International Journal of Research in Engineering and Innovation (IJREI)
journal home page: http://www.ijrei.com
ISSN (Online): 2456-6934

ORIGINAL ARTICLE

A comprehensive review of advancements in surface grinding techniques and parameters

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Article Information

Received: 05 August 2024
Revised: 18 October 2024
Accepted: 21 November 2024
Available online: 15 November 2024

Keywords:

Roughness
Material Removal Rate
Surface grinding
RSM
Taguchi
ANOVA

Abstract

Surface grinding is a crucial machining process used to achieve precise, smooth finishes on flat surfaces, influenced by factors such as grinding wheel speed, cutting depth, feed rate, material properties, and tool quality. These parameters significantly affect surface roughness and material removal rate (MRR), the two primary performance metrics. This review examines recent advancements in surface grinding, focusing on optimization techniques like the Taguchi method, response surface methodology (RSM), and analysis of variance (ANOVA), which have improved both MRR and surface quality for materials like EN8, EN31, and Inconel alloys. The paper also discusses the use of advanced tools such as cubic boron nitride (CBN) wheels, which offer superior performance compared to traditional grinding wheels. Additionally, it highlights challenges in achieving consistent results and the potential for further improvements through innovative methods, modeling, and simulation. The findings provide a comprehensive overview of surface grinding research, identifying areas for future development and optimization in this field.

1. Introduction

Grinding is a material removal and finishing process widely used for shaping and refining the surfaces of metal and other materials. It is renowned for its precision, often exceeding the accuracy of lathes and milling machines by a factor of ten. The process utilizes abrasive particles embedded in a tool, commonly referred to as grit, to achieve the desired finish. Surface grinders typically comprise an abrasive disk, a holding device (electromagnetic or vacuum-based chuck), and a reciprocating table. [1] Commonly used materials in grinding processes include steel and cast iron, which exhibit minimal tendencies to clog the grinding wheel. Other materials, such as aluminum, stainless steel, brass, and certain plastics, are also frequently employed.

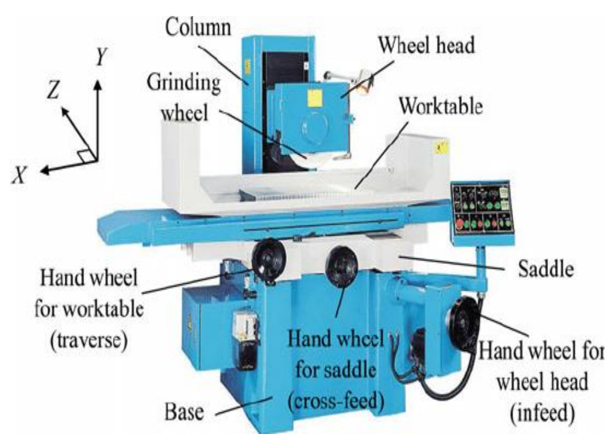

Figure 1. Schematic Diagram of Surface Grinding Machine [1]

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https://doi.org/10.36037/IJREI.2024.8404.

2. *Literature Review*

Sanjeevi, R., Kumar, et al. [2] investigated the optimal value of fine surface roughness on material EN24 using the response surface method. According to the ANOVA results, the cutting depth and greater grinding wheel velocity were the important factors in SR. The effect of DOC and velocity on SR is seen in figure 2.

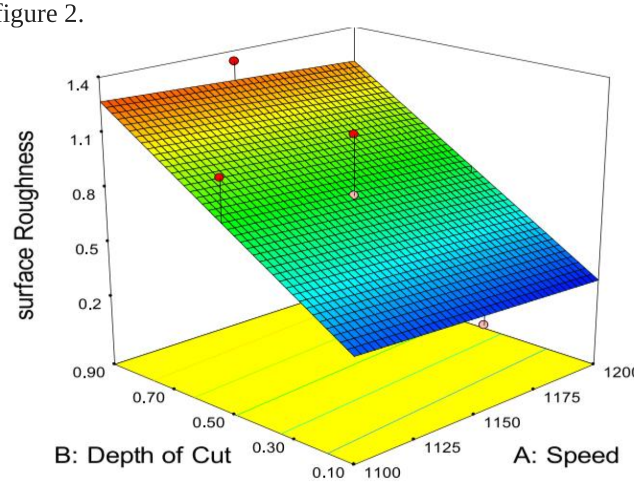

Figure 2. Relation Between Input and Output Parameter [2]

De Souza Ruzzi, R., et al. [3] computed that wheel velocity was the important input parameter and cutting depth was the second most important of all output parameters on material Inconel 625. Surface roughness, cutting force, and specific energy decline with increasing wheel velocity. With increasing wheel velocity, plastic deformity leads to decreased surface quality (increased surface roughness) and increased surface hardness due to strain hardening. Additionally, it can be seen from Fig. 3 that work strengthening is generally unaffected by the abrasive grit size.

