Advances in Dynamical Systems and Applications.
ISSN 0973-5321, Volume 16, Number 2, (2021) pp. 1867-1881

https://www.ripublication.com/adsa.htm

Influence of the Surface Quality of Stainless Steel JIS 420 and JIS 440 on Lapping Process

Suwit Thammasang[1] and Somkiat Thermsuk[1,*]

[1] *Department of Production Design Technology Faculty of Technical Education, Rajamangala University of Technology Isan Khon Kaen Campus, Thailand.*

Corresponding author.

ABSTRACT

This objective of research was studied the Influence of the surface quality of stainless steel JIS 420 and JIS 440 on lapping process. Factorial experiment was applied to analyze the four-alumina powder size of 0.3 µm and nine-lapping time of 30, 60, 90, 120, 150, 180, 210, 240 and 270 min, respectively. In preparing of specimen surface roughness for experimental, was used the ratio between the alumina powder of 200 g, alumina powder lubricant of 150 ml and water of 1 l which has Five surface roughness values, Ra were then prepared: 0.4 µm, 0.8 µm, 1.2 µm, 1.6 µm and 2.0 µm, respectively. Alumina abrasive powder size of 0.3 µm the surface quality of stainless steel JIS 440 on lapping process at a surface roughness of Ra 0.8 µm at 30 min resulted in the best average surface roughness (Ra) of 0.0575 µm when considering the satisfaction value. (Desirability: D) with regard to statistical processing, it was found that the value was as high as 99.37%.

Keywords: Alumina powder, lapping process, surface roughness, factorial experiment.

INTRODUCTION

Material science and technology make remarkable progress and the application of newly developed materials to various devices have increased rapidly. In particular, when fabricating a high-performance device, it is often necessary to adopt high-level lapping and polishing.[1] Generally, lapping and polishing occur by the sliding frictions between particles and a surface. The lap or polishing pad (polisher) travels across a workpiece surface against which particles of sand or mud- type slurry are forced to the point of contact.[2] Grinding is one of the most important abrasive processes. it is used to perform smooth and precise dimensions and surfaces. usually, the material removal rate from the workpiece is low in grinding operations compared to that in milling or other cutting operations. [3] At present, the process of polishing surface are processes which are widely used in industrial applications the continuously expanding industries are the automotive, sanitary, furniture and electronic industries. this requires more researches and analyses of work surfaces requiring very high surface roughness in order to increase product value for maximum return, lapping is a finishing method used to obtain high surface quality. Important parameters affecting the lapping process are thought to be abrasive grain size, lapping pressure, lapping speed, quantity of lapping compound supplied and the viscosity of the compound. [4] The result would be glossy skin and very high-resolution value. The type of materials that will be used to fine-tune the aforementioned surface all of which affect the surface smoothness of the work surface in the final surface finishing, which is considered cleaning and surface modification of metal by a combination of mechanical and chemical processes. To eliminate burrs or spines on the surface of the material being processed (Debarring /burr Removing) including defects on the surface and make the texture of the workpiece look as desired, skin properties that are often modified by beauty, smoothness of the surface, adhesion ability, wear resistance, corrosion resistance from chemicals slowing or preventing tarnishing and electrical conductivity. [5] Lapping is a method that adjusts the plane surface to increase accuracy. Abrasive machining technology [6–9] possessing extinct advantages of high efficiency, high flexibility, high accuracy and low surface damage has been extensively used in machining of flat and free form surfaces as compared with traditional machining technologies, such as cutting, milling and drilling processes with geometric tools [10–12]. The most common scrubbing method is bearing which can be found in piston in the oil pump [13]. The measurement accuracy is very important for high-precision technology relating to the work surface polishing process [14]. The influence on the process of scrubbing the surface in a thorough scrubbing consideration from the experiment depends on many factors [16]. The quality and accuracy of the surface shape can be achieved by forming the type in the lapping process which requires continuous experimentation to ensure high efficiency. [15,17-18] Adjust Including statistical analysis of variance (ANOVA) [19-20]. The objective of this research is to compare the influences of 4 types of alumina polishing powder on the average surface roughness (Ra) of JIS 420 and JIS 440 stainless steel in the surface treatment process by applying the Design and Analysis of Experiment (DOE) principles to perform process parameters determination of statistical significance.

EXPERIMENTAL PROCEDURE

The stainless steel that is similar to Ferritic stainless steel but with a higher carbon content, this group of stainless steels can be hardened to increase strength. The microstructure after hardening gives a martensite structure. most consider to the strength and resistance to rust in Moderate only due to the amount of carbon The higher the corrosion resistance is reduced. However, it will not corrode in mildly corrosive solutions or in neutral solutions. Examples of applications are bearings, shafts, gears, springs, etc. Beginning with the preparation of the work piece before heat treatment by bringing the stainless flat bar steel JIS 420 and JIS 440 to cut to size 35 x 35 x 6 mm, then the workpiece is cut by milling machine to the size 30 x 30 x 5 mm. After that, storing the surface with a flat surface grinding process and using a medium aluminum oxide grinding wheel (H) No. 80 on the surface of the test piece on both sides with area size of 30 x 30 mm which has Five surface roughness values, Ra were then prepared: 0.4 µm, 0.8 µm, 1.2 µm, 1.6 µm and 2.0 µm, respectively as shown in Figure 1.The next step is the continuous heat treatment process starting at annealing temperature of 400°C for a period of 10 min, then increase the temperature to 820°C for a period of 30 min. When the time limit is reached, then dip the workpiece into the plating substance of black-colored used engine oil. While oiling should have oscillations in order to thoroughly coat the workpiece in every part. Once the oil has been moistened, all of the work will be placed in a sand bucket to allow it to cool down. Last, the final step is to use sandpaper to finish the surface.

