Comparison of Alumina Powder Behavior on Surface Roughness using the Surface Lapping Technique for JIS 420 and JIS 440 Stainless Steel Materials

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ABSTRACT

The current research compared the behavior of alumina powders on the surface roughness of stainless steel materials, JIS 420, and JIS 440 using the surface lapping technique. The study employed the Design of Experiments (DeE) approach and specifically a factorial experiment, to analyze the impact of four different sizes of alumina powder, i.e. 0.05, 0.30, 1.00, and 3.00 µm, and nine different lapping times, i.e. 30, 60, 90, 120, 150, 180, 210, 240, and 270 min, on multiple responses, including weight loss and Average Surface Roughness (Ra) values along the x and y axes. These responses were explored to assess the surface quality of JIS 420 and JIS 440 during the lapping process. To prepare the specimen conditions for the surface roughness experiments, 200 g of alumina powder, 150 ml of alumina powder lubricant, and 1 lt of water were used. Finally, the statistical analysis resulted in the optimization of the lowest multi-response values, such as an Ra value of 0.0630 µm on the x-axis and an Ra value of 0.0688 on the y-axis. For the JIS 440, the optimal conditions were determined to be 1 µm alumina powder and a lapping time of 30 min. These statistical analyses demonstrated a high level of satisfaction (desirability), with a value as high as 90.25% during the statistical processing phase.

Keywords-lapping process; alumina powder; surface roughness; factorial experiment

I. INTRODUCTION

The efficacy of lapping processes hinges upon many input parameters, with machining speed, pressure, and duration of contact among the lap plate, abrasive paste, and workpiece standing out as pivotal factors. In the contemporary manufacturing landscape, quality emerges as a matter of paramount concern, wielding significant influence over customer satisfaction. Whether within the confines of small-scale enterprises or the expansive reaches of the aerospace sector, surface quality stands as a defining metric, with surface roughness serving as the primary gauge [1-3]. In the pursuit of top-tier quality alumina, lapping processes operate as indispensable tools, facilitating plane lapping and polishing procedures. These techniques enjoy widespread adoption owing to their ability to yield meticulous and refined abrasive finishing [4-5]. The automotive, sanitary, furniture, and electronic industries are currently witnessing substantial growth and expansion. This surge underscores the necessity for comprehensive research and analysis of functional surfaces, especially those demanding exceptionally high surface roughness, to elevate product value and optimize outcomes. Among the arsenal of methods employed to refine industrial surfaces, polishing emerges as a key player, with lapping standing out as a technique offering precise control over workpiece surfaces through either material removal or polishing [6, 7]. Lapping and polishing procedures hinge primarily on the interaction of sliding friction between particles and the workpiece's surface. In these processes, a lap or polishing pad (commonly referred to as a polisher) traverses the surface of the workpiece, propelling slurry particles akin to sand or mud against the contacting surface. This interplay of sliding friction plays a pivotal role in material removal and surface refinement, ultimately culminating in the desired surface finish [8, 9]. Lapping indeed offers notable advantages, including high efficiency, adaptability, precision, and minimal surface damage, which have led to its widespread adoption for the creation of both flat and intricate surfaces. In comparison to conventional machining methods, such as cutting, milling, and drilling that rely on geometric tools, lapping showcases significantly enhanced capabilities. Its efficiency and versatility position lapping as the preferred method for achieving meticulous surface textures across various industrial applications [10-12]. In the realm of surface refinement, lapping emerges as a cornerstone technique, particularly crucial for devices reliant on alumina base layers. Utilizing solid abrasives affixed on a lapping disc, lapping becomes a specialized tool for high-speed machines, affording precise control over surface finishing. In the pursuit of high-precision technologies associated with surface polishing, accurate measurement is substantial for evaluating and supervising surface quality, ensuring alignment with specifications and tolerances [13-16]. Thorough consideration of the surface polishing process is shaped by numerous factors, which are typically identified through experimentation. These factors exhibit variability and encompass parameters, such as the choice of abrasive materials, formulation of abrasive paste or slurry, applied pressure, scrubbing duration, and inherent characteristics of the workpiece material [18]. Achieving the desired quality and precision of surface shape in the lapping process often demands specialized shaping methods. These methods necessitate continuous experimentation for optimal effectiveness to be ensured. Through systematic exploration of various shaping techniques, such as precise control of lapping pressure, manipulation of relative motion between the lap and workpiece, or adjustment of abrasive slurry composition, manufacturers can enhance surface shape to meet precise specifications [17, 10-20]. Statistical Analysis of Variance (ANOVA) serves as a valuable tool for fine-tuning and optimizing the lapping process. Researchers can statistically analyze the effects of different factors on the process and determine their significance using this approach [21, 22]. This analysis aids in identifying the factors that exert the most substantial influence on surface roughness, thereby facilitating appropriate adjustments. By pinpointing key variables and their impact, manufacturers can refine their lapping processes with precision, ultimately enhancing surface quality and meeting stringent specifications. [24-26]. The objective of the present study was to compare the behavior of alumina powder concerning surface roughness following a surface lapping technique on JIS 420 and JIS 440 stainless steel materials. The research focused on evaluating the impact of four different alumina abrasives on the Ra of JIS 420 and JIS 440 materials during the polishing process. To achieve this objective, the study employed the principles of DoE for a comprehensive and statistical analysis of various process parameters. The primary aim was to ascertain the statistical significance of these parameters. The results of this research offer a detailed understanding of the distinctions between the lapping of JIS 420 and JIS 440 as well as the relationship between the type of alumina abrasive and surface roughness in these materials. By systematically exploring these variables and employing statistical analysis techniques, the study provides valuable insights that can inform and optimize the lapping process for these specific materials, ultimately enhancing surface quality and meeting the desired specifications.