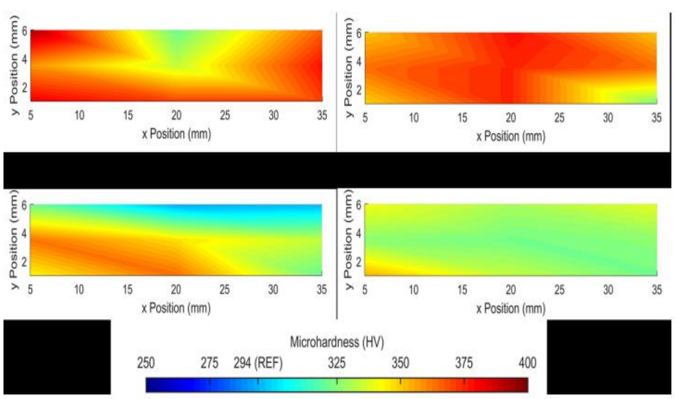

Figure 3. Microhardness distribution on the Inconel 625 alloy surface after grinding in various cutting conditions [3]

Saravanakumar, A. et al. [4] computed better surface roughness on mild steel using Taguchi L18 orthogonal array. They found three parameters for cutting depths that have the greatest influence on surface roughness. The analysis of the grinding parameter revealed that, compared to other interactions, the relationship between both table speed and cutting depth had the greatest impact on surface roughness. He, Z., Zhao et al. [5] analyzed modeling is done to look into jet pressure, plastic strain, and the circulation of RSF for a WJP process on aluminum 6061 alloy, while experiments are done to look into the impact of peening parameters based on the CEL technique in ABAQUS. While erosion intensity rises with higher jet pressure, more jet passes, and a steeper incidence angle, it falls with higher jet traverse velocity. Li, P., Jin, T., et al. [6] computed the consequences of wheel velocity on the discharge action of brittle optical metals. Grinding power, ground surface roughness, ground surface aspects, and surface deformed depth are better by rising the wheel velocity for grinding operation. However, there is a limit to the improvement of the ground surface by increasing the wheel speed, and this is thought to be due to the effects of vibration due to the increase in the wheel velocity. The variable used for analyzing the consequences of wheel velocity is represented in table 1.

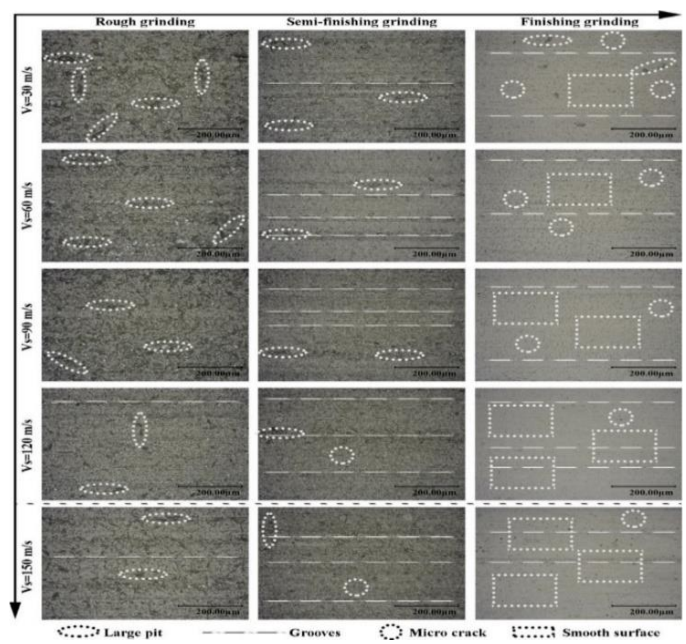

Figure 4. Surface morphologies versus the wheel speed for the three grinding processes [6]

