**Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 57 Issue: 04:2024
DOI: 10.5281/zenodo.11059414**

INFLUENCE OF ALUMINA POWDER ON SURFACE QUALITY IN LAPPING PROCESS ON THE C3604 BRASS MATERIAL UTILIZING FACTORIAL EXPERIMENTAL DESIGN AND ANALYSIS

SOMKIAT THERMSUK
Department of Industrial Technical Education, Faculty of Technical Education, Rajamangala University of Technology Isan Khonkaen Campus, Thailand, 150 Srichan Rd., Muang, KhonKaen, Thailand.

WIROJ THASANA
Department of Mechanical Engineering, Faculty of Agriculture and Technology, Rajamangala University of Technology Isan Surin Campus, Thailand, 145 Surin-Prasat Rd., Nokmuang, Muang, Surin, Thailand.

PRAMOT SRINOI
Department of Industrial Engineering, Faculty of Engineering, Kasem Bundit University Rom Klao Campus, Thailand, 60 Rom Klao Rd., Min Buri, Bangkok, Thailand.

PICHAI JANMANEE
Department of Industrial Engineering, Faculty of Engineering, Rajamangala University of Technology Krungthep, Thailand, 2 Nang Linchi Rd., Tung Maha Mek, Satorn, Bangkok, Thailand.

SUWIT THAMMASANG *
Department of Industrial Technical Education, Faculty of Technical Education, Rajamangala University of Technology Isan Khonkaen Campus, Thailand, 150 Srichan Rd., Muang, KhonKaen, Thailand.
*Corresponding Author E-mail: suwit.tu@rmuti.ac.th

Abstract

The research undertaken delves deeply into engineering exploration of surface lapping, primarily focusing on statistically analyzing the hardness via ANOVA. This research was studied the Influence of Alumina Powder on Surface Quality in Lapping Process on the C3604 Brass Material Utilizing Factorial Experimental Design and Analysis. Design and analysis of experiment (DOE) about factorial experiment was applied to analyze the four-Alumina Powder size of 0.05, 0.30, 1.00, and 3.00 µm and nine-lapping time of 30, 60, 90, 120, 150, 180, 210, 240 and 270 min, respectively. These multi-responses of factorial experiment were the weight loss and three Ra-value (e.g. the Ra-value on x-axial, the Ra-value on y-axial, and the Ra-value on cross-axial) which analyzed to effect surface quality of brass C3604 on lapping process. In preparing specimen condition of surface roughness for experimental, were used the alumina powder of 200gram alumina powder lubricant of 150millilitre and water of 1 liter. Finally, the statistical analysis result of optimized the lower multi-response (e.g. the weight loss of 0.0730 µm, the Ra-value on x-axial of 0.1198 µm, the Ra-value on y-axial of 0.1834, and the Ra-value on cross-axial of 0.1838 µm, respectively.) was exhibited the alumina powder size of 0.30 µm and the lapping time of 210 min. These statistical analyses were shown the satisfaction value. (Desirability: D) with regard to statistical processing, it was found that the value was as high as 83.80%.

Keywords: Lapping Process, Weight Loss, Surface Roughness, Factorial Experiment.

1. INTRODUCTION

The dynamics of lapping processes are notably shaped by diverse input parameters, underscoring the critical role played by variables such as machining speed, pressure, and the duration of contact among the lap plate, abrasive paste, and work piece. Refinements in polishing methods targeting the augmentation of surface texture without instigating alterations or detriment to the material have been the focus of extensive research over numerous years. Moreover, the advent of novel lubricants has emerged, effectively diminishing friction between the work piece and lapping plate, thereby culminating in heightened surface quality and decreased wear on the lapping plate [1-2]. Normally, lapping and polishing processes occur due to the sliding friction between particles and a surface. During the process, a lapping or polishing tool is passed across a material surface while particles of sand or mud-type slurry are forced against it at the point of contact [3]. Grinding is one of the most important abrasive processes used to achieve precise dimensions and smooth surfaces. Typically, the material removal rate from the work piece is lower in grinding operations compared to other general machining methods [4]. This research analyzes work surfaces that require very high surface roughness to add value to the product for maximum return. Lapping is a finishing method used to obtain high surface quality [5-6].

The result of using lapping as a finishing method would be a bright and high-resolution surface. The type of materials used to fine-tune the surface affects its smoothness in the final finishing stage, which involves cleaning and improving the surface of metal materials through a combination of mechanical and chemical manufacturing processes [7-8]. The lapping process is a method used to adapt plane surfaces to increase accuracy and precision. It is a type of abrasive machining technology [9–12]. Lapping possesses distinct advantages of high efficiency, flexibility, accuracy, precision, and low surface damage. It is commonly used in machining smooth and independent form surfaces compared to conventional machining technologies that use geometrical tools. Measurement accuracy and precision are crucial in high-precision technology related to the surface polishing process [13-16]. The effect of surface scrubbing on the lapping process depends on many parameters, as observed in experiments [18].

The quality, accuracy, and precision of the surface shape can be achieved by adjusting the type of lapping process used. Continuous experimentation is necessary to ensure high efficiency [17, 19-20]. Utilizing statistical methodologies like analysis of variance (ANOVA) enables meticulous adjustments in the lapping process, leading to superior efficiency and quality outcomes. ANOVA facilitates a detailed examination of various factors impacting the process, allowing for precise optimization of parameters like pressure, abrasive particle size, and duration. By discerning influential factors and their interactions, manufacturers can fine-tune the process with precision, ensuring consistent high-quality results [21-22]. This study holds promise for application within manufacturing or engineering sectors utilizing the lapping process for brass C3604. It provides valuable insights into selecting suitable alumina powder sizes and determining optimal polishing durations to achieve the desired surface roughness. The primary objective is to compare the impact of four types of alumina polishing powder on the average surface roughness (Ra) of brass C3604 during surface lapping. Employing principles of Design and Analysis of Experiment (DOE), this research will establish process parameters and statistically analyze their significance.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 57 Issue: 04:2024
DOI: 10.5281/zenodo.11059414