II. EXPERIMENTAL PROCEDURE

Stainless steel shares similarities with the Ferritic stainless steel, but has a higher carbon content, belongs to a group of materials that can be hardened. Following hardening, the microstructure of stainless steel is transformed into a martensitic structure. While appreciated for its strength, its resistance to rust is typically moderate due to its higher carbon content. The higher the carbon content is, the lower the corrosion resistance. However, it remains resistant to corrosion in mildly corrosive or neutral solutions. Common applications of this material include bearings, shafts, gears, springs, and other components requiring both strength and moderate corrosion resistance. Stainless steel Grade 420 has a chemical composition consisting of approximately 0.15% - 0.40% carbon, 12% - 14% chromium, with small amounts of silicon, manganese, phosphorus, and sulfur. On the other hand, stainless steel grade 440 has a chemical composition, including approximately 0.65% - 0.75% carbon, 16% - 18% chromium, with additional molybdenum, and similar trace elements. The specific composition of stainless steel materials, such as JIS 420 and JIS 440, may vary depending on the intended application, while small amounts of other alloys like silicon and carbon may be added. These materials exhibit diverse properties, which makes them suitable for various industries. They possess good strength and formability, allowing for efficient shaping and fabrication. Additionally, they demonstrate excellent corrosion resistance. Their malleable characteristics render stainless steel materials ideal for machining tasks requiring precision components or the fabrication of intricate shapes. In such applications, an aluminum oxide grinding wheel, particularly a white stone-type grinding stone crafted from aluminum oxide, is commonly used. The grinding stone typically has dimensions of 205 × 19 × 31.75 mm, with its grit size being identified as WA60JV, indicating precise abrasive particle dimensions. Figure 1 presents the equipment and materials utilized in the outlined preparation process, offering a clear illustration of the sequential steps involved in the procedure.

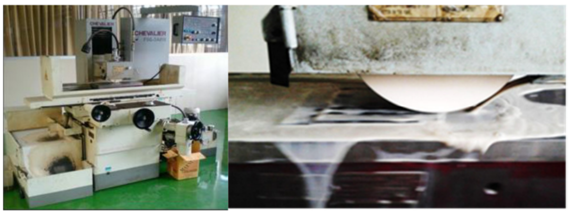

Fig. 1. The grinding machine of flat surface machining.

During the experimental phase, the fine polishing process commences with the meticulous blending of precise quantities of alumina powder (200 g), alumina powder lubricant (150 ml), and water (1 lt) for the desired ratio to be obtained. This intricately calibrated mixture plays a key role in achieving Ra values. The formulation of this blend is intricately managed to ensure the uniformity and reproducibility of results. Subsequently, the carefully prepared specimens of the JIS 420 and JIS 440 materials, characterized as flat bars with dimensions of 35 × 35 × 5 mm and having undergone the initial grinding process, are enlisted for the experimental procedure. These meticulously crafted specimens act as the subjects of evaluation for the fine polishing process. In the context of the experiment, a sample test is conducted on the surface of a lapping plate. Figure 2 elucidates the experimental setup, illustrating the configuration and arrangement of the components, and thus the placement of JIS 420 and JIS 440 specimens on the surface of a lapping plate, with the fine polishing process mixture being evenly applied across the surfaces. Following the setup, the fine polishing process was executed with time intervals of 30, 60, 90, 120, 150,180, 210, 240, and 270 min. Each interval represents a distinct duration for the fine finishing process. The purpose behind varying these time intervals is to investigate how they affect the Ra value of the specimens. By employing different time durations in the experiment, we sought to unveil the relationship between the duration of the fine polishing process and the resultant surface quality, gaining a deeper understanding of the ideal time required to achieve the specific surface roughness targets. The surface roughness value is measured using a microscope (3D Measuring Laser Microscope, Model OLS5000) in 4 sets. Each piece undergoes measurement at 5 points. The measurement procedure involves taking the piece and utilizing a magnification power of 20 times in front of the lens. The surface roughness value was then measured at specific points: the Top Right angle (TR) and the Bottom Right angle (BR) of the workpiece along the x and y axis, the Top Left angle (TL) and Bottom-Left angle (BL) of the workpiece along the x and y axis, and the Center Point (C) of the workpiece along the x and y axis, as evidenced in Figure 3. This visual representation not only summarizes the findings, but also aids in comprehending the link between the duration of the fine polishing process and the resulting surface roughness of the specimens. The gathered data provide insights into how the duration of the fine finishing process influences the quality of the resulting surface.