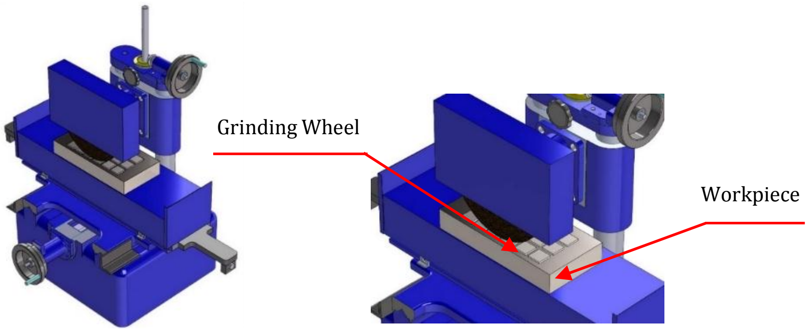


Figure 1. The process of grinding a flat surface.

The process of refining fine skin will start from mixing the ratio between the amount of alumina scrub powder of 200g, lubricant, alumina scrub powder at 150 ml and clean 1 l water to get the surface roughness values (Ra) which has Five surface roughness values, Ra were then prepared: 0.4 µm, 0.8 µm, 1.2 µm, 1.6 µm and 2.0 µm, respectively Then turn on the machine the Lapping Machine and mix the ingredients first by 5 minutes. The next step is to take these specimens of JIS 420 and JIS 440 stainless steel to conduct the experiment by using Piece Test available on the disc's surface as shown in Figure 2. After that, the experiment was performed by adjusting the time interval in the fine finishing process, which is 30, 60, 90, 120, 150, 180, 210, 240 and 270 min to collect the average surface roughness data: (Ra) of the specimen as shown in Figure 3.

Figure 2. Face flat lapping machine

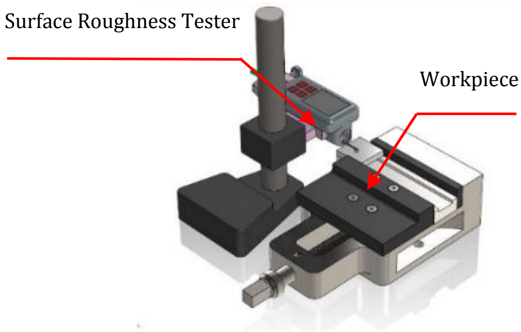


Figure 3. Data collection of average parameter surface roughness (Ra)

RESULTS

When all the experiments were conducted according to the statistical experimental plan with the analysis of factorial experiments. which has Five surface roughness values, Ra were then prepared: 0.4 µm, 0.8 µm, 1.2 µm, 1.6 µm and 2.0 µm, respectively. With the alumina polishing powder studied sizes of 0.3 µm, the main parameters response for statistical analysis is the average surface roughness (Ra) of the specimen of the JIS 420 and JIS 440 stainless steel material as shown in Table 1, 2

Table 1. Average surface roughness data (Ra) for statistical analysis JIS 420

		(Lapping Time; min)								
(Alumina Powder; µm)	Ra (µm) Grinding	30	60	90	120	150	180	210	240	270
0.3	0.4	0.177	0.151	0.131	0.153	0.153	0.144	0.117	0.168	0.161
0.3	0.4	0.163	0.163	0.144	0.144	0.144	0.145	0.123	0.158	0.158
0.3	0.4	0.171	0.167	0.159	0.140	0.145	0.141	0.161	0.166	0.183
0.3	0.4	0.163	0.172	0.140	0.154	0.141	0.156	0.133	0.171	0.159
0.3	0.4	0.181	0.156	0.164	0.154	0.156	0.152	0.144	0.159	0.184
0.3	0.4	0.154	0.178	0.155	0.141	0.152	0.153	0.142	0.166	0.166
0.3	0.8	0.112	0.183	0.159	0.147	0.138	0.131	0.113	0.127	0.172
0.3	0.8	0.295	0.167	0.168	0.152	0.143	0.133	0.109	0.128	0.165
0.3	0.8	0.239	0.180	0.179	0.122	0.150	0.113	0.108	0.125	0.144
0.3	0.8	0.142	0.167	0.171	0.157	0.148	0.130	0.120	0.124	0.142
0.3	0.8	0.236	0.168	0.172	0.146	0.135	0.123	0.105	0.123	0.141
0.3	0.8	0.205	0.185	0.175	0.153	0.138	0.127	0.117	0.134	0.123

		(Lapping Time; min)								
(Alumina Powder; μm)	Ra (μm) Grinding	30	60	90	120	150	180	210	240	270
0.3	1.2	0.170	0.148	0.160	0.149	0.144	0.158	0.149	0.147	0.111
0.3	1.2	0.240	0.169	0.165	0.151	0.130	0.132	0.147	0.132	0.102
0.3	1.2	0.202	0.183	0.145	0.147	0.133	0.135	0.159	0.127	0.101
0.3	1.2	0.175	0.138	0.145	0.160	0.132	0.149	0.146	0.128	0.109
0.3	1.2	0.184	0.169	0.149	0.134	0.127	0.139	0.152	0.143	0.108
0.3	1.2	0.160	0.156	0.159	0.127	0.128	0.134	0.155	0.148	0.112
0.3	1.6	0.250	0.152	0.127	0.158	0.141	0.093	0.141	0.135	0.124
0.3	1.6	0.705	0.256	0.175	0.159	0.133	0.097	0.133	0.141	0.113
0.3	1.6	0.299	0.163	0.101	0.148	0.142	0.110	0.128	0.145	0.128
0.3	1.6	0.336	0.260	0.118	0.156	0.128	0.109	0.142	0.133	0.131
0.3	1.6	0.309	0.132	0.102	0.149	0.143	0.096	0.128	0.143	0.124
0.3	1.6	0.180	0.248	0.132	0.138	0.131	0.090	0.143	0.133	0.129
0.3	2.0	1.542	0.186	0.153	0.114	0.164	0.161	0.144	0.165	0.164
0.3	2.0	0.926	0.497	0.184	0.162	0.154	0.156	0.161	0.171	0.152
0.3	2.0	1.324	0.550	0.162	0.131	0.141	0.167	0.146	0.168	0.144
0.3	2.0	0.218	0.137	0.139	0.102	0.162	0.166	0.145	0.177	0.157
0.3	2.0	0.412	0.442	0.169	0.129	0.150	0.161	0.166	0.173	0.156
0.3	2.0	0.156	0.156	0.163	0.141	0.161	0.163	0.163	0.162	0.155