2. EXPERIMENTAL PROCEDURE

The Brass C3604 is a versatile alloy composed of copper, zinc, and other essential elements. With a wide range of mechanical properties, this type of brass offers an excellent choice for various applications across multiple industries, including plumbing, electronics, automotive manufacturing, electrical equipment manufacturing, and marine construction. The primary components of C3604 brass consist of copper (65-80% by weight) and zinc, while the remaining 20-35% comprises tin (1-2%), aluminum (0.02-0.6%), nickel (0.02-0.07%), lead (0.01-0.05%), iron (0.01-0.07%), and manganese (0.001%). The specific composition may vary depending on the intended application, and small amounts of other alloys like silicon and arsenic may be added. C3604 brass exhibits a diverse range of properties that make it highly suitable for a wide array of industries. It possesses good strength and formability characteristics, allowing for efficient shaping and fabrication processes. Moreover, it demonstrates excellent corrosion resistance, particularly in saltwater environments, making it well-suited for marine applications. The malleable characteristics of C3604 brass facilitate effortless machining and welding, rendering it ideal for tasks that demand precision components or the swift and accurate fabrication of intricate shapes. In this context, an aluminum oxide grinding wheel is utilized, specifically employing a white stone-type grinding stone crafted from aluminum oxide. The grinding stone possesses dimensions of 205 x 19 x 31.75 mm, and its grit size is identified as WA60JV, signifying its precise abrasive particle dimensions Fig. 1 provides a visual representation of the equipment and materials employed in the outlined preparation process, offering a clear illustration of the sequential steps involved in the preparation procedure.

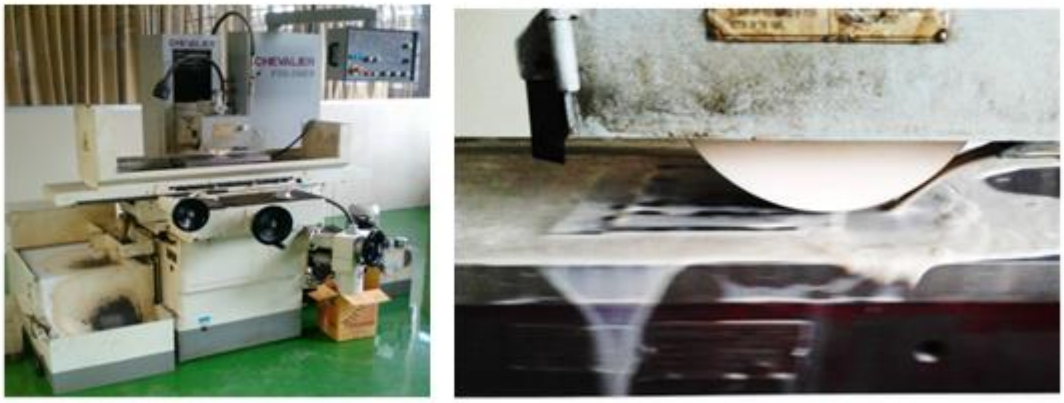

Fig 1: The Grinding machine of flat surface machining

During the experimental phase, the refinement of the fine skin process begins by mixing specific quantities of Alumina Powder 200gram. Alumina powder lubricant 150millilitre and water 1 liter. To achieve the desired ratio. This mixture is crucial in obtaining the average surface roughness values, also known as Ra-values. Subsequently, the prepared specimens of brass C3604, characterized as flat bars measuring 35 x 35 x 5 mm brass C3604 are utilized in the experiment, employing a piece test conducted on the surface of Lapping plate Fig. 2 provides a visual representation of this setup, showcasing the configuration and arrangement of the experimental components. Subsequently, the experiment was conducted by varying the time interval in the fine finishing process. Time intervals of 30, 60, 90, 120, 150, 180, 210, 240, and 270 minutes were selected to investigate their impact on the average surface roughness (Ra-value) of the specimens. The surface roughness value is measured using a microscope (3D Measuring Laser Microscope, Model OLS5000) by assessing the surface roughness value in 4 sets. Each piece undergoes measurement at 5 points per test piece.

The measurement procedure involves taking the piece and utilizing a magnification power of 20 times in front of the lens (Lens). The surface roughness value is then measured at specific points: the top right angle (TR) and lower right angle (BR) of the workpiece along the x and y axial, the top left corner (TL) and bottom-left angle (BL) of the workpiece along the x and y axial, and the center point (Center; C) of the workpiece along the x and y axial. as shown in Fig. 3 The experimental data will undergo analysis, including the calculation of arithmetic mean surface roughness values for each time period. These findings will be graphically presented to provide both a concise summary and a comprehensive understanding of how the timing of the surface improvement process relates to the surface roughness of C3604 brass. This analysis will offer valuable insights into the impact of treatment time on enhancing surface quality.

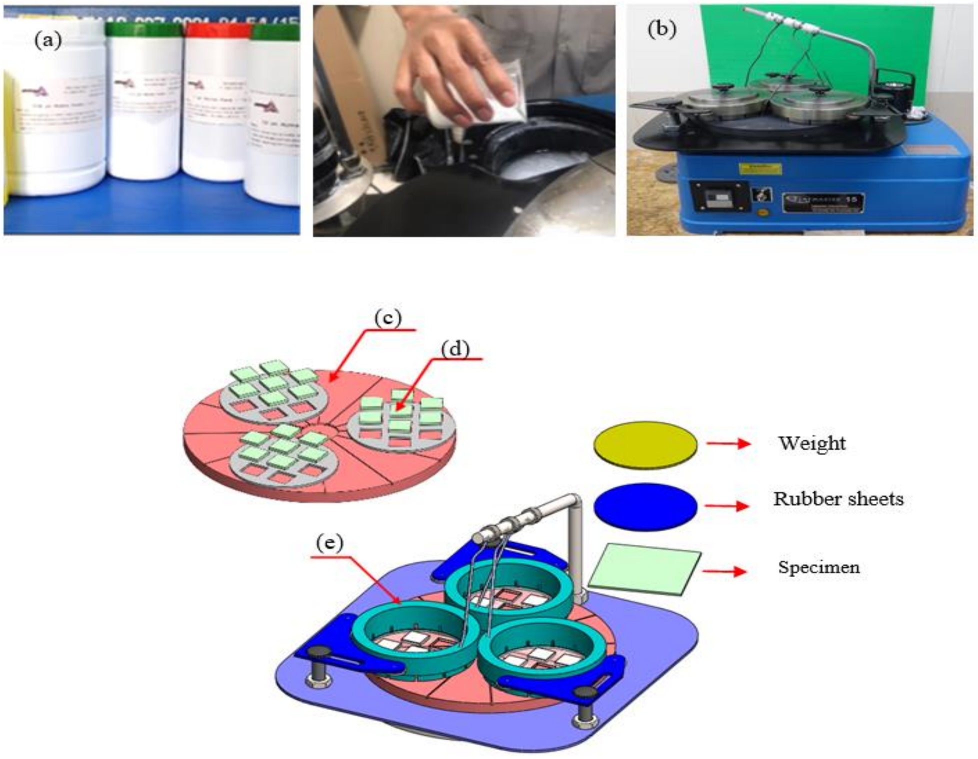

Fig 2: (a) Alumina (b) Lapping Machine (c) Polishing Plate (d) Specimen (e) Conditioning Rings

Fig 3: 3D Measuring Model OLS5000 Roughness (Ra)

3. RESULTS AND DISCUSSION

Results should Specimens The statistical analysis of variance (ANOVA) revealed that both the main effect term and interaction term of the multi-responses were found to be statistically significant at a 95% confidence level. This indicates that the factors being investigated, including the time interval in the fine finishing process, have a significant influence on the measured outcomes.