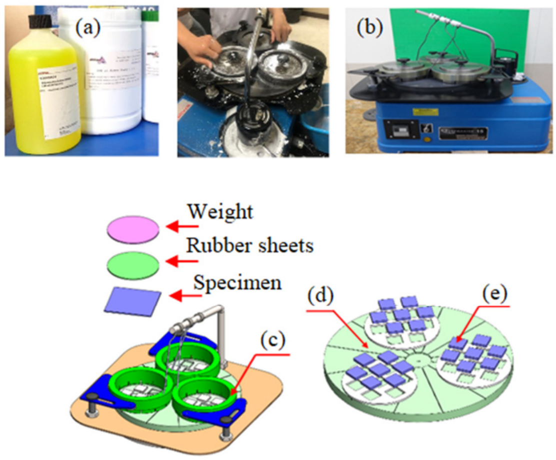

Fig. 2. (a) Alumina (Al_2O_3), (b) lapping machine, (c) conditioning rings, (d) polishing plate, (e) specimen.

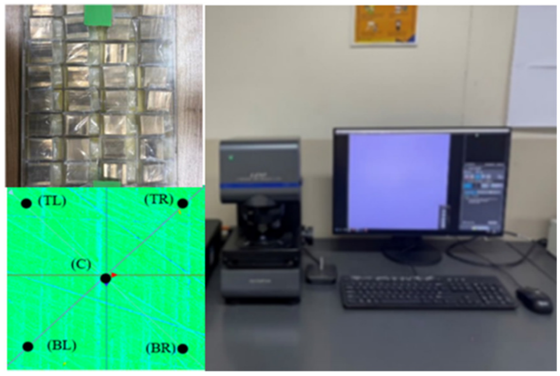

Fig. 3. 3D measuring laser microscope model OLS5000.

III. RESULTS

The ANOVA results exhibit that both the main effect term and the interaction term of the multiple responses were statistically significant at a 95% confidence level. This suggests that the factors being investigated, i.e. the time intervals in the fine polishing process, have a substantial influence on the measured outcomes. The Pareto chart further corroborated these findings, as all bars exceeded the critical reference line of the P-value statistic at a 95% confidence level, underscoring their significance in the experimental results. The experiment revolved around adjusting the time intervals in the fine polishing process to gather Ra value data from JIS 420 and JIS 440 specimens on the surface of a lapping plate. Time intervals of 30, 60, 90, 120, 150, 180, 210, 240, and 270 min were selected for data collection, with increments of 30 min. These specific time intervals were selected to examine the effect of different durations on surface roughness. The collected data were then analyzed to establish the connection between the time interval and surface roughness. The primary response variable was the optimal Ra value. All of these factors were incorporated as a part of the factorial experiment. These response variables were thoroughly investigated to assess the impact of time on the surface quality of material JIS 420 and JIS 440 specimens during the polishing process. The experimental data are presented in Tables I-IV, offering valuable insights into how varying time intervals affect the surface roughness characteristics of the test specimens.

TABLE I. SURFACE ROUGHNESS DATA (Ra) JIS 420 FOR STATISTICAL ANALYSIS (X-AXIS)

Al_2O_3	**Lapping Time (min)**								
(μm)	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**
0.05	0.078	0.130	0.146	0.113	0.110	0.146	0.194	0.212	0.121
0.05	0.093	0.127	0.139	0.110	0.115	0.125	0.206	0.198	0.137
0.05	0.141	0.129	0.221	0.139	0.137	0.174	0.159	0.112	0.141
0.05	0.161	0.131	0.211	0.134	0.136	0.115	0.210	0.086	0.134
0.05	0.080	0.112	0.152	0.110	0.127	0.125	0.191	0.098	0.137
0.30	0.199	0.090	0.215	0.133	0.132	0.134	0.194	0.076	0.075
0.30	0.107	0.083	0.271	0.108	0.089	0.164	0.155	0.061	0.068
0.30	0.107	0.099	0.216	0.051	0.102	0.133	0.128	0.205	0.035
0.30	0.099	0.090	0.220	0.051	0.120	0.127	0.128	0.136	0.165
0.30	0.090	0.099	0.245	0.049	0.158	0.131	0.101	0.169	0.148
1.00	0.084	0.089	0.074	0.098	0.096	0.113	0.178	0.109	0.134
1.00	0.082	0.078	0.103	0.093	0.132	0.083	0.084	0.192	0.110
1.00	0.077	0.127	0.073	0.094	0.071	0.087	0.072	0.110	0.146
1.00	0.077	0.113	0.130	0.105	0.142	0.094	0.052	0.106	0.143
1.00	0.079	0.076	0.105	0.093	0.243	0.095	0.103	0.088	0.140
3.00	0.109	0.146	0.111	0.162	0.190	0.187	0.143	0.160	0.123
3.00	0.107	0.112	0.091	0.131	0.217	0.157	0.161	0.092	0.134
3.00	0.168	0.145	0.092	0.153	0.128	0.216	0.196	0.180	0.154
3.00	0.102	0.162	0.095	0.131	0.199	0.116	0.162	0.094	0.130
3.00	0.107	0.273	0.112	0.137	0.218	0.131	0.146	0.072	0.132