Table 2. Average surface roughness data (Ra) for statistical analysis JIS 440

		(Lapping Time; min)								
(Alumina Powder; μm)	Ra (μm) Grinding	30	60	90	120	150	180	210	240	270
0.3	0.4	0.362	0.254	0.095	0.098	0.104	0.096	0.125	0.148	0.098
0.3	0.4	0.270	0.116	0.098	0.077	0.104	0.090	0.136	0.158	0.088
0.3	0.4	0.143	0.176	0.099	0.101	0.100	0.111	0.141	0.153	0.096
0.3	0.4	0.293	0.075	0.084	0.093	0.091	0.103	0.130	0.163	0.102
0.3	0.4	0.201	0.077	0.092	0.090	0.098	0.087	0.120	0.151	0.092
0.3	0.4	0.122	0.110	0.096	0.086	0.098	0.097	0.136	0.138	0.090

		(Lapping Time; min)								
(Alumina Powder; µm)	Ra (µm) Grinding	30	60	90	120	150	180	210	240	270
0.3	0.8	0.061	0.141	0.075	0.061	0.066	0.126	0.083	0.095	0.122
0.3	0.8	0.047	0.105	0.067	0.092	0.076	0.099	0.132	0.084	0.090
0.3	0.8	0.059	0.197	0.086	0.055	0.099	0.110	0.111	0.103	0.082
0.3	0.8	0.053	0.349	0.062	0.072	0.072	0.122	0.101	0.114	0.102
0.3	0.8	0.057	0.069	0.088	0.069	0.069	0.076	0.106	0.109	0.101
0.3	0.8	0.068	0.090	0.081	0.080	0.092	0.087	0.097	0.085	0.099
0.3	1.2	0.105	0.135	0.157	0.115	0.112	0.106	0.089	0.093	0.075
0.3	1.2	0.886	0.474	0.254	0.191	0.155	0.154	0.095	0.093	0.076
0.3	1.2	0.631	0.318	0.152	0.152	0.190	0.163	0.078	0.084	0.090
0.3	1.2	0.148	0.121	0.158	0.162	0.120	0.105	0.076	0.089	0.083
0.3	1.2	0.318	0.259	0.209	0.160	0.167	0.108	0.079	0.088	0.085
0.3	1.2	0.218	0.182	0.162	0.164	0.111	0.102	0.084	0.080	0.086
0.3	1.6	0.430	0.205	0.095	0.167	0.086	0.117	0.073	0.093	0.089
0.3	1.6	1.318	0.779	1.174	0.677	0.178	0.387	0.490	0.173	0.270
0.3	1.6	0.874	0.849	0.079	0.629	0.316	0.135	0.053	0.095	0.094
0.3	1.6	0.533	0.098	0.120	0.118	0.080	0.119	0.078	0.098	0.088
0.3	1.6	0.378	0.115	0.650	0.472	0.114	0.116	0.090	0.136	0.110
0.3	1.6	0.516	0.078	0.498	0.161	0.089	0.101	0.083	0.080	0.089
0.3	2.0	1.247	0.142	0.310	0.077	0.300	0.238	0.089	0.082	0.155
0.3	2.0	1.587	1.718	0.905	0.530	0.555	0.693	0.156	0.463	0.268
0.3	2.0	1.543	0.981	1.112	0.210	0.091	0.172	0.096	0.074	0.095
0.3	2.0	0.569	0.416	0.311	0.100	0.081	0.092	0.133	0.102	0.105
0.3	2.0	0.321	0.545	0.140	0.180	0.275	0.350	0.189	0.137	0.161
0.3	2.0	0.139	0.322	0.067	0.225	0.191	0.109	0.079	0.083	0.096

Workpiece before surface polishing and after surface polishing with surface roughness Ra 0.4, 0.8, 1.2, 1.6, 2.0 µm respectively, which is stainless steel according to JIS 420 and JIS 440 standard and when examined for microstructure at 100 times magnification, all 9 specimens after lapping the time levels are 30, 60, 90, 120, 150, 180, 210, 240 and 270 minutes respectively, for JIS 420 and JIS 440 stainless steels. The microstructure is martensitic. As shown in the Figure 4.

