"NANO FINISH OF ALUMINUM ALLOY THROUGH LAPPING" – A REVIEW

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Abstract: Lapping is a finishing operation, which falls in the category of precision machining process that employs loose abrasive with multipoint sharp edges that provides the cutting action. Lapping operation is used to generate fine surface finish as well as geometry. It is a slow operation, whose purpose apart from achieving fine finish is to also refine form accuracy such as flatness. The surface quality achieved by lapping gets affected due to process parameters, if improperly controlled, provides highly inconsistent results. Operation parameters such as lapping load conditions, operating speed, abrasive grain size and hardness, specimen material, size and weight decides the material removal rate, surface roughness and quality. From the view point of achieving the most favorable outcomes, it is a major necessity to properly select the controlling parameters with proper operating conditions. This will reduce cost, time and provide required results. Such review will help in establishing the basis for any research study work in the similar direction.

Keywords **– Lapping, Nano Finish, Diamond Abrasive, Design of Experiment, Roughness.**

1. INTRODUCTION

Surface finish and dimensional accuracy are currently the most significant aspect in the engineering industries owing to the advent of technology. One of the most prominent factors that determine the performance of a final product is the surface quality. The aspect of surface quality might have an effect on the product's requirements such as assembly fits, aesthetic appearance and specifications that were the end requirement for the customer. A certain part that has been produced by some manufacturing process, generally requires an end finishing operation for the requirement of the surface quality aspect which costs around 10-15% of the overall cost for the production

[20]The machining processes for finishing operations are generally classified in three categories as per the extent of their provided accuracy namely (1) Conventional Machining (CM) (2) Precision Machining (PM) (3) Ultra-precision Machining (UPM). The accuracy in conventional machining can reach up to 1μm, whereas in case of precision machining and ultra-precision machining can reach up to 0.01μm and 0.001μm respectively. The finishing operations that involves machining by loose abrasives are type of precision machining operations. Loose abrasives machining processes consists of: Lapping, Polishing and Grinding. These processes are able to generate finely finished surface for both brittle and ductile materials.

Surface quality refers to surface finish. [21] Surface finish is also called surface texture, which comprises of three main components namely Lay, Surface Roughness and Waviness. Lay (form) is repeating patterns formed upon the surface by the manufacturing operation, wear out machine bed or table. Roughness is surface irregularity observed as vertical deviations which are generated by cutting tool, abrasive grain and operation feed. Waviness is formed upon surface as a result of warping, vibration or deflection of tool during process. These surface components generated simultaneously by simply overlapped over each other. The surface roughness is indicated mostly by Ra value.

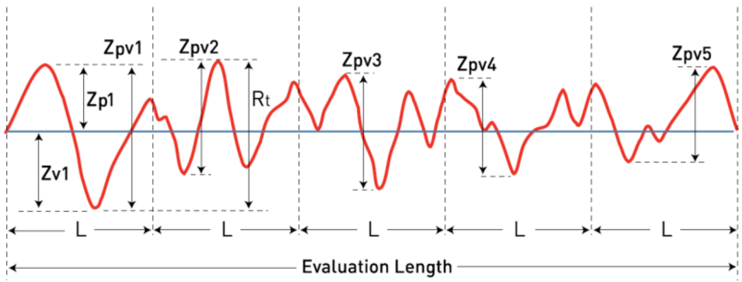

Figure 1 Surface Peaks and Valleys for a sampling length [21]

Rp = high peak above of mean line.
Rv = low valley below of mean line.
Ra = mean of all the peaks and valleys over a sampling length.
Rt = Distance between the high peak and low valley.

The surface roughness can be evaluated by a number of contact and non-contact methods which include Portable Roughness Tester, Atomic Force Microscopy, X- ray Diffraction, Scanning Electron Microscopy, Transmission Electron Microscopy, High Resolution Transmission Electron Microscopy, and Field Emission Scanning Electron Microscopy.