The Pareto chart further supported these findings, as all bars exceeded the critical reference line of the F-value statistic at a 95% confidence level, indicating their importance in the experimental results. The experiment focused on adjusting the time interval in the lapping process to collect average surface roughness data (Ra-value) from brass C3604 specimens using a grinding wheel.

Time intervals of 30, 60, 90, 120, 150, 180, 210, 240, and 270 minutes were chosen for data collection. With increments of 30 minutes. These intervals were chosen to evaluate the effect of varying durations on surface roughness. The collected data was then subjected to analysis to determine the relationship between the time interval and surface roughness.

Two key responses, namely the weight loss and Ra-value, were considered as part of the factorial experiment. These responses were analyzed to assess the impact of the time interval on the weight loss and surface quality of the brass C3604 specimens during the lapping process.

The experimental data, including the weight loss and Ra-value measurements, can be found in Table 1 providing valuable insights into the effects of different time intervals on the surface roughness characteristics of the specimens.

Table 1: The experimental data of weight loss and Ra-value

Powder (μm)	Time (min)	Weight Loss (g)	Ra (μm)		
			x-axial	y-axial	Cross-axial
0.05	30	0.0247	0.0790	0.3400	0.3480
0.05	30	0.0230	0.2360	0.3880	0.3810
0.05	30	0.0243	0.2750	0.3500	0.3910
0.05	30	0.0235	0.2320	0.3400	0.3720
0.05	30	0.0237	0.1910	0.3360	0.2770
0.05	60	0.0348	0.1840	0.5840	0.5630
0.05	60	0.0350	0.1480	0.4720	0.4210
0.05	60	0.0350	0.2490	0.5280	0.4870
0.05	60	0.0349	0.0170	0.3990	0.3460
0.05	60	0.0345	0.0750	0.6090	0.7730
0.05	90	0.0252	0.0610	0.3080	0.3070
0.05	90	0.0257	0.0290	0.2620	0.2880
0.05	90	0.0255	0.0770	0.3160	0.3180
0.05	90	0.0253	0.0690	0.4500	0.4810
0.05	90	0.0254	0.0170	0.3530	0.3430
0.05	120	0.0577	0.3750	0.2610	0.3590
0.05	120	0.0577	0.2960	0.0660	0.4580
0.05	120	0.0585	0.3460	0.0590	0.3020
0.05	120	0.0579	0.3830	0.2500	0.3880
0.05	120	0.0584	0.3530	0.1780	0.3900
0.05	150	0.1072	0.1960	0.0840	0.1450
0.05	150	0.1069	0.2380	0.0410	0.2760
0.05	150	0.1082	0.2390	0.0050	0.2190
0.05	150	0.1068	0.1820	0.0320	0.2260
0.05	150	0.1068	0.2590	0.0630	0.1760
0.05	180	0.1160	0.2240	0.6670	0.8000
0.05	180	0.1157	0.2280	0.6010	0.5550
0.05	180	0.1160	0.0450	0.2430	0.2210
0.05	180	0.1155	0.2600	0.6150	0.4830
0.05	180	0.1160	0.1040	0.4030	0.5000
0.05	210	0.1096	0.2060	0.5080	0.5290
0.05	210	0.1093	0.0960	0.2910	0.3070
0.05	210	0.1102	0.1100	0.1110	0.3670
0.05	210	0.1097	0.1270	0.4840	0.4450
0.05	210	0.1097	0.1420	0.3850	0.3310
0.05	240	0.4177	0.0320	0.4140	0.3440
0.05	240	0.4177	0.1480	0.7200	0.5360
0.05	240	0.4178	0.1110	0.5270	0.5410
0.05	240	0.4176	0.1390	0.8870	0.7700
0.05	240	0.4176	0.4000	0.6460	0.6290
0.05	270	0.0865	0.1490	0.5750	0.5670
0.05	270	0.0871	0.3990	0.5310	0.5570
0.05	270	0.0868	0.2260	0.3610	0.3650
0.05	270	0.0867	0.1350	0.3610	0.3280
0.05	270	0.0871	0.0850	0.4020	0.3320

Table 1: The experimental data of weight loss and Ra-value (Cont.)

Powder (μm)	Time (min)	Weight Loss (g)	Ra (μm)		
			x-axial	y-axial	Cross-axial
0.30	30	0.0119	0.1660	0.3370	0.4000
0.30	30	0.0119	0.0710	0.5180	0.4830
0.30	30	0.0118	0.0400	0.4000	0.4290
0.30	30	0.0112	0.1410	0.3980	0.4470
0.30	30	0.0117	0.1520	0.4090	0.4190
0.30	60	0.0127	0.2800	0.1410	0.2520
0.30	60	0.0129	0.3530	0.4040	0.1840
0.30	60	0.0130	0.0830	0.2180	0.2410
0.30	60	0.0130	0.3290	0.0440	0.0550
0.30	60	0.0132	0.1930	0.1220	0.0930
0.30	90	0.0836	0.1740	0.4320	0.5220
0.30	90	0.0837	0.1770	0.4510	0.4230
0.30	90	0.0845	0.1690	0.4810	0.4390
0.30	90	0.0830	0.2460	0.4620	0.4270
0.30	90	0.0831	0.1820	0.4580	0.4580
0.30	120	0.1060	0.3510	0.0220	0.3820
0.30	120	0.1050	0.3430	0.0050	0.3460
0.30	120	0.1052	0.4240	0.1660	0.4770
0.30	120	0.1053	0.3970	0.0090	0.4200
0.30	120	0.1057	0.4140	0.0280	0.3850
0.30	150	0.1514	0.2660	0.1140	0.2500
0.30	150	0.1511	0.3620	0.2210	0.2920
0.30	150	0.1512	0.2350	0.1250	0.3170
0.30	150	0.1507	0.4390	0.1370	0.4960
0.30	150	0.1508	0.3930	0.2380	0.3560
0.30	180	0.1752	0.2290	0.3690	0.5440
0.30	180	0.1737	0.3470	0.3240	0.5220
0.30	180	0.1745	0.3920	0.3820	0.4230
0.30	180	0.1747	0.3240	0.3860	0.2940
0.30	180	0.1745	0.4670	0.3600	0.6380
0.30	210	0.0739	0.0530	0.1100	0.1150
0.30	210	0.0724	0.0790	0.1630	0.2060
0.30	210	0.0729	0.1090	0.1840	0.2130
0.30	210	0.0726	0.2160	0.2400	0.1910
0.30	210	0.0731	0.1420	0.2200	0.1940
0.30	240	0.0723	0.3280	0.0650	0.3780
0.30	240	0.0720	0.3120	0.2410	0.3470
0.30	240	0.0720	0.2540	0.0970	0.2340
0.30	240	0.0719	0.4320	0.1740	0.4150
0.30	240	0.0721	0.2840	0.1420	0.2310
0.30	270	0.1369	0.0030	0.6050	0.5450
0.30	270	0.1369	0.0480	0.4320	0.3810
0.30	270	0.1378	0.1420	0.4500	0.4290
0.30	270	0.1370	0.3640	0.6280	0.5850
0.30	270	0.1377	0.1420	0.5560	0.5060