TABLE II. SURFACE ROUGHNESS DATA (Ra) JIS 420 FOR STATISTICAL ANALYSIS (Y-AXIS)

Al_2O_3	**Lapping Time (min)**								
(μm)	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**
0.05	0.091	0.124	0.116	0.102	0.131	0.151	0.151	0.217	0.118
0.05	0.104	0.115	0.130	0.134	0.128	0.166	0.151	0.162	0.159
0.05	0.132	0.123	0.218	0.137	0.133	0.152	0.171	0.055	0.128
0.05	0.156	0.136	0.199	0.131	0.158	0.114	0.182	0.061	0.137
0.05	0.086	0.111	0.188	0.104	0.144	0.167	0.185	0.086	0.144
0.30	0.157	0.092	0.219	0.097	0.097	0.124	0.168	0.060	0.083
0.30	0.106	0.079	0.224	0.086	0.109	0.178	0.153	0.070	0.081
0.30	0.117	0.068	0.220	0.053	0.096	0.144	0.109	0.185	0.054
0.30	0.102	0.068	0.237	0.040	0.107	0.146	0.136	0.114	0.176
0.30	0.122	0.077	0.218	0.059	0.175	0.158	0.116	0.160	0.148
1.00	0.067	0.097	0.072	0.093	0.137	0.090	0.128	0.097	0.150
1.00	0.081	0.120	0.092	0.087	0.135	0.084	0.136	0.175	0.162
1.00	0.080	0.134	0.092	0.088	0.092	0.078	0.085	0.084	0.156
1.00	0.059	0.091	0.125	0.064	0.159	0.089	0.103	0.118	0.133
1.00	0.067	0.063	0.094	0.061	0.209	0.097	0.087	0.075	0.113
3.00	0.133	0.172	0.103	0.146	0.170	0.152	0.132	0.166	0.144
3.00	0.123	0.126	0.080	0.129	0.194	0.132	0.193	0.160	0.164
3.00	0.114	0.130	0.097	0.140	0.166	0.234	0.168	0.169	0.130
3.00	0.121	0.117	0.121	0.109	0.166	0.178	0.154	0.131	0.136
3.00	0.125	0.233	0.125	0.112	0.190	0.163	0.197	0.143	0.139

TABLE III. SURFACE ROUGHNESS DATA (Ra) JIS 440 FOR STATISTICAL ANALYSIS (X-AXIS)

Al_2O_3	**Lapping Time (min)**								
μm	30	60	90	120	150	180	210	240	270
0.05	0.074	0.089	0.236	0.064	0.228	0.107	0.239	0.116	0.146
0.05	0.087	0.089	0.213	0.222	0.152	0.072	0.195	0.147	0.200
0.05	0.095	0.212	0.217	0.139	0.135	0.078	0.176	0.154	0.160
0.05	0.098	0.115	0.200	0.235	0.161	0.081	0.222	0.144	0.229
0.05	0.093	0.152	0.250	0.202	0.094	0.129	0.152	0.091	0.118
0.30	0.079	0.084	0.135	0.131	0.133	0.071	0.081	0.063	0.135
0.30	0.143	0.108	0.194	0.191	0.088	0.050	0.115	0.134	0.077
0.30	0.103	0.082	0.101	0.201	0.111	0.100	0.074	0.168	0.083
0.30	0.049	0.044	0.100	0.108	0.115	0.124	0.073	0.111	0.099
0.30	0.036	0.046	0.096	0.138	0.130	0.091	0.138	0.098	0.086
1.00	0.063	0.111	0.118	0.115	0.242	0.051	0.198	0.122	0.112
1.00	0.073	0.128	0.324	0.099	0.155	0.071	0.214	0.057	0.140
1.00	0.057	0.091	0.188	0.071	0.136	0.188	0.189	0.112	0.085
1.00	0.061	0.113	0.084	0.067	0.158	0.141	0.331	0.104	0.118
1.00	0.061	0.126	0.132	0.086	0.188	0.095	0.259	0.128	0.099
3.00	0.070	0.085	0.127	0.092	0.152	0.092	0.119	0.116	0.113
3.00	0.102	0.101	0.079	0.106	0.057	0.150	0.092	0.139	0.100
3.00	0.058	0.096	0.079	0.105	0.079	0.080	0.114	0.104	0.092
3.00	0.070	0.068	0.144	0.111	0.091	0.111	0.118	0.093	0.101
3.00	0.061	0.054	0.100	0.063	0.096	0.103	0.103	0.096	0.105

TABLE IV. SURFACE ROUGHNESS DATA (Ra) JIS 440 FOR STATISTICAL ANALYSIS (Y-AXIS)