2. Lapping Process

[8]Lapping is a precision machining process for producing fine finish surfaces. This is a slow cutting action process. Apart from achieving reduced surface roughness, it another purpose is the removal of material as well as to modify the shape and to improve surface form accuracy, which includes flatness of flat surfaced and sphericity for ball shaped objects. Lapping is an abrasive based machining operation where loose cutting abrasive particles play a very major role in achieving the desired surface finish. A number of loose abrasive are available for the machining. These abrasives provides cutting action with multipoint cutting edges that results in material removal by chips that are smaller than the one in finishing operations using cutting tools having defined edges. These abrasive based process is suitable for a large number of material application that are typical employed for the components used in aerospace applications, automotive industry, fluid sealing, handling and other precision engineered industry applications. Lapping process is performed by a lapping machine which consists of a circular flat lap plate generally of cast iron, three conditioning rings for holding work pieces, lapping lubricant supply pipe and driving motor. The operation is performed of rubbing motion of work piece and lapping plate with loose abrasives between them. The abrasives perform the cutting action and are applied on the plate in the form of slurry made by mixing with lapping lubricant oil in certain fixed ratio. It helps in reducing wear and tear between the two as well as dissipating heat and removal of waste chips from the lap plate.

3. Lapping Abrasives

Abrasives are generally micron sized particles have hardness and multiple undefined cutting edges. Selection an abrasive is done based on material hardness, desired surface roughness value, material remove rate and operating cost. [18]Generally four types of lapping abrasives are used namely (1) Silicon Carbide (SiC) (2) Aluminum Oxide (Al_2O_3) (3) Boron Carbide (4) Diamond. These abrasive have unique properties and application for various materials. Silicon Carbide possess a blocky geometry and used for rough finishes where high material removal rate is requirement. Aluminum Oxide possess an angular sharp structure, softer than SiC and used for non-ferrite materials where fine finish and low material removal is required. Boron Carbide is harder compared to the SiC and Al_2O_3, possesses a crystal block structure and provide moderate surface texture quality. Diamond is the hardest material with sharp edged structure and provides extreme fine surface finishes at low grain size. Diamond abrasive are highly expensive.

Lapping process consists of certain factors to be controlled in order to achieve the desired results which includes abrasive grain size, lapping load, lapping lubricant, work piece material and operation time. Thus in a lapping operation, low grit size abrasive (high grain size) is used when high stock removal is the requirement and high grit size abrasive (low grain size) is used when high surface finish is the requirement.

4. Literature Review

Justyna Molenda and Adam Barylski [1] conducted the lapping operation on Al_2O_3 sealing elements, where the major aim was to analyze different operating parameters and the outcomes of machining operation. The machining outcomes to be studied were surface roughness R_a and material removal rate (MRR) under varying lapping parameters such as the grain mesh size, applied pressure and operation time. Each of the test specimens were weighed before and after of the process to check the material removal rate in gm/min, and also the thickness of each specimens were measured before and after of the process to determine the material removal rate in mm/min. The lapping operation was done using single plate lapping machine ABRALAP 380, that consists of three conditioning rings and cast iron lap plate with provided grooves at a speed of 64 rpm. The abrasives material used for the experiment was Boron Carbide. The lapping operation was performed for 15 and 20 minutes duration. The results from the experiment was obtained such that the material removal rate is maximum for 20 minutes operation time compared to 15 minutes operating time. Surface roughness of the end product highly depends upon the abrasive grain size. The smaller the abrasive grain size used, the better is the surface finish acquired. It was concluded that material removal rate and surface roughness majorly depends upon the lapping abrasive grain size and the operation time.

Casmir Agbaraji and Shivakumar Raman [2] conducted the research experiment for lapping operation on three materials as Aluminum 2024, Stainless steel 304 and 1018 Steel by utilizing three abrasive types, namely silicon carbide, garnet and aluminum oxide. They performed an in depth experimental analysis and especially for the effect on material removal rate and surface roughness resulted by three different abrasives were studied. To determine the influence of each process parameters on the outcomes, ANOVA was performed. The test specimens were weighed before and after the experiment to check the material removal rate in gm/min.

Table 1 Abrasives used in the experiment [2]

Abrasive	Knoop Hardness ($kg\ mm^{-2}$)	Hardness number (Mohs)	Grain size (µm)	Color
Garnet	1360	8	23, 8	Brown
White Al_2O_3	2000 – 3000	9	23, 8	White
SiC	2100 - 3000	9.5	23, 8	Grey

From the process, it was founded that Al_2O_3 and SiC abrasive resulted in high material removal rate compared to garnet. Out of the three abrasives used Al_2O_3 gives the best surface finish. The material Al 2024 depicted a good surface compared to SS 304 and 1018 Steel, maybe due to the reason that as it is softer in nature so the material removal is easier and faster compared to the later. ANOVA results suggested that the effect of abrasive grain size, hardness and type of work material had effect on the output surface finish and material removal rate. Further, there also occurred a two way interaction between the abrasive grain size and work material.