Table 1: The experimental data of weight loss and Ra-value (Cont.)

Powder (µm)	Time (min)	Weight Loss (g)	Ra (µm)		
			x-axial	y-axial	Cross-axial
1.00	30	0.0365	0.1140	0.2970	0.3300
1.00	30	0.0359	0.1680	0.3350	0.3940
1.00	30	0.0363	0.1570	0.3120	0.2860
1.00	30	0.0363	0.1440	0.4780	0.4430
1.00	30	0.0361	0.0960	0.3300	0.3050
1.00	60	0.0130	0.2010	0.3040	0.2880
1.00	60	0.0119	0.3540	0.3910	0.5000
1.00	60	0.0131	0.2130	0.4880	0.4630
1.00	60	0.0127	0.1450	0.3050	0.2910
1.00	60	0.0131	0.1460	0.4250	0.4350
1.00	90	0.1171	0.3680	0.0940	0.4240
1.00	90	0.1174	0.5040	0.1060	0.4990
1.00	90	0.1164	0.3510	0.0440	0.3350
1.00	90	0.1174	0.4350	0.2350	0.4480
1.00	90	0.1169	0.4190	0.2160	0.4260
1.00	120	0.0854	0.2220	0.3620	0.3660
1.00	120	0.0849	0.2280	0.3870	0.3730
1.00	120	0.0856	0.2720	0.4740	0.4850
1.00	120	0.0852	0.3410	0.6550	0.5850
1.00	120	0.0861	0.2700	0.4270	0.4310
1.00	150	0.0842	0.4540	0.0100	0.4550
1.00	150	0.0845	0.3430	0.1090	0.2870
1.00	150	0.0835	0.4580	0.1290	0.4650
1.00	150	0.0845	0.3290	0.0040	0.4010
1.00	150	0.0840	0.4170	0.1390	0.4330
1.00	180	0.1673	0.0650	0.4420	0.4210
1.00	180	0.1667	0.0960	0.3260	0.2700
1.00	180	0.1676	0.1790	0.4540	0.4140
1.00	180	0.1673	0.1560	0.4840	0.4720
1.00	180	0.1672	0.2020	0.2500	0.2860
1.00	210	0.0955	0.3440	0.1220	0.3840
1.00	210	0.0954	0.3280	0.1590	0.2820
1.00	210	0.0955	0.3750	0.1450	0.3340
1.00	210	0.0953	0.4430	0.2730	0.4040
1.00	210	0.0956	0.2990	0.1020	0.2340
1.00	240	0.0257	0.1880	0.1540	0.2310
1.00	240	0.0254	0.2630	0.0650	0.2130
1.00	240	0.0258	0.4350	0.0570	0.3920
1.00	240	0.0257	0.2280	0.1050	0.2200
1.00	240	0.0259	0.2310	0.0280	0.1860
1.00	270	0.1468	0.5840	0.1430	0.5620
1.00	270	0.1463	0.4810	0.2370	0.4560
1.00	270	0.1468	0.4950	0.0840	0.4780
1.00	270	0.1470	0.3780	0.3330	0.3210
1.00	270	0.1475	0.2870	0.0780	0.2600

Table 1: The experimental data of weight loss and Ra-value (Cont.)

Powder (µm)	Time (min)	Weight Loss (g)	Ra (µm)		
			x-axial	y-axial	Cross-axial
3.00	30	0.0524	0.5460	0.1700	0.5710
3.00	30	0.0522	0.5820	0.0710	0.6260
3.00	30	0.0550	0.3890	0.1870	0.4730
3.00	30	0.0528	0.5130	0.2440	0.5470
3.00	30	0.0526	0.4530	0.0540	0.4100
3.00	60	0.0178	0.3310	0.0490	0.3580
3.00	60	0.0176	0.3240	0.3250	0.3760
3.00	60	0.0184	0.3200	0.0250	0.2640
3.00	60	0.0186	0.2770	0.0050	0.2770
3.00	60	0.0192	0.2970	0.0260	0.3700
3.00	90	0.0896	0.4840	0.1410	0.5110
3.00	90	0.0902	0.2340	0.0310	0.2490
3.00	90	0.0906	0.3330	0.0300	0.3590
3.00	90	0.0896	0.2530	0.0360	0.0960
3.00	90	0.0910	0.4470	0.1710	0.4440
3.00	120	0.1112	0.2360	0.2820	0.1630
3.00	120	0.1188	0.0870	0.0970	0.4230
3.00	120	0.1191	0.0030	0.3870	0.3810
3.00	120	0.1186	0.0040	0.3170	0.3090
3.00	120	0.1194	0.1330	0.5210	0.5020
3.00	150	0.2183	0.2900	0.1110	0.3370
3.00	150	0.2185	0.5960	0.0480	0.6130
3.00	150	0.2188	0.4520	0.0480	0.5020
3.00	150	0.2185	0.3890	0.1410	0.3330
3.00	150	0.2125	0.3560	0.1700	0.4220
3.00	180	0.2028	0.2250	0.6660	0.8230
3.00	180	0.2036	0.6360	0.4140	0.5020
3.00	180	0.2037	0.7740	0.7420	0.6250
3.00	180	0.2032	0.6550	0.6130	0.9960
3.00	180	0.2035	0.3580	0.4510	0.5440
3.00	210	0.0525	0.0190	0.4890	0.4270
3.00	210	0.0524	0.5060	0.1040	0.4740
3.00	210	0.0534	0.3720	0.0530	0.3710
3.00	210	0.0531	0.3240	0.0700	0.3480
3.00	210	0.0529	0.3560	0.0340	0.4390
3.00	240	0.3087	0.2880	0.4050	0.3920
3.00	240	0.3094	0.2550	0.5400	0.5180
3.00	240	0.3089	0.1470	0.5930	0.5380
3.00	240	0.3085	0.3550	0.7590	0.6740
3.00	240	0.3089	0.1120	0.5250	0.4870
3.00	270	0.1249	0.3460	0.0010	0.3050
3.00	270	0.1253	0.2760	0.1080	0.2920
3.00	270	0.1254	0.4880	0.1160	0.4580
3.00	270	0.1254	0.3970	0.1380	0.5040
3.00	270	0.1252	0.3320	0.0870	0.3030