Al_2O_3	**Lapping Time (min)**								
μm	30	60	90	120	150	180	210	240	270
0.05	0.094	0.097	0.189	0.068	0.216	0.132	0.215	0.115	0.184
0.05	0.075	0.096	0.188	0.200	0.176	0.067	0.221	0.140	0.185
0.05	0.092	0.182	0.188	0.196	0.124	0.062	0.218	0.149	0.181
0.05	0.086	0.128	0.158	0.207	0.177	0.064	0.201	0.132	0.190
0.05	0.078	0.136	0.327	0.181	0.100	0.116	0.138	0.116	0.156
0.30	0.071	0.089	0.103	0.138	0.108	0.076	0.070	0.047	0.149
0.30	0.131	0.094	0.176	0.217	0.090	0.052	0.090	0.134	0.077
0.30	0.104	0.105	0.126	0.158	0.110	0.067	0.093	0.151	0.086
0.30	0.041	0.049	0.125	0.121	0.124	0.158	0.086	0.137	0.095
0.30	0.041	0.041	0.075	0.134	0.157	0.074	0.133	0.064	0.073
1.00	0.070	0.092	0.108	0.103	0.218	0.070	0.238	0.116	0.114
1.00	0.076	0.106	0.174	0.088	0.127	0.102	0.259	0.110	0.126
1.00	0.078	0.082	0.161	0.073	0.120	0.144	0.216	0.159	0.083
1.00	0.069	0.102	0.085	0.055	0.178	0.119	0.274	0.101	0.101
1.00	0.051	0.118	0.125	0.076	0.175	0.105	0.236	0.125	0.093
3.00	0.082	0.080	0.135	0.098	0.159	0.093	0.109	0.123	0.092
3.00	0.121	0.086	0.088	0.127	0.080	0.126	0.093	0.156	0.069
3.00	0.056	0.097	0.090	0.094	0.093	0.073	0.092	0.130	0.080
3.00	0.071	0.063	0.130	0.102	0.082	0.085	0.107	0.090	0.074
3.00	0.059	0.059	0.102	0.080	0.100	0.091	0.099	0.148	0.078

The results of the factorial experimental analysis, as exhibited in Tables V and VI, clearly demonstrate that several factors have a significant influence on the Ra value of the test JIS 420 and JIS 440 specimens. These include: (A) the material and (B) the alumina size which entails four different values: 0.05 μm, 0.30 μm, 1.00 μm, and 3.00 μm, and (C) polishing time (C), corresponding to 330, 60, 90, 120, 150,180, 210, 240, and 270 min. The analysis considered both the main effect of each parameter, representing its individual impact on surface roughness, and the interaction between parameters, signifying their combined influence. The statistical analysis was conducted at a 95% confidence level, with the results disclosing the substantial influence of each parameter and that of their interactions. The fact that the P-Value was less than 0.05 confirms the statistical significance at a 95% confidence level. These significant findings underscore the critical importance of considering multiple factors when determining the resulting surface roughness of the JIS 420 and JIS 440 test pieces. Not only do the size of the alumina particles and the duration of the lapping process play pivotal roles, but the type of lapping plate employed also significantly influences the surface roughness outcomes. It is evident that optimizing these parameters is essential for achieving the desired surface quality. Therefore, a comprehensive understanding and careful control of these variables can lead to more precise and consistent results in the lapping process.

TABLE V. RESULTS FROM FACTORIAL EXPERIENCES Ra (X-AXIS)

Source	DF	SS	MS	F-value	p-value
Model	71	0.51395	0.00723	5.80	< 0.001
Linear	12	0.18998	0.01583	12.68	< 0.001
Materials (A)	1	0.00661	0.00661	5.30	0.022
Alumina Powder (B)	3	0.05098	0.01699	13.61	< 0.001
Lapping Time (C)	8	0.13239	0.01654	13.25	< 0.001
2-Way Interactions	35	0.20174	0.00576	4.62	< 0.001
Materials*Alumina Powder	3	0.07022	0.02340	18.74	< 0.001
Materials*Lapping Time	8	0.02567	0.00320	2.57	0.010
Alumina Powder* Lapping Time	24	0.10584	0.00441	3.53	< 0.001
3-Way Interactions	24	0.12222	0.00509	4.08	< 0.001
Materials* Alumina Powder* Lapping Time	24	0.12222	0.00509	4.08	< 0.001
Error	288	0.35967	0.00124	-	-
Total	359	0.87362	0.00723	-	-

TABLE VI. RESULTS FROM FACTORIAL EXPERIENCES Ra (Y-AXIS)

Source	DF	SS	MS	F-value	p-value
Model	71	0.51618	0.00727	8.08	< 0.001
Linear	12	0.18617	0.01551	17.24	< 0.001
Materials (A)	1	0.00878	0.00878	9.76	0.002
Alumina Powder (B)	3	0.05291	0.01763	19.60	< 0.001
Lapping Time (C)	8	0.12448	0.01556	17.29	< 0.001
2-Way Interactions	35	0.22299	0.00637	7.08	< 0.001
Materials*Alumina Powder	3	0.07165	0.02388	26.54	< 0.001
Materials*Lapping Time	8	0.03885	0.00485	5.40	< 0.001
Alumina Powder* Lapping Time	24	0.11248	0.00468	5.21	< 0.001
3-Way Interactions	24	0.10700	0.00445	4.95	< 0.001
Materials* Alumina Powder* Lapping Time	24	0.10700	0.00445	4.95	< 0.001
Error	288	0.25920	0.00090	-	-
Total	359	0.77538		-	-