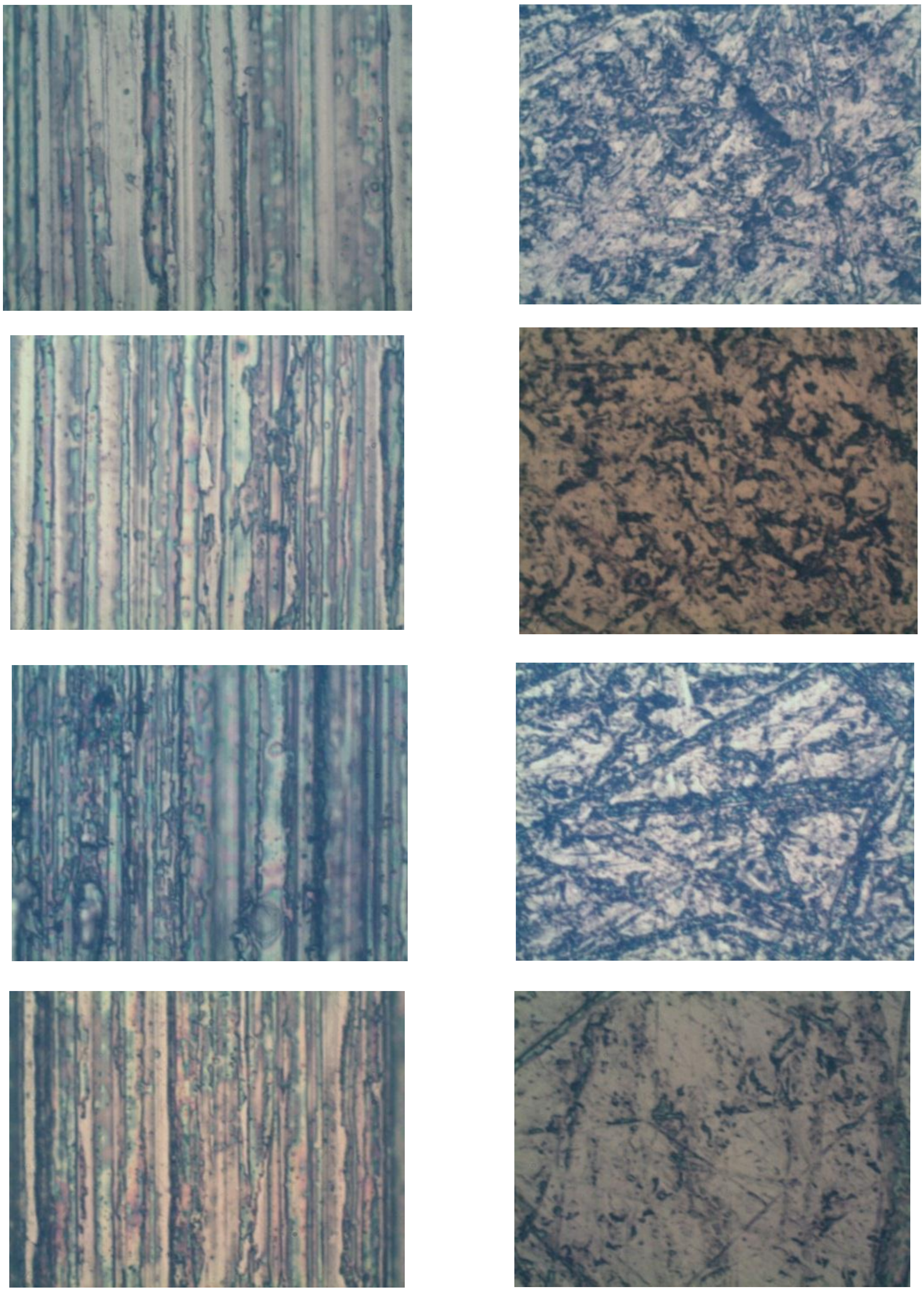
	Before surface polishing	**After surface polishing**