The statistical analysis of the factorial experiment yielded separate results for four key parameters: weight loss, Ra-value on the x-axial, Ra-value on the y-axial, and Ra-value on the cross-axial. In each of these analyses, both the main effect terms and interaction terms of the multi-responses were found to be statistically significant at a 95% confidence level. This signifies that the factors under investigation exerted a significant influence on the measured outcomes across all four parameters. The results highlight the importance of considering both the individual effects of the factors and their interactions in understanding the overall impact on weight loss and the various Ra-values. The significant findings underscore the need to carefully consider and control these factors to achieve desired outcomes and improve the surface quality of the studied brass C3604 specimens.

The statistical analysis provides valuable insights into the interplay between the experimental variables and the measured responses, allowing for more informed decision-making and optimization of the lapping process. The obtained P-values for the analysis of variance (ANOVA) results, as shown in Table 2 - 5 were found to be significantly lower than the predetermined significance level (α-value) of 0.05. The P-values were less than 0.001, indicating a highly significant relationship between the factors and the measured responses. To visually illustrate the significance of these findings, Pareto charts were constructed for each analysis, as depicted in Fig. 4 - 7 respectively. In each Pareto chart, all bars exceeded the critical reference line of the F-value statistic at a 95% confidence level.

This reinforces the statistical significance of the main effect terms and interaction terms of the multi-responses in relation to the investigated factors. The Pareto charts provide a clear visualization of the relative magnitudes of the effects, indicating which factors have the most substantial impact on the weight loss and the various Ra-values. These findings reinforce the importance of considering and controlling these factors to optimize the lapping process and achieve the desired surface quality of the brass C3604 specimens.

Table 2: The statistical analysis results of weight loss

Source	**DF**	**SS**	**MS**	**F-value**	**P-value**
Model	35	1.24900	0.035686	49287.65	< 0.001
Linear	11	0.64820	0.058927	81387.94	< 0.001
Alumina Powder (µm)	3	0.05833	0.019445	26856.65	< 0.001
Lapping Time (min)	8	0.58986	0.073733	101837.18	< 0.001
2-Way Interactions	24	0.60080	0.025033	34575.01	< 0.001
Alumina Powder (µm) *Lapping Time (min)	24	0.60080	0.025033	34575.01	< 0.001
Error	144	0.00010	0.000001		
Total	179	1.24910			

Table 3: The statistical analysis results of the Ra-value on x-axial

Source	DF	SS	MS	F-value	P-value
Model	35	2.6435	0.075530	8.72	< 0.001
Linear	11	0.8962	0.081475	9.41	< 0.001
Alumina Powder (µm)	3	0.6582	0.219397	25.33	< 0.001
Lapping Time (min)	8	0.2380	0.029754	3.44	< 0.001
2-Way Interactions	24	1.7473	0.072805	8.41	< 0.001
Alumina Powder (µm) *Lapping Time (min)	24	1.7473	0.072805	8.41	< 0.001
Error	144	1.2471	0.008660		
Total	179	3.8906			

Table 4: The statistical analysis results of the Ra-value on y-axial

Source	DF	SS	MS	F-value	P-value
Model	35	5.5378	0.15822	15.49	< 0.001
Linear	11	2.1263	0.19330	18.93	< 0.001
Alumina Powder (µm)	3	0.5313	0.17709	17.34	< 0.001
Lapping Time (min)	8	1.5950	0.19938	19.52	< 0.001
2-Way Interactions	24	3.4114	0.14214	13.92	< 0.001
Alumina Powder (µm) *Lapping Time (min)	24	3.4114	0.14214	13.92	< 0.001
Error	144	1.4707	0.01021		
Total	179	7.0084			

Table 5: The statistical analysis results of the Ra-value on cross-axial

Source	DF	SS	MS	F-value	P-value
Model	35	1.9764	0.05647	5.29	< 0.001
Linear	11	0.6642	0.06038	5.66	< 0.001
Alumina Powder (µm)	3	0.1714	0.05712	5.35	< 0.001
Lapping Time (min)	8	0.4929	0.06161	5.77	< 0.001
2-Way Interactions	24	1.3122	0.05467	5.12	< 0.001
Alumina Powder (µm) *Lapping Time (min)	24	1.3122	0.05467	5.12	< 0.001
Error	144	1.5370	0.01067		
Total	179	3.5133			

The template is designed when validating experimental results, it is important to assess the form of residuals obtained from the experimental data. The residuals should adhere to the principles of residual values, including having a normal distribution, as observed in the versus fits graph. This allows for checking the variance of the error values. In order for the data to be considered good, the variance of the error values should be consistent when examining the versus order graph. Consistent variance indicates that the errors have a stable and predictable pattern, independent of the order in which the data points are collected. This consistency is crucial for ensuring the accuracy and reliability of the data. By evaluating the conformity of the residuals and ensuring normal distribution and consistent variance, researchers can establish the validity and reliability of the experimental data. These assessments help to verify the quality of the experimental design and analysis, and contribute to the overall trustworthiness of the research findings. The good data information must have characteristics of good control charts as shown in Fig. 8 - 11 respectively. By analyzing control charts, one can identify patterns, trends, or shifts in the process that may impact the quality or consistency of the data. Control charts serve as a tool for quality control and process improvement, enabling organizations to detect and address issues, maintain process stability, and ensure the reliability and accuracy of experimental results.