When factorial experiments were conducted, the analysis performed, particularly with the employment of the pareto chart of the standardized effects, provided crucial insights. By analyzing the pareto chart, it becomes evident that the interaction term ABC, which represents the combined influence of alumina powder, lapping time, and lapping plate type, exceeds the critical lines. This observation highlights that all three factors have a significant impact on workpiece roughness following the fine lapping process. The presence of the ABC interaction term beyond the critical lines indicates that the combined effects of alumina powder, lapping time, and lapping plate type play a crucial role in determining the quality of the workpiece surface. This interaction suggests that these factors can work together, either synergistically or antagonistically, influencing the outcome of the fine lapping process. The significance of these factors and their interactions is revealed in Figures 4 and 5, which depict the pareto chart of the standardized effects. This graphical representation offers a clear illustration of how factors A, B, and C influence workpiece surface roughness and how their interactions contribute to the overall outcome. It is vital for manufacturers and researchers to comprehend the influence of these factors as well as their interactions to be able to optimize the fine lapping process. This knowledge empowers them to make informed decisions regarding the optimal selection of alumina powder, lapping time, and lapping plate type to achieve the desired workpiece surface roughness. By understanding the intricate relationships between these variables, practitioners can tailor their lapping processes to meet specific surface quality requirements. This ensures not only the efficiency and effectiveness of the manufacturing process, but also the consistency and reliability of the finished products. Furthermore, the ability to control these parameters with precision allows for greater flexibility in adapting to different material types and application needs.

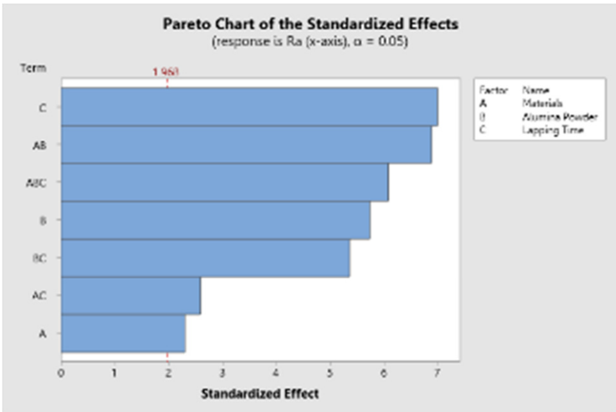

Fig. 4. Pareto chart of (x-axis).

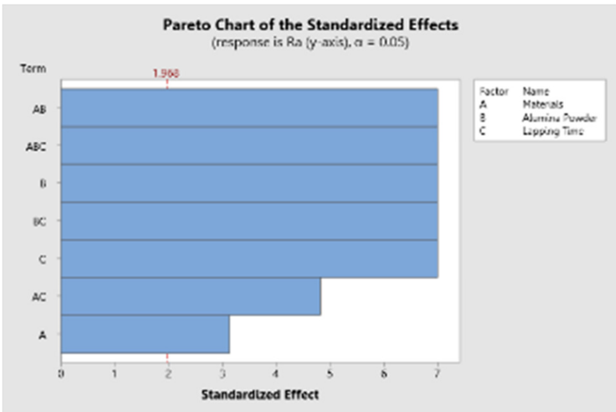

Fig. 5. Pareto chart of (y-axis).

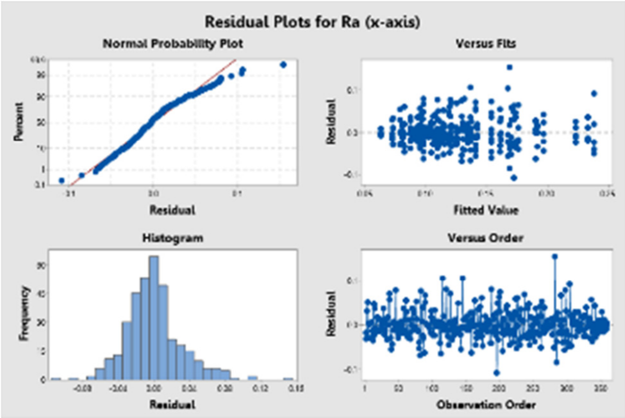

Fig. 6. Residual plots (x-axis).

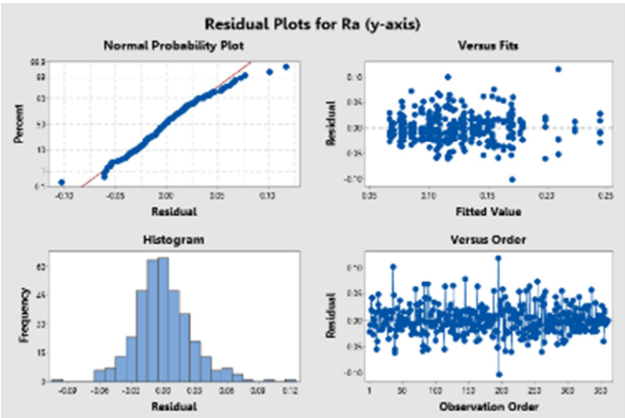

Fig. 7. Residual plots (y-axis).