Ra 0.4
JIS 420

Ra 0.4
JIS 440

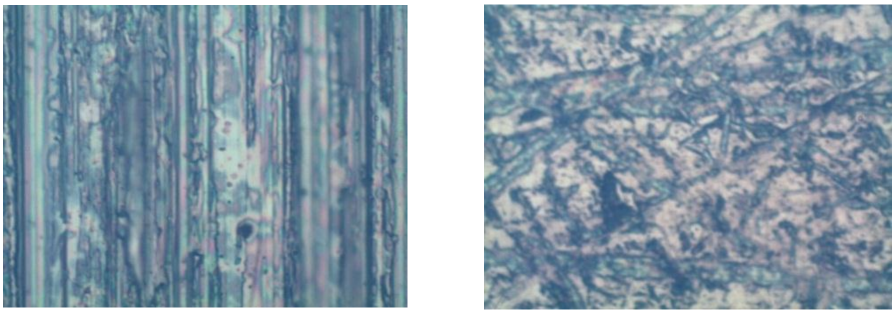
Ra 0.8
JIS 420

Ra 0.8
JIS 440



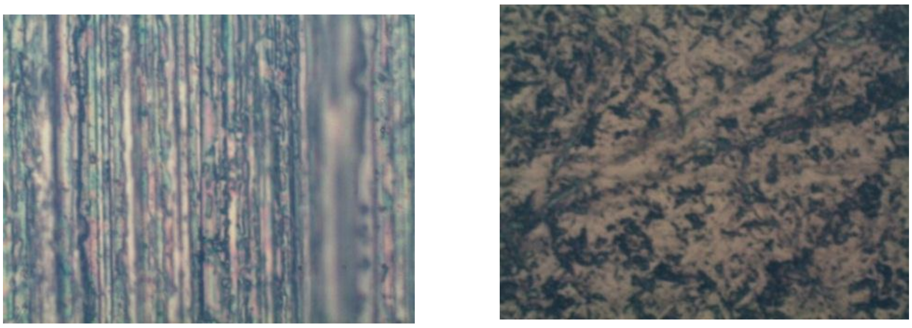
Ra 1.2

JIS 420



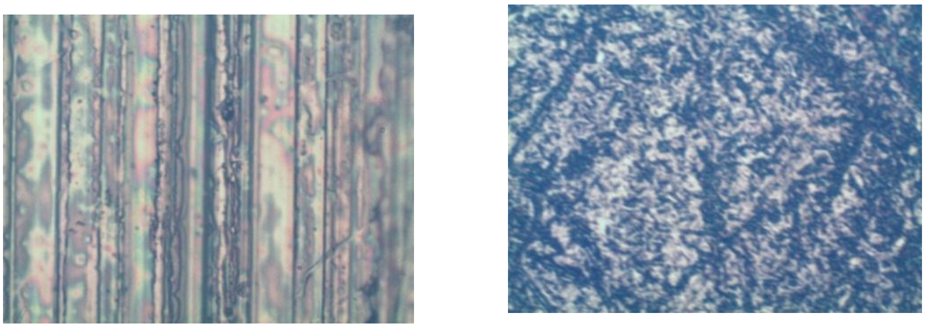
Ra 1.2

JIS 440



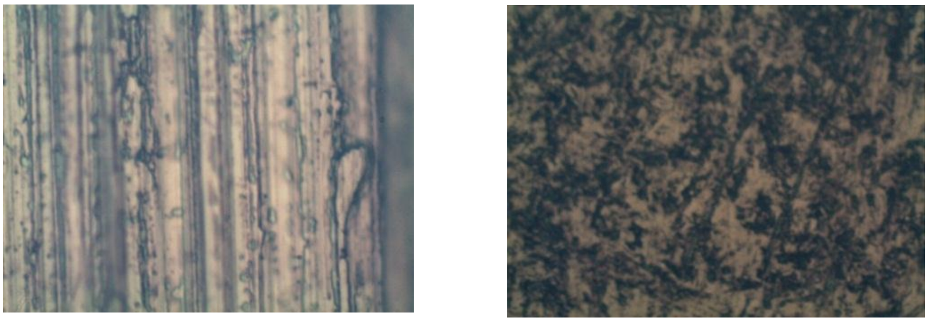
Ra 1.6

JIS 420



Ra 1.6

JIS 440



Ra 2.0

JIS 420

Ra 2.0

JIS 440

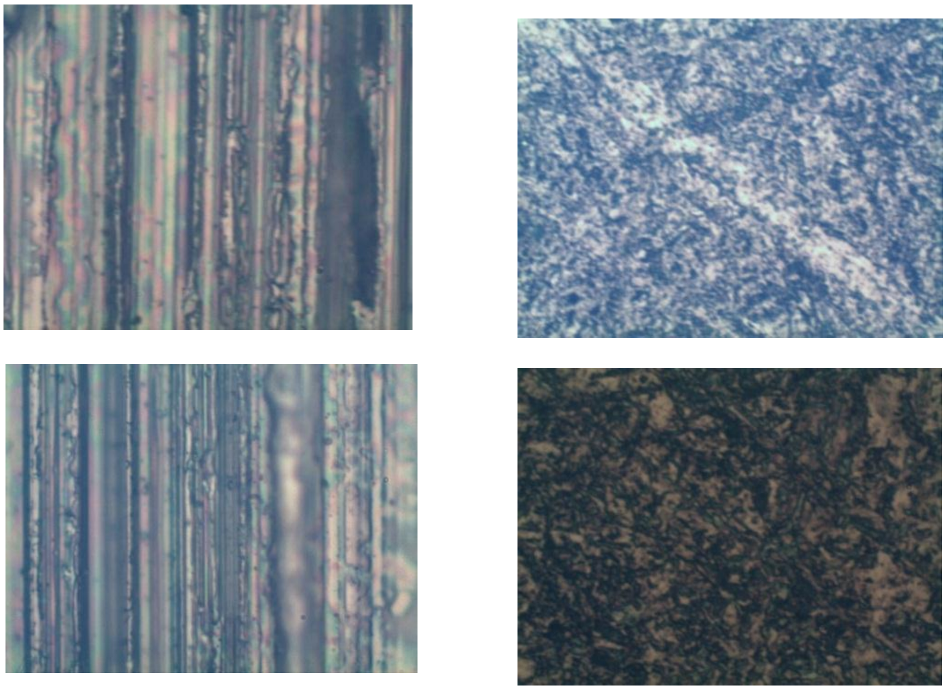


Figure 4. Examined for microstructure at 100 times magnification JIS 420 and JIS 440

The results from the Factorial Experiment analysis shown in Table 3. found that all 5 Grinding size parameters are 0.4 µm 0.8 µm 1.2 µm 1.6 µm and 2.0 µm and the Lapping Time parameters for all 9 surface finishing periods of 30, 60, 90, 120, 150, 180, 210, 240 and 270 min have influences on the average surface roughness (Ra) of the test piece for stainless steel material JIS 420 and JIS 440. The main influence of each parameter (Main Effect) and the joint influence between the parameters (Interaction) are at a 95% confidence level since the P-Value < α value or 0.01 < 0.05

Table 3. Results from factorial experiences.

Source	**DF**	**SS**	**MS**	**F-value**	**P-Value**
Model	89	11.4669	0.12884	5.27	< 0.001
Linear	13	6.2084	0.47757	19.52	< 0.001
Materials (A)	1	0.1539	0.15389	6.29	0.013
Ra-Grinding (µm) (B)	4	2.3168	0.57920	23.67	< 0.001
Time (min) (C)	8	3.7377	0.46722	19.09	< 0.001
2-Way Interactions	44	4.5297	0.10295	4.21	< 0.001
Materials*Ra-Grinding (µm)	4	0.7127	0.17818	7.28	< 0.001

Source	DF	SS	MS	F-value	P-Value
Materials*Time (min)	8	0.4386	0.05482	2.24	0.024
Ra-Grinding (μm)*Time (min)	32	3.3784	0.10557	4.31	< 0.001
3-Way Interactions	32	0.7288	0.02277	0.93	0.579
Materials*Ra-Grinding(μm)*Time (min)	32	0.7288	0.02277	0.93	0.579
Error	450	11.0117	0.02447		
Total	539	22.4785			

When considering the residual analysis, the Pareto Chart of the Standardized Effects shows the factor A is the Materials, B is the Grinding C is the Time, to fine-tune the surface. When BC, AB, AC, Lapping Time is found to be beyond critical lines, so these three factors affect the workpiece roughness after fine workmanship with a significant process of skin lapping as shown in Figure 5. When considering the results of the experiment for the Validation of experimental forms, the examination results are shown by assuming that the form of residuals obtained from the experimental data must be in accordance with the principle of Residual values and have the normal distribution from the Versus Fits graph which can check for the variance of the error values. The good data needs to have the variance of the error value must be consistent from the Versus Order graph independence in order to make the data accurate and reliable. The good data information must have characteristics of good control charts as shown in Figure 6.