J. Kang and M. Hadfield [3] performed the process of lapping upon Si_3N_4 ball bearing blanks that had different fracture toughness and surface hardness, by using different loads, operating speeds as well as lapping lubricants by employing a novel eccentric lapping machine. The lapping machine was designed, developed and made by author in house. The machine's upper plates with flat lap surface is stationary, while the grooves are provided on lower plate that is driven by AC motor using belt pulley drive mechanism.

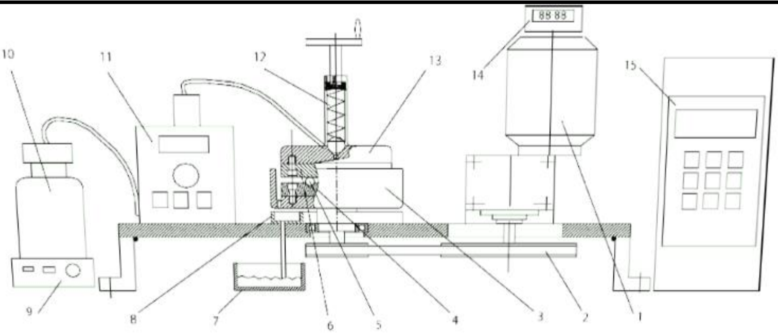

Figure 2 Novel eccentric lapping machine [3] (1) AC motor and gearbox combination; (2) pulleys and belt; (3) flange shaft; (4) lower plate; (5) ceramic ball; (6) upper plate; (7) lapping fluid collection tank; (8) lapping fluid tray; (9) Magnetic stirrer; (10) lapping fluid container; (11) pump; (12) spring-loading unit; (13) Backing plate; (14) time counter; (15) Micro Master inverter.

It was found that material removal rate increased linearly as the operation speed increases. At high operating speeds (above 270rpm), cracks as well as surface spalls were spotted on the material after the process. As the study included number of operation parameters, ANOVA was employed to determine the significance of the parameters, which described that the lapping load is the most influential factor. It was observed that at high load conditions, the balls did not roll freely much and on the other hand roundness error of the rolling balls increased. The lapping fluids had effect on the material removal rate at low load conditions, but their effect was very less at high load condition on material removal rate. The conclusion for material removal mechanism of lapping process using eccentric lapping machine on bearing balls of Si_3N_4 was due to mechanical abrasive wear mostly.

Ramkumar R, Nishanth S, and Balaji V [4] performed the lapping operation on mild steel work piece material, using a single plate lapping machine. They used Al_2O_3 as lapping abrasives. They reduced the size of Al_2O_3 lapping abrasives from micron range to Nano range. This reduction of size of particles of Al_2O_3 was accomplished using a Planetary Ball Milling machine. Initially the work piece specimen were turned on a conventional lathe, followed by grinding them using a surface grinder in order to achieve a certain initial finish of surface. Then after the work piece were lapped using Nano abrasives. When the mild steel specimens were lapped using micro Al_2O_3 abrasives for 30 minutes, the overall surface finish was obtained as 0.19 µm. While lapping the work piece using Nano Al_2O_3 abrasives for 15 minutes, the surface roughness value was obtained as 0.07 µm. Thus finer the grit size, better is the surface finish results.

M. R. Pratheesh Kumar, B. S. Arun and R. Aravind Babu [5] performed the lapping operation on stainless steel specimens of circular in shape. They planned and conducted the experiment using Design of Experiment. The lapping abrasive material was Al_2O_3 abrasive particles. The initial and final thickness as well as weight of specimens were checked in order to comment on the material removal rate. For the design of experiments, they employed the 3^3 fractional factorial design. The three parameters chosen for the experiment were abrasive, time and load with level values of each. The experiment was conducted on an automatic single plate lapping machine with three conditioning rings. Performing a series experiments by varying the process parameters, the effect upon responses such as material removal rate and surface finish was studied. The experiment results were then studied for optimization using MINITAB software. It was concluded that the material removal decreases with decrease in abrasive grit size and on the other hand increases with increase in lapping load. In order to reduce the material removal rate and surface roughness a combination of factors including low value of load, high value of operating time the smallest possible size abrasive should be employed for the optimal results.

Dobrescu Tiberiu Gabriel, Pascu Nicoleta Elisabeta, Ghinea Mihai and Popescu Adrian [6] studied the process of lapping operation on silicon wafers. The process was designed properly and analyzed by employing ANOVA techniques. The design of the experiment was done by employing factorial design. The factors considered as input parameters for the experiment were (1) Lapping pressure (2) Lapping oil (3) Abrasive grain size (4) Operation speed. Each factors was chosen at two level values of them. The study was conducted on a parallel plane lapin machine. Here the surface roughness of the silicon wafers were before and after the machining in order to comment on the percentage improvement of surface roughness value due to the considered process parameters.