Residual analysis involves checking the normality of the residuals' distribution through a normal probability plot. In good data, the residuals should conform to a normal distribution. To assess the constancy of residual variance, a versus fits graph is employed. In good data, the residuals' variability should exhibit relative consistency. Additionally, the independence of residuals is examined using a versus order graph. In good data, this plot should display a random scatter without discernible patterns. Control charts are essential tools in statistical process control, frequently deployed to monitor and analyze processes over time. By visually representing the criteria and assumptions in Figures 6 and 7, these charts exhibit the characteristics of effective control charts. They assist in interpreting experimental results more effectively. The main effect graphs (Figures 8 and 9) portray the primary influence of each variable on the resulting value and provides the most relevant results. This observation stresses the influence of these three parameters on the Ra response of JIS 420 and JIS 440 test specimens. These results are in accordance with the conclusions drawn from the factorial experimental analysis. As explained in Tables V and VI, upon a closer examination of the parameters, the interaction plot of Ra values, depicted in Figures 10 and 11, reveals a distinct pattern between the materials (parameter A) and the alumina size (parameter B). The interaction plot of Ra values manifests the combined influence of these variables. The characteristics of the graph show intersecting directions, indicating mutual influence. Even with a statistical confidence level of 95%, this difference remains statistically significant. Therefore, it can be deduced that the combined influence of these three parameters substantially affects the Ra response of JIS 420 and JIS 440 specimens, in line with the results obtained from the experimental analysis.

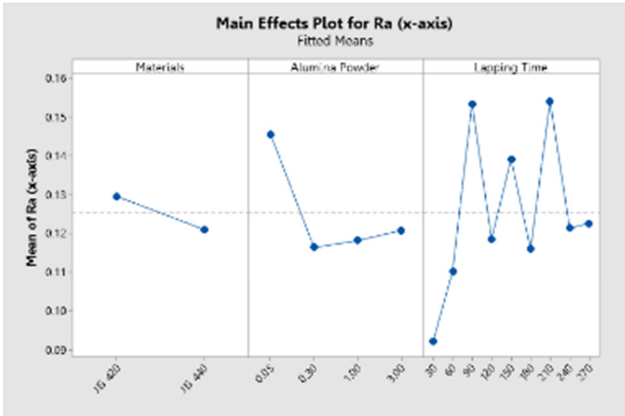

Fig. 8. Main effects (x-axis).

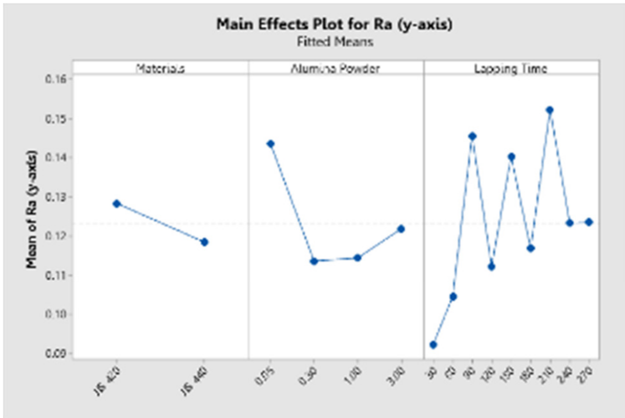

Fig. 9. Main effects (y-axis).

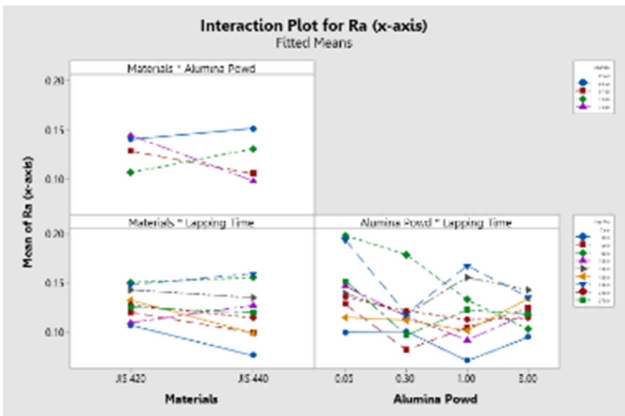

Fig. 10. Interaction plot (x-axis).

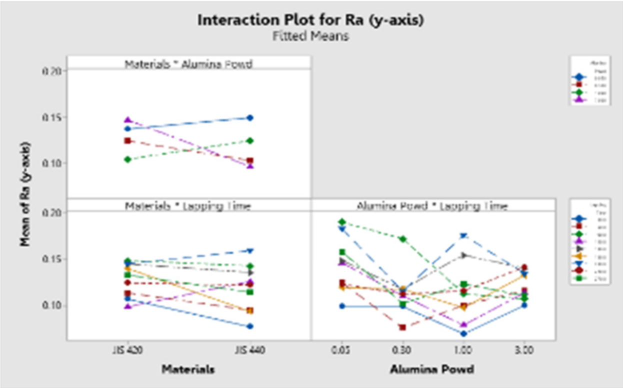

Fig. 11. Interaction plot (y-axis).