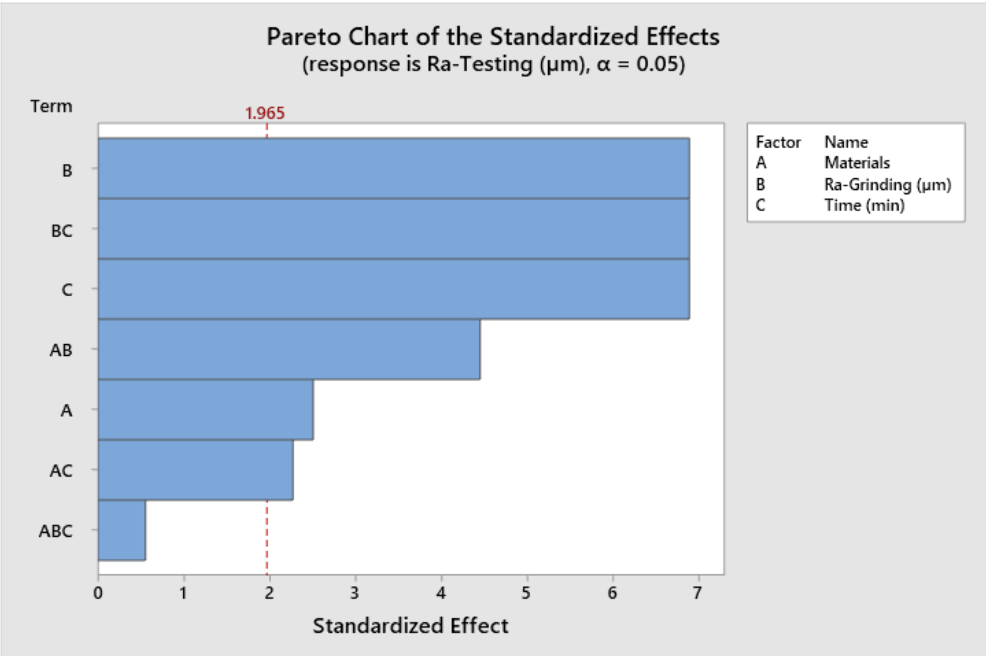


Figure 5. Pareto Chart of the Standardized Effect

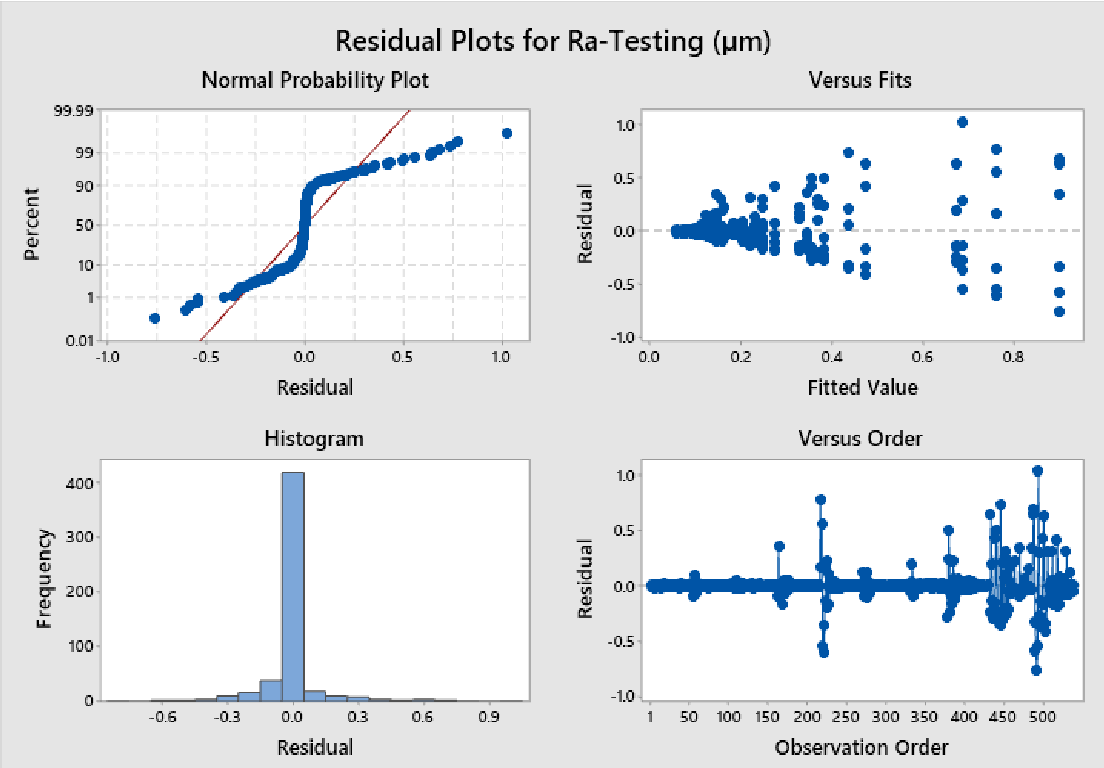


Figure 6. Residual Plots for Ra

When considering the main effect plot of each parameter shown in Figure 7. it can be seen that the graph, both the (A) is the Materials, (B) is the Grinding (C) is the Time, parameters are not parallel with the reference line in the horizontal axial. This means of these three parameters influenced the average surface roughness response (Ra) of the specimen of JIS 420 and JIS 440 stainless steel material, graph showing the mutual influence between the factors concerning Grinding and the time that affect the surface roughness value (Ra). which gave consistent results with the results from the Factorial Experiment Analysis as follows Shown in table 3. In addition, the interaction between parameters shown in Figure 8. can be seen that (A) Materials (B) Grinding and (C) Time. at a statistical confidence level of 95%, it still considered a significant result. This means the common influence between these three parameters influenced the average surface roughness response (Ra) of the specimen JIS 420 and JIS 440 stainless steel material, which gave consistent results with the results from the Factorial Experiment Analysis as follows Shown in table 3.

