 3* *Point 4* *Point 5* 5×5mm
Levels	*Point 1*	*Point 2*	*Point 3*	*Point 4*	*Point 5*	

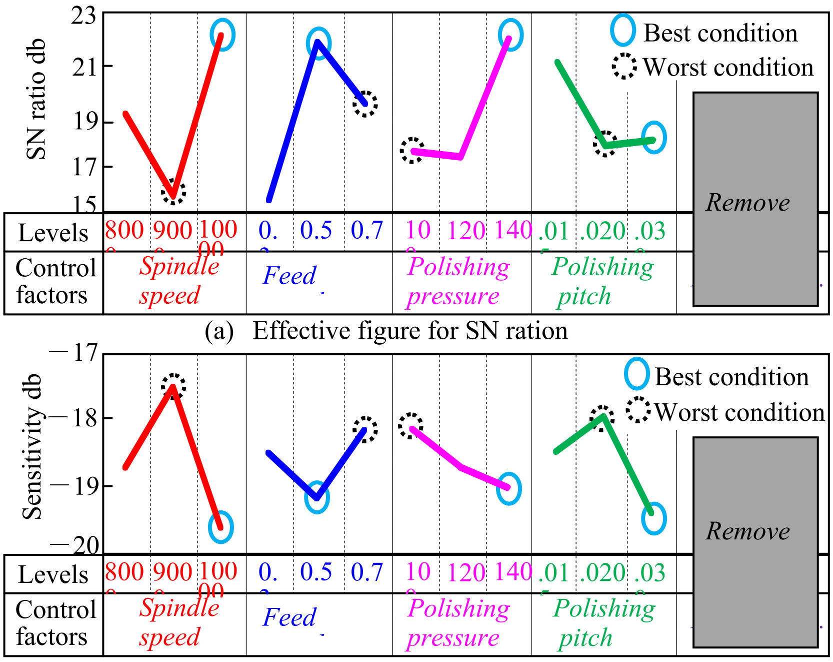


Figure 7 : Relationship between SN ratio or Sensitivity and each lever of each control factor in the Second trial

factors have large influence for surface roughness, and the levels of the each control factor are established nearby the optimum condition of the first trial. The effective figures for SN ratio and Sensitivity in the Second trial are shown in Figure 7. The optimum condition is that spindle speed was 10000 min-1, feed speed was 0.5mm/min, polishing pressure was 140 MPa and polishing pitch was 0.030mm in the Second trial. The SN ratio becomes very large and the Sensitivity becomes very small at the optimum condition. At that time, this polishing can make smooth and fine surface and the polishing has very high robustness. And average and standard deviation of surface roughness at best and worst polishing condition were also estimated by equations (3) and (4).

4.3 Evaluation regarding decision of the optimum condition for polishing tool

The optimum condition for polishing tool is evaluated in the experiment. Polishing condition used in the experiment is shown in Table 5. Work piece material is carbide. Specifications of the polishing tool and the slurry are similar to the previous experiment. Best and worst conditions in the Second trial are included for the polishing conditions.

Surface roughness of the polishing with best and worst conditions is shown in Figure 8. The results of the experiment are similar to the calculated results by the Innovation Tool using Taguchi-methods. The optimum condition for polishing tool was decided by only twice trials. Therefore the Innovation tool using the Taguchi-methods was useful for development with short-term and lower cost.

Table 5: Best and worst conditions for the polishing

Polishing condition	Best condition	Worst condition
Spindle speed min^{-1}	10000	9000
Feed speed mm/min	0.5	0.7
Polishing pressure MPa	140	100
Polishing pitch mm	0.3	0.2

Polishing tool	Material of polishing head (Ball head)	Epoxy resin
	Diameter of polishing head (Ball head)	ϕ 1.0 mm
	Diamond grain in ball head (#=Mesh size)	#2500
	Pipe	0.7 mm
Slurry	Base liquid	Water
	Diamond grain in slurry (#=Mesh size)	#2500
	Rate of grain (slurry : diamond)	10 wt% (9:1)
	Ratio of PEO (Poly-ethylene-oxide) for water	2 wt%
Work piece		Carbide

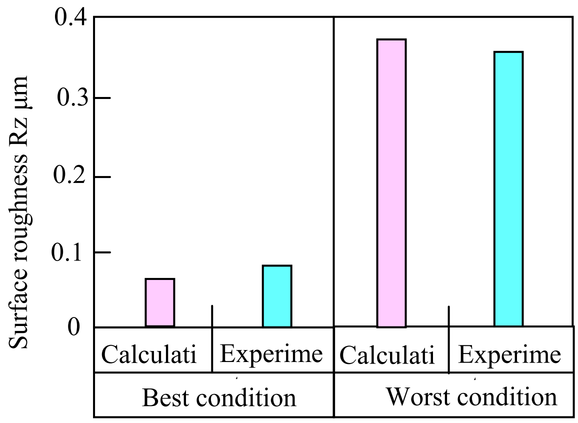


Figure 8 : Surface roughness of the polishing with best and worst conditions (By the Innovation Tool using Taguchi-methods)

5 CONCLUSIONS

- The innovation tool using Taguchi-methods was useful for decision of optimum condition.
- The proposed method effectively predicted the optimum polishing condition in experiment for evaluation.
- The predicted results conformed to the results of the actual polishing.

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