It is worth noting that the superior quality of the JIS 440 material exhibits the most favorable Ra, signifying the lowest Ra achieved. After conducting a comprehensive analysis, it was determined that the JIS 440 is the preferred choice. The optimal conditions involved using alumina polishing powder with a size of 1.0 µm and a fine-tuning time of 30 min. Additionally, the satisfaction level for Ra on the x-axis was evaluated at 90.54%. This corresponds to achieving an Ra value with a measurement resolution on the x-axis of 0.0630 µm. Similarly, the satisfaction level for the Ra value on the y-axis reached 89.96%, resulting in the lowest Ra value on the y-axis, which measured 0.0688 µm. These findings can be seen in Figure 12.

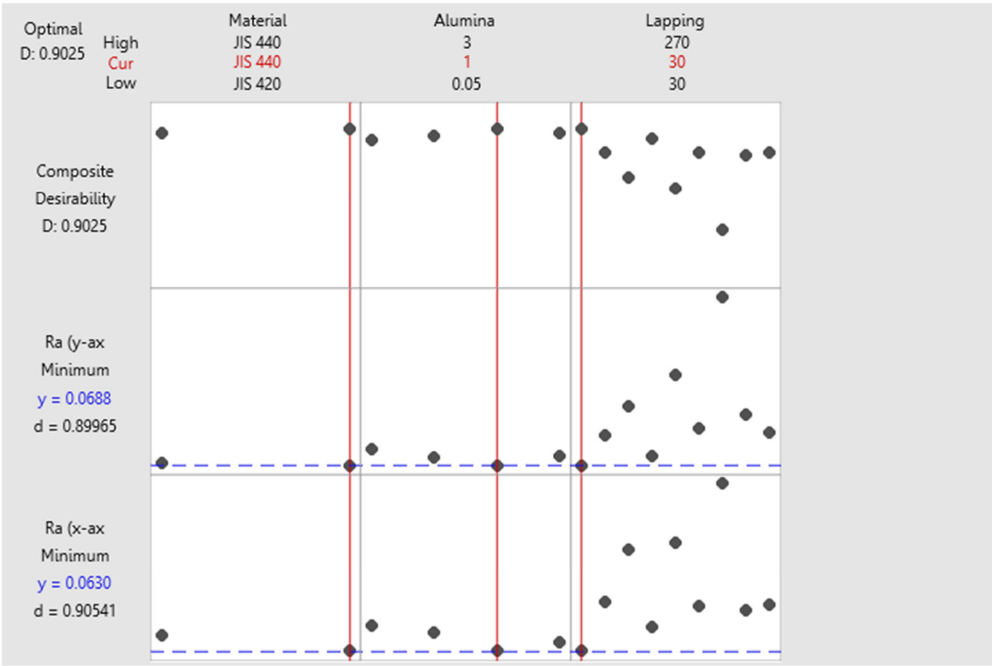

Fig. 12. Response optimization.

IV. CONCLUSIONS

The lapping process is widely recognized as a precise machining technique that provides various benefits in achieving exceptional flatness and surface finish. Although it does come with certain limitations, continuous advancements in material engineering and technology play a crucial role in overcoming these constraints. These advancements play an essential part in enhancing the overall efficiency and effectiveness of the lapping process. The purpose of the current research was to compare the influence of alumina powder on surface roughness by employing a surface refinement technique on samples of the JIS 420 and JIS 440 materials. To achieve this goal, a Design of Experiments (DoE) approach and particularly a factorial experiment was designed and conducted with the intention of analyzing the influence of three crucial factors: materials, the size of alumina powder, and lapping time. The study involved four distinct alumina powder sizes: 0.05 µm, 0.30 µm, 1.00 µm, and 3.00 µm. Furthermore, it examined nine different lapping times: 30, 60, 90, 120, 150, 180, 210, 240, and 270 min. The investigation's findings provided valuable insights into the influence of alumina powder on surface roughness and the resulting surface quality when using a surface refinement technique on JIS 420 and JIS 440. The selection of the JIS 440 as the preferred choice was a result of this analysis. The outcome of the analysis revealed the following average surface roughness (Ra) values: Ra of 0.0630 µm on the x-axis and Ra of 0.0688 µm on the y-axis. The research determined that the optimal alumina powder size was 1.0 µm, and the appropriate lapping time was 30 min. The statistical analysis conducted in this research showed a high level of contentment, as evidenced by the desirability value (D), which reached a substantial 90.25%. The outcomes of this research carry significant practical implications for industries and professionals involved in surface refinement procedures, particularly when working with the JIS 440 material. Implementing the precise parameters proposed from the results of this study, i.e. an optimal alumina powder size of 1.0 µm and a lapping time of 30 min, has the potential to result in improved surface finishes in the production of JIS 440 components.

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