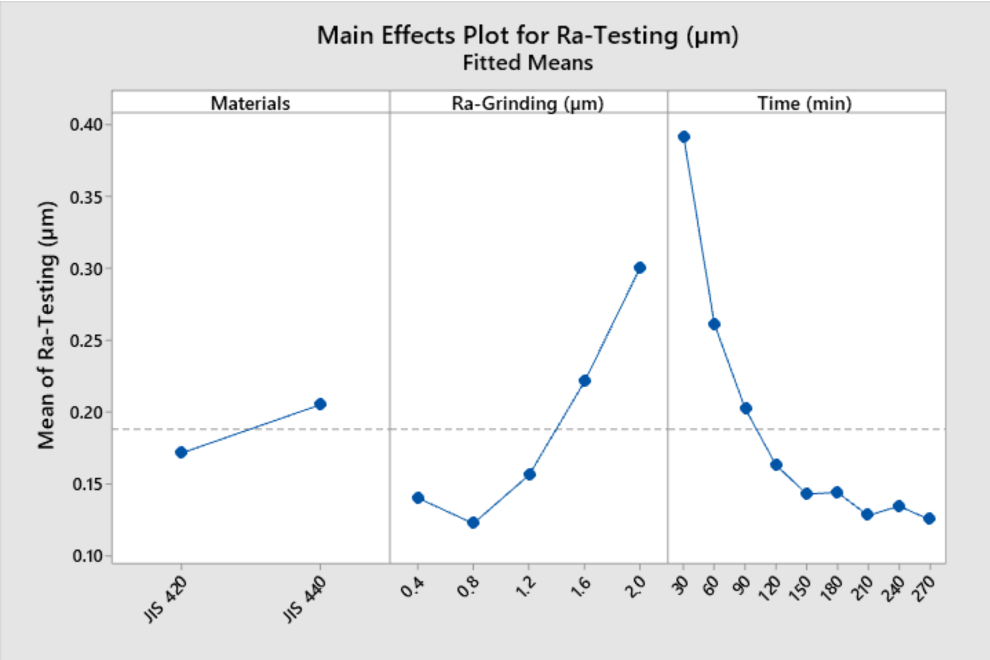


Figure 7. Main Effects Plot for Ra

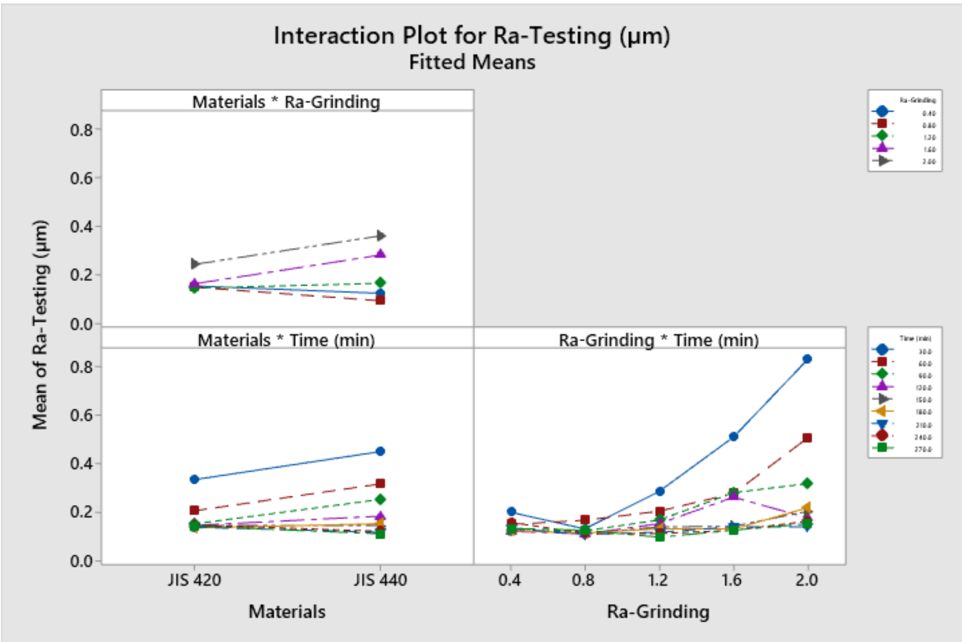


Figure 8. Interaction Plot for Ra

In determining the most suitable parameters of This means of these three parameters influenced the average surface roughness response, the (A) is the Materials, (B) is the Grinding (C) is the Time, they will result in the quality of the work surface. The stainless steel material JIS 440 is good, which indicates that the average roughness (Ra) is the smallest (Minimum), which is the most suitable condition is the size of Grinding Ra were then prepared 0.8 µm and the fineness adjustment time of 30 min will result in a Ra value of 0.0575 µm. In addition, when considering the satisfaction value (Desirability: D) regarding statistical processing found to be very high as 99.37% as shown in Figure 9.

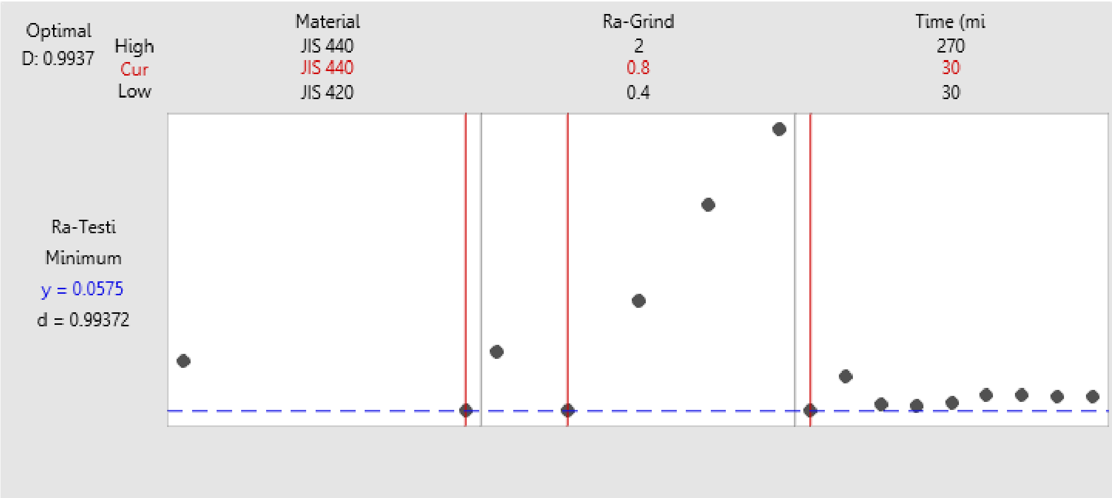


Figure 9. Response Optimization

DISCUSSION AND CONCLUSIONS

By conducting a study on the improving optimized the surface quality of stainless steel JIS 420 and JIS 440 on lapping process Factorial experiment was applied to analyse the four-alumina powder size of 0.3 µm and nine-lapping time of 30, 60, 90, 120, 150, 180, 210, 240 and 270 min, respectively which has Five surface roughness values, Ra were then prepared: 0.4 µm, 0.8 µm, 1.2 µm, 1.6 µm and 2.0 µm, respectively. in fine surface processing using the factorial design techniques, the findings are the optimum condition of this process The stainless steel material JIS 440 was the size of the Grinding Ra were then prepared 0.8 µm and the fineness adjustment time of 30 min which will result in an average surface roughness (Ra) of 0.0575 µm. Moreover, these moments of fine grained increase would result in a surface roughness average (Ra) lower as well. Due to the accumulation of metal debris that replaces the furrow of the material surface until it becomes homogeneous from heat generated in the fine surface treatment process.