Table 2 Experiment operating parameters [6]

Symbol	Factor	Levels	
		High (+)	Low (-)
A	Grain size	320 mesh	600 mesh
B	Lapping pressure	4.144 [N/cm^2]	0.828 [N/cm^2]
C	Number of supply of lapping compound	41	20
D	Lapping speed	30 rpm	10 rpm

From the study it was concluded that, the improvement of the surface roughness value of wafers highly depend on the grain size. The effect of the lapping lubricant on the output response was found to be very less compared to other input parameters. The material removal rate increases with high grain size and gradually decreases with the decrease in grain size. Thus the most optimal combination for attaining maximum efficiency were, low factor levels for grain size, operation speed and lapping pressure.

Lalit Suhas Deshpande, Shivakumar Raman, Owat Sunanta and Casmir Agbaraji [7] studied the effect of different abrasives on the material geometry. The material used for the study were stainless steel and bronze specimens that were lapped using different abrasives. The abrasives that were used in the study were garnet, Al_2O_3 and SiC with their particle size of 15 µm (600 mesh grit). The height as well as weight of the specimens were measured before and after the experiment in order to comment on the material removal rate. The surface roughness of the work piece specimen were determined using a portable roughness tester in order to understand the percentage improvement in finish due to different abrasives and input parameters. It was concluded that there were no significant changes observed on the surface topography when the specimen were observed by SEM microscopy. While there were significant changes in surface roughness and flatness due to each type of abrasive. The harder and smaller the abrasive size, the better was the flatness and lower surface roughness. Among the three abrasives used, SiC is the hardest, it showed the highest value of material removal rate. Thus SiC with low value of applied load shows the best result for material removal rate, while Al_2O_3 showed the best results for surface finish and flatness. The results of flatness were found to be depend upon the hardness of abrasive and applied load.

Xiaobin Le and M. L. Peterson [8] studied the material removal rate in flat lapping operation under certain operating conditions in order to understand the influence of input factors on material removal rate. The material used as test specimen were nickel-zinc ferrite circular work pieces that are commonly used as magnetic heads in electronic storage industry. Diamond dust suspended in a mixture of ethylene glycol and water was used as lapping abrasive. The experiment was initiated by first charging the entire lapping plate by diamond abrasive and running the machine for 15 minutes without putting the work piece in the conditioning rings. Here the experiment were conducted in two consecutive groups with aim to study the material removal rate more closely. The difference between the groups of experiment was in the applied load and abrasive concentration. The lapping operation was conducted for 15 minutes for both the groups. After the experiment, it was observed that the material removal rate increases as the process time increases since the lap plate charging time. As the time passes, the abrasive concentration decreases between the plate and work piece, which results in dry wear and tear, resulting under uneven material removal rate and cutting action. As the time passes, after a certain interval the abrasives break down into smaller particles and gets carried away with lapping lubricant resulting in less particle participation in cutting process. Thus the production time rises, and decrease in material removal rate. When the load applied is more than needed, and as diamond is hard material, they found the particles getting embedded on the lapping plate as well as on work piece surface resulting in decrease in surface finish. During the lapping it is very necessary to remove the waste slurry at regular time interval from the plate surface.

G. Q. Cai, Y. S. Lu, R. Cai and H. W. Zheng [9] studied the operation of plane lapping and polishing. They studied the process by both, with and without the guarding ring to study the pressure distribution in the process. They found that for lapping and polishing operations, applied load is an important parameter. As there is increase in applied load, the material removal rate also increases linearly so there always exist differences of material removal rate for different amount of applied load. During the study contact touch between the work piece and lap plate was assumed as frictionless. During the study, they considered certain assumption as (1) the abrasive grains have equal spherical geometry of same size (2) abrasive grains move between the work piece and plat only by action of rolling (3) individual abrasive grain don't interfere. For pressure distribution without guard ring, they took the following ratio as Ø: $\mu_1 (1-v_0) / \mu_0 (1-v_1)$ where v_0, μ_0 and v_1, μ_1 are poisons ratio and sheer modulus of elasticity of the work piece and plate respectively.