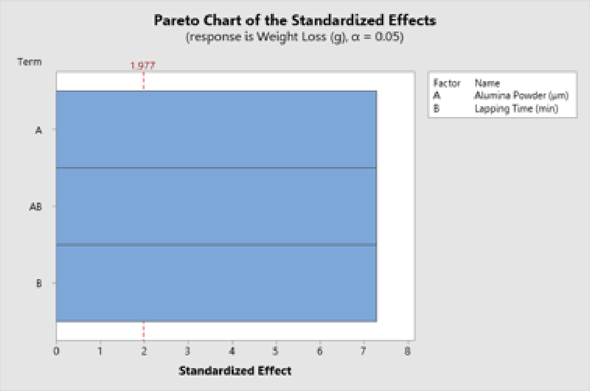

Fig 4: Pareto-chart of weight loss

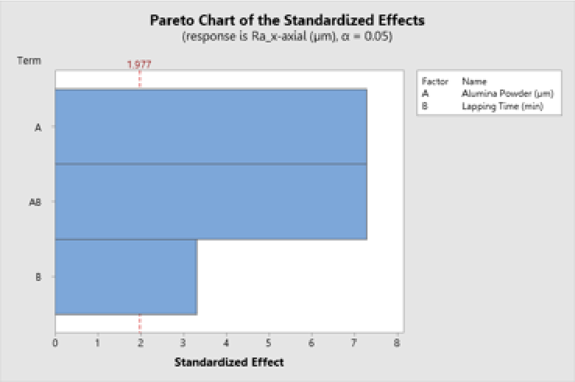

Fig 5: Pareto-chart of Ra-value x-axial

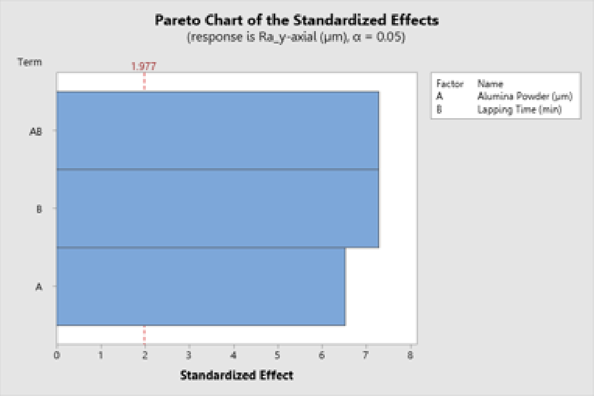

Fig 6: Pareto-chart of Ra-value y-axial

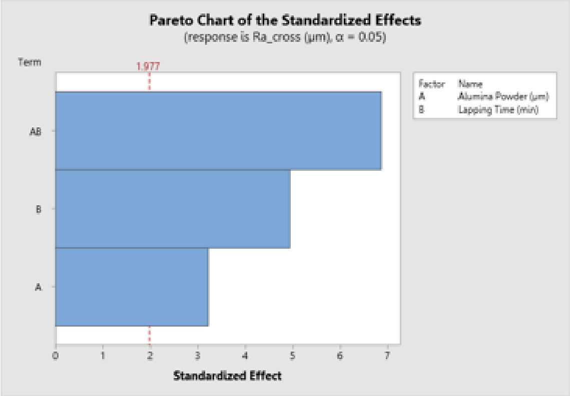

Fig 7: Pareto-chart of Ra-value cross-axial

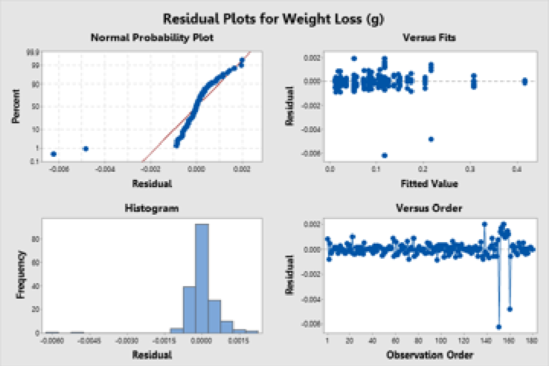

Fig 8: Residual Plots of weight loss

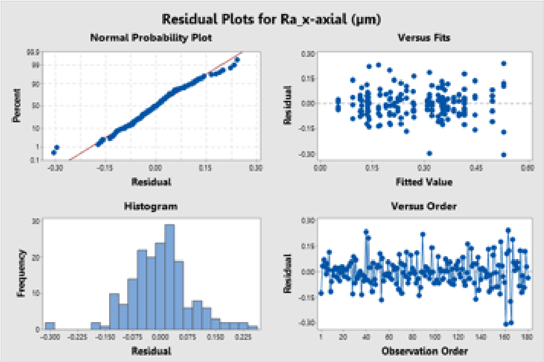

Fig 9: Residual Plots of Ra-value x-axial

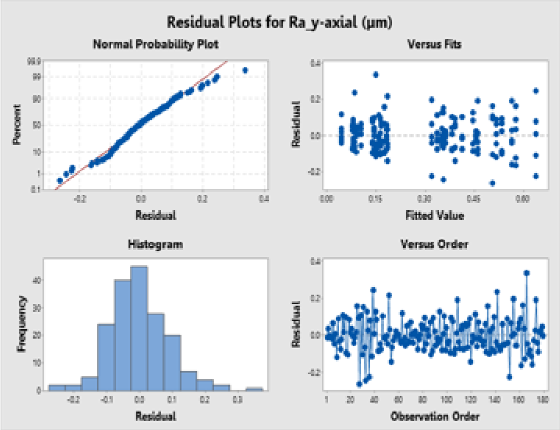

Fig 10: Residual Plots of Ra-value y-axial

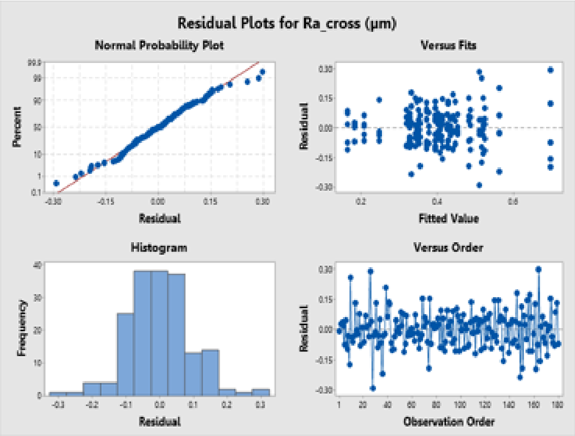

Fig 11: Residual Plots of Ra-value cross-axial

The main effect plot for multiple responses, including weight loss, Ra-values on the x-axial, y-axial, and cross-axial Fig. 12 - 15 reveals an interesting finding. The graph-line representing the trend of alumina powder does not run parallel to the reference line on the horizontal axial. This indicates that the multi-responses of brass C3604 in the lapping process are significantly influenced by two parameters: alumina powder and lapping time. These effects have been established with a statistical confidence level of 95%. Furthermore, the interaction plot of the multiple responses Fig. 16 - 19 demonstrates an intriguing pattern. All the graph-lines display a shapeless form, suggesting that there is mutual interaction between the two parameters, alumina powder and lapping time, in affecting the multiple responses of brass C3604 during the lapping process. This finding is statistically significant at a confidence level of 95% By examining these main effect plots, we can determine the direction and magnitude of the effects of alumina powder size and lapping time on each response variable. This information is crucial in understanding the factors that contribute to the surface quality and weight loss of brass C3604 during the lapping process.