ACKNOWLEDGEMENTS

The author would like to thank the laboratory, Faculty of Engineering Industrial Engineering Rajamangala University of Technology Krungthep. This facility offers the use of a lapping machine for conducting research, as well as the Minitab Version 18 software program to analyse the results. Validation of experimental forms.

REFERENCES

[1] J.L. Yuan , P. Zhao, J. Ruan, Z.X. Cao, W.H. Zhao, T. Xing. Lapping and polishing process for obtaining super-smooth surfaces of quartz crystal. Journal of Materials Processing Technology, 2003, pp. 116-119.

[2] Toshiro K. Doi, Osamu Ohnishi, Eckart Uhlmann and Arne Dethlefs. Chapter 6 - Lapping and Polishing. Handbook of Ceramics Grinding and Polishing, 2015, pp. 263-325.

[3] Ahmed Bakr Khoshaim, Zonghua Xu, Ioan D. Marinescu. Chapter 9 - ELID Grinding with Lapping Kinematics. Handbook of Ceramics Grinding and Polishing, 2015, pp. 394-448.

[4] Jeong-Du Kim and Min-Seog Choi. Stochastic approach to experimental analysis of cylindrical lapping process. Wear,170 1993, pp. 131-136.

[5] Dusit Singpommat, Somkiat Thermsuk, Unchalee Inkampa. Influence parameters the surface roughness of JIS 440 stainless steel on lapping process. International Journal of Advanced Research in Engineering and Technology, 2020, pp. 747-754.

[6] Mingsheng Jin, Liming Wang, Senbin Ye, Huan Qi, Jie Kang, Tao Hong, Zhufang Fang, Xiaoxing Dong. A novel functionally graded lapping and polishing method for the improvement of material removal uniformity. Journal of Manufacturing Processes, 2020, pp. 102-110.

[7] Jan C. Aurich, Benjamin Kirsch, Dinesh Setti, Dragos Axinte, Anthony Beaucamp, Paul Butler- Smith, Hitomi Yamaguchi. Abrasive processes for micro parts and structures. CIRP Annals -Manufacturing Technology,2019, pp. 653-676.

[8] Biao Zhao, Wenfeng Ding, Zhenzhen Chen, Changyong Yang. Pore structure design and grinding performance of porous metal-bonded CBN abrasive wheels fabricated by vacuum sintering. Journal of Manufacturing Processes, 2019, pp. 125-132.

[9] Huan Qi, Donghui Wen, Qiaoling Yuan, Li Zhang, Zhenzhen Chen. Numerical investigation on particle impact erosion in ultrasonic-assisted abrasive slurry jet micro-machining of glasses.Powder Technology, Volume 314, 1 June 2017, pp. 627-634.

[10] Yishun Wang, Bin Zou, Juncheng Wang, You Wu, Chuanzhen Huang. Effect of the progressive tool wear on surface to pography and chip formation in micro-milling of Ti–6Al–4V usingTi(C7N3)-based cermet micro-mill.Tribology International,Volume 141, January 2020, 105900.

[11] Haojun Yang, Wenfeng Ding, Yan Chen, Sylvain Laporte, Jiuhua Xu, Yucan Fu. Drilling force model for forced low frequency vibration assisted drilling of Ti-6Al-4V titanium alloy. International Journal of Machine Tools and Manufacture.Volume 146, November 2019, 103438.

[12] Yishun Wang, Bin Zou, Chuanzhen Huang. Tool wear mechanisms and micro-channels quality in micro-machining of Ti-6Al-4V alloy using the Ti(C7N3)-based cermet micro-mills.Tribology International,Volume 134, June 2019, pp. 60-76.

[13] A. P. Babichev, N. V. Mategorin, D. V. Getmanskii, P. D. Motrenko, and V. V. Nelidin, Vibrational Lapping of Cylindrical Parts, Russian Engineering Research, (2009) pp. 99–101.

[14] Kuo-Yi Chang, Yu-Hua Song and Tsann-Rong Lin, Analysis of Lapping and Polishing of a Gauge Block, Int J Adv Manuf Technol, 20,2002, pp .414–419.

[15] Toshiyuki Enomoto, Yasuhiro Tani and Kazuya Orii, Development of a Lapping Film Utilizing Agglomerative Superfine Silica Abrasives for Edge Finishing of a Silicon Wafer, Initiatives of Precision Engineering at the Beginning of a Millennium, 2001, pp. 391-395.

[16] V. F. Makarov, K. R. Muratov, and E. A. Gashev, Optimal Cutting Time and Speed in Abrasive Lapping of Ceramic, Russian Engineering Research, 2017, Vol. 37, pp. 916–918.

[17] Zhongjun Qiu, Feng Zhou Fang, Liyu Ding and Qunzhang Zhao, nvestigation of diamond cutting tool lapping system based on on-machine image measurement, Int J Adv Manuf Technol, 2011, Vol.56 pp. 79–86.

[18] Berthold Schlecht,Felix Rudolph, and Stefan Schumann, Experimental studies and simulation of hypoid gear lapping, Forsch Ingenieurwes, 2017, Vol.81 pp. 95–100.

[19] Nannan Zhu, Fangzhi Zheng, Yongwei Zhu, Sheng Xu, and Dunwen Zuo, Research of abrasive embedment-free lapping on soft-brittle lithium niobate wafer, Int J Adv Manuf Technol, 2016, Vol.87 pp. 1951–1956.

[20] Y. Choopani, M. R. Razfar, P. Saraeian, and M. Farahnakian, Experimental investigation of external surface finishing of AISI 440C stainless steel cylinders using the magnetic abrasive finishing process, Int J Adv Manuf Technol, 2016, Vol.83 pp. 1811–182.