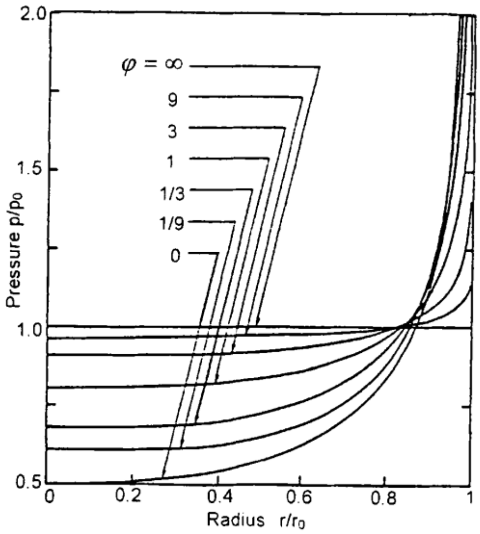

Figure 3 Effect of factor Ø on pressure distribution [9]

From the figure for Ø values, it depicted that distribution of lapping pressure is mostly uneven, which increases as the work piece radius. So usually high Poisson's ratio and shear modulus of elasticity are the significant properties for lapping plate material. They concluded that in case for lapping with guard ring, the ring material and the pressure distribution are independent. With the increase in radius, work piece surface pressure increases and it even more near the edge. The distribution for pressure is even for range of E= 0.5 to 0.8, where E is ratio of load bearing on the guard ring to the total load. When less than 0.5, partial contact takes place on the ring. In other words, in case of lapping with guard ring, contact pressure will be well distributed for certain suitable ring size and load ratio E.

Andrea Deaconescu [10] discussed regarding a computer software based intelligent decision assisting system that is developed for attaining the optimization of lapping operation by employing Taguchi's techniques. For a process, in order to narrow down to a decision regarding any factor or method or approach, number of multiple elements has to be kept in mind. From the view point desired operation outcomes and in order assist in decision making, a computer based system was developed to assist in reduction of human error involved in studying of any situation for the process. The software Lappmaster works based on the algorithm generated by Taguchi techniques for design of process. The computer application assists the experimenter in collecting and organizing the data for the experiment thus generates certain analyzed results to help in undertaking the best decisions. This approach for studying and analyzing the factors was done by employing Ishikawa diagram and Pareto chart, which arranges the factors in order of their contribution and significance for the process. This also helps in minimizing the variability in results due to uncontrollable noises in the working environment as it affects the variability of the output responses.

Tetsuro Iyama, Ikuo Tanabe, Aung Lwin Moe, Kazuo Yoshi and Fumiaki Nasu [11] carried out a study regarding the development about an automated lapping operation system for machining of dies and moulds. The designed system comprised of elementary lapping tools with a standard milling machine. Different materials such as SKD61 (high carbon with chromium alloy tool steel) and V10 (powder metallurgical steel) achieved mirror surface by machining in this system. In the present study, with the help of calculations from lapping models they developed this intelligent lapping operation system for operating at optimum conditions. They studied the interrelationships among the surface roughness Ra, Vickers hardness of test specimen, applied operating pressure and grain size.

Evans C. J., Paul E., Dornfeld D., Lucca D. A., Byrne G., Tricard M. and Klocke F. [12] reviewed and described the basic mechanisms involved in the material removing for lapping and polishing processes while identifying the key relations existing in a lapping process. They described that for any of the lapping operation, there exists four process components and mechanisms for the material removal are explained by the interactions as well as interrelationships among these four components. These components are (1) Test specimen (2) Lapping lubricant (3) Abrasive grain (4) Lap plate. There exists six numbers of pairing interactions among the above stated components, out of which three interactions does not include test specimen and other three includes it. Applied loading conditions for the process are a key factor in material removal. The relation between the abrasive grain size and the test specimen appears linear since as the grain size differs surface of the test specimen gets affected respectively.

5. Conclusions

I. Aim of the lapping process is to provide the desirable work piece quality such as high surface quality and reduced dimensional errors. Stock removal and the end surface quality depends upon certain parameters namely lapping load conditions, specimen material, lapping lubricant, operating speed and time.

II. Pressure distribution in lapping and polishing process are uneven, as it is low in the center and rises up near the specimen edge. It also depends upon the use and no use of guard ring and size of the specimen.

III. Material removal rate and surface roughness highly depends upon abrasive grain size, lapping load and operation time.

IV. Diamond is the hardest abrasive material, it provides best surface finishes for operation with its low grain size. The fine grains carry away comparatively less material, each of them cuts less and generate less heat, resulting in best surface finish. Low grit size (high grain size) are suitable where high stock removal is the requirement with moderate surface finish.

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