Fig 12: Main effects plot of weight loss

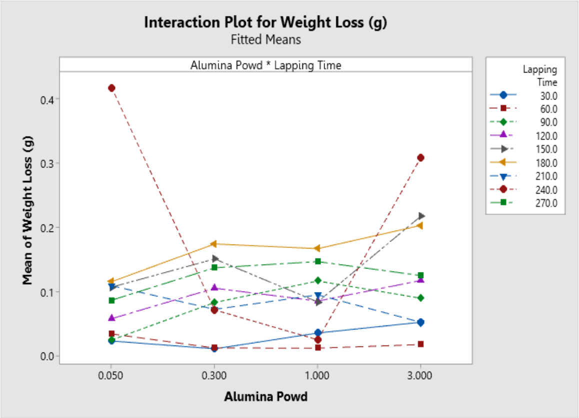

Fig 16: Interaction plot of weight loss

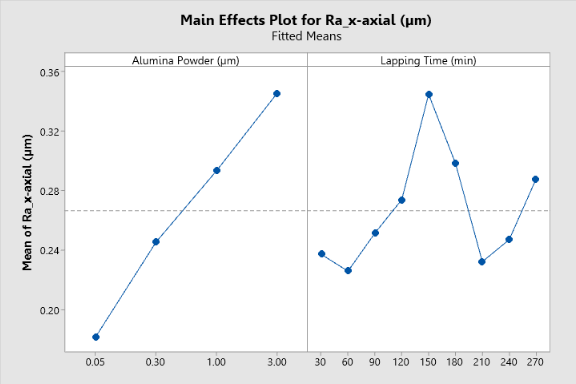

Fig 13: Main effects plot of Ra x-axial

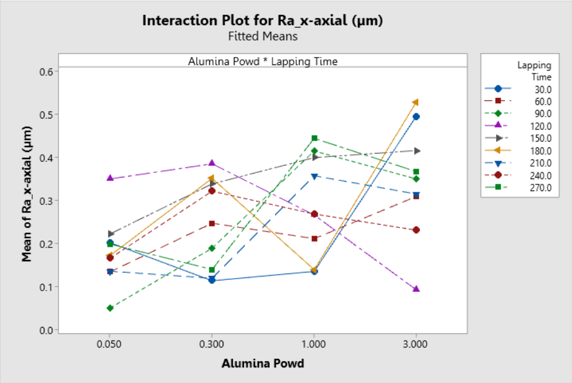

Fig 17: Interaction plot of Ra x-axial

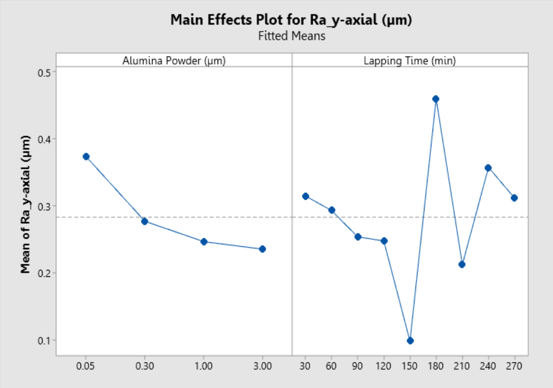

Fig 14: Main effects plot of Ra y-axial

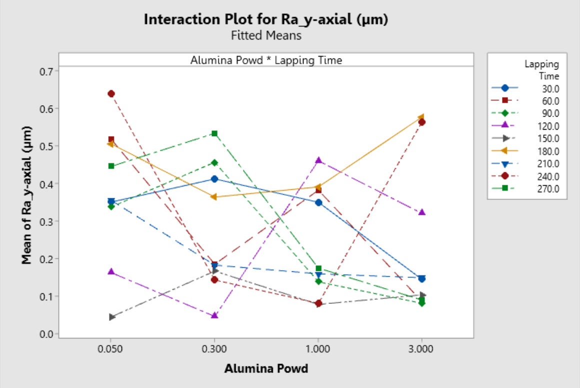

Fig 18: Interaction plot of Ra y-axial

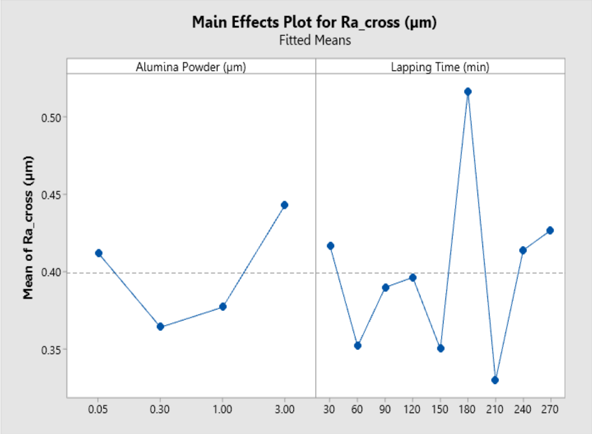

Fig 15: Main effects plot of Ra cross-axial

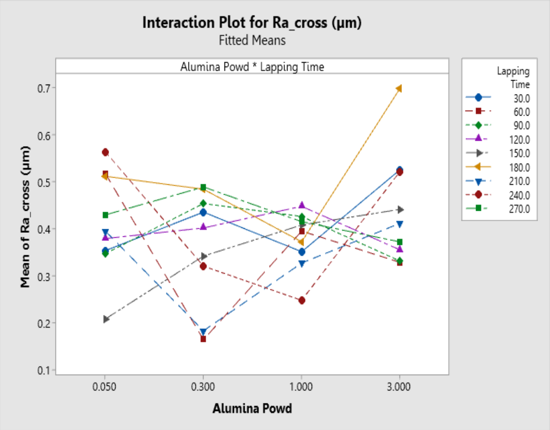

Fig 19: Main effects plot of Ra cross-axial

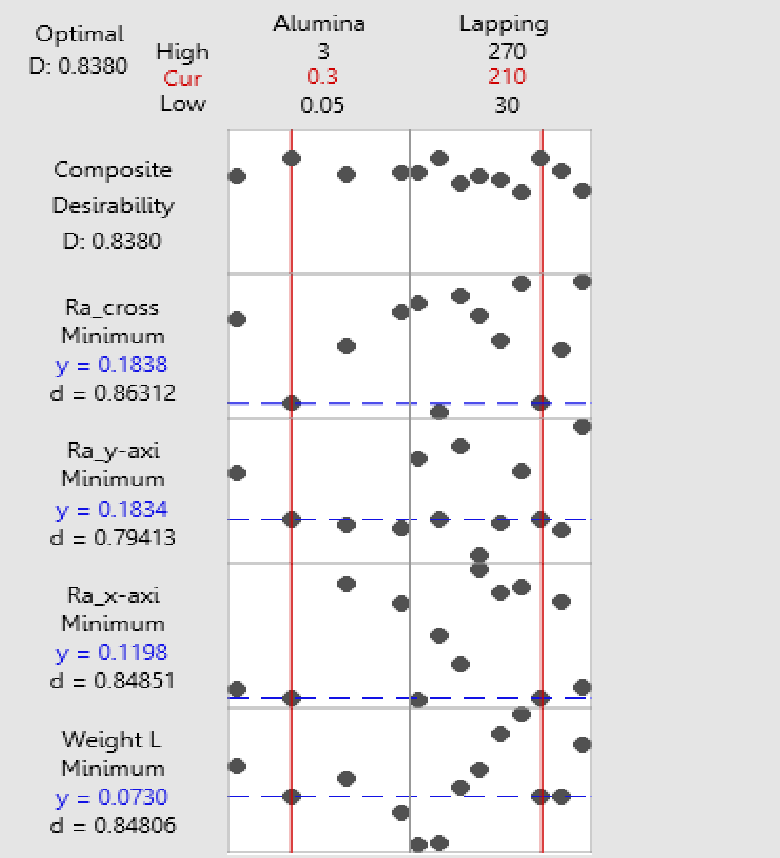

Fig 20: Response Optimization

4. CONCLUSION

This research stands out due to its distinctive amalgamation of factors, its direct applicability to industrial processes, and its tailored recommendations for achieving the highest surface quality for C3604 brass material. The insights gleaned from this study not only augment the current knowledge base but also hold substantial value for industries, researchers, and practitioners aiming to enhance surface quality in material processing. This comprehensive investigation into surface lapping's engineering facets is primarily centered around conducting rigorous statistical hardness analyses via (ANOVA). The lapping process is widely acknowledged for its precision in machining, delivering exceptional flatness and surface finish. While it has limitations, continuous advancements in material engineering and technology are addressing these challenges, augmenting the efficiency and effectiveness of lapping. These advancements significantly enhance the quality and performance of lapped components, rendering it an invaluable technique across diverse industries. Optimizing two key parameters, alumina powder size, and lapping duration, significantly reduced multi-response factors (weight loss, Ra-values on x, y, and cross-axial) for brass C3604 during the lapping process. This optimization, achieved at a 95% statistical confidence level, utilized a 0.30 µm alumina powder size and a 210minute lapping time, effectively mitigating adverse effects and enhancing desired outcomes. Statistical analyses indicated an impressive overall satisfaction value (Desirability: D) of 83.80%, showcasing high contentment with the results. This satisfaction value encompasses four sub-analyses: Weight Loss: Achieving a satisfaction value of 84.80% indicated favorable outcomes with minimal weight loss 0.0730 µm. Ra-value on x-axial: With a satisfaction value of 84.85%, notable improvement was observed in lowering the Ra-value on the x-axial 0.1198 µm. Ra-value on y-axial: Marking a satisfaction value of 79.41%, significant progress was made in reducing the Ra-value on the y-axial 0.1834 µm. Ra-value on cross-axial: Attaining a satisfaction value of 86.31% showcased positive results in minimizing the Ra-value on the cross-axis 0.1838 µm. These satisfaction values, graphically represented in Fig. 20 visually illustrate the successful optimization of the lapping process for brass C3604, effectively addressing multiple response variables.

Acknowledgment

The author expresses gratitude to the laboratory at the Faculty of Engineering, Industrial Engineering, Rajamangala University of Technology Krungthep. This facility provided access to a lapping machine for conducting research, and the Minitab software program was utilized for result analysis. The validation of experimental forms is acknowledged, and appreciation is extended to the Office of the Thailand Science Research and Innovation (TSRI) for their support in funding research operations.

References

1) Anthony T.H. Beaucamp, Kotaro Nagai, Tomoko Hirayama, Mutsumi Okada, “Elucidation of material removal mechanism in float polishing,” Precision Engineering, Vol.73, pp. 423-434, 2022.

2) Andrea Deaconescu and Tudor Deaconescu, “Improving the Quality of Surfaces Finished by Lapping by Robust Parameter Design,” Journal of Economics, Business and Management, Vol.2(1), pp. 1-4, 2014.

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

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

5) Jeong-Du Kim and Min-Seog Choi, “Stochastic approach to experimental analysis of cylindrical lapping process,” International Journal of Machine Tools and Manufacture, Vol. 35, Issue 1, January, pp. 51-59, 1995.

6) Somkiat Thermsuk, Suwit Thammasang , Danai Sonsuphap , and Thanapol Sombat, “Influence Parameters the Surface Roughness of JIS SCMS420 Stainless Steel on Lapping Process,” Lecture Notes in Networks and Systems, LNNS 335, pp. 423–430, 2022.

7) 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, pp. 747-754, 2020.

8) Suwit Thammasang and Somkiat Thermsuk, “Influence of the Surface Quality of Stainless Steel JIS 420 and JIS 440 on Lapping Process,” Advances in Dynamical Systems and Applications, Vol. 16, Number 2, pp. 1867-1881, 2021.

9) 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, pp. 102-110, 2020.

10) 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, pp. 653-676, 2019.

11) 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, pp. 125-132, 2019.

12) 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, Vol. 314, 1 June, pp. 627-634, 2017.

13) 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, Vol. 141, January, 105900, 2020.

14) 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, Vol. 146, November, 103438, 2019.

15) 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,
Vol. 134, June, pp. 60-76, 2019.

16) 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, pp. 414–419, 2002.

17) 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, pp. 391-395, 2021.

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

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

20) Berthold Schlecht, Felix Rudolph, and Stefan Schumann, “Experimental studies and simulation of hypoid gear lapping,” Forsch Ingenieurwes, Vol.81, pp. 95–100, 2017.

21) 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, Vol.87, pp. 1951–1956, 2016.

22) 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, Vol.83, pp. 1811–182, 2016.