Figure 4 displays the 2D visual known for appearing surface combined with crystal optical glass made using various disk velocities and grinding techniques. The fragmented areas' pits, pores, and micro cracks decrease as the wheel velocity rises from 30 meters/sec to 120 meters/sec for each grinding step, while the polycarbonate areas scraping or plowing grooves, and graceful surface rises. However, when the disk velocity is increased from 120 meters/sec to 150 meters/sec, the ground morphologies do not significantly alter. Ranga, P., & Gupta, E. D. [7] reviewed different factors, such as wheel velocity, cutting, feed, coolant, etc. for material EN 31. On numerous machines, including CNC turning and CNC surface grinding, it has carried out all these parameters on a variety of materials, including EN8, EN10, and EN24, among others. It is found that all these parameters are important for surface roughness. Sinha, M. K. et al. [8] studied the surface burnt of an alumina wheel to a SiC wheel for dry grinding using Inconel 718, the apparent coefficient of friction is the smallest when using an alumina wheel. The easier it is to grind, the less heat is produced, and eventually, there are no burn marks on the ground surface. This is indicated by a lower value for the degree of friction seen in fig 5.

Table 1. Variable used in Grinding of Fused Silica [6]

Grinding	Grit size	Density of active grains	Grinding speed	Work speed	Depth of grinding	Material removal rate
Conditions	d_g (μm)	C (mm^{-1})	v_S (m/s)	v_W (m/min)	a_p (μm)	Z_W mm^3/s
Rough grinding	151 μm	7.975	30, 60, 90, 120, 150	2.4	200	8
Semi finishing grinding	91 μm	19.184	30, 60, 90, 120, 150	1.2	50	1
Finishing grinding	41 μm	97.076	30, 60, 90, 120, 150	0.6	10	0.1

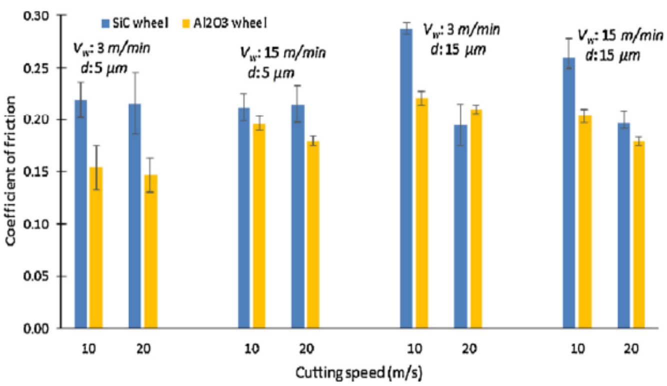

Figure 5. Coefficient of friction variations [8]

Praveen Kumar, V. Kolhar, and Dr. R.G. Mench [9] analyzed the optimization of process parameters in piston grinding operations using the Taguchi technique. Their findings indicated that reducing the cutting depth and increasing speed significantly minimized the need for rework. Manimaran, G., and Kumar, M.P. [10] conducted a study on the impact of different cooling environments, including dry, wet, and cryogenic cooling, during the grinding of EN31 bearing steel. Their results showed that using an SG wheel reduced surface roughness by approximately 24% and 12% under cryogenic cooling compared to wet and dry cooling, respectively. Al_2O_3 wheels demonstrated reductions of about 20% and 6% under the same conditions. Although cryogenic cooling provided superior results, it occasionally caused minor surface defects, especially at high feed rates and work speeds.

Kumar Patel, D., et al. [11] explored the surface finishing capabilities of EN8 steel in both surface and cylindrical grinding. Their study revealed that surface grinding produced a finer finish compared to cylindrical grinding. Furthermore, the grinding wheel's material and grade were identified as key determinants of surface roughness in both methods. Pal, D., Bangar, A., Sharma, R., and Yadav, A. [12] investigated the grinding parameters for materials such as EN24, EN31, and die steel using the Taguchi L9 orthogonal array. Their research demonstrated that an increase in grinding speed reduced surface roughness, with improvements observed as speed rose from 100 to 160 rpm and again at 200 rpm. Similarly, increasing the grinding disk grain size from G46 to G60 contributed to smoother surfaces, with reduced roughness corresponding to increased material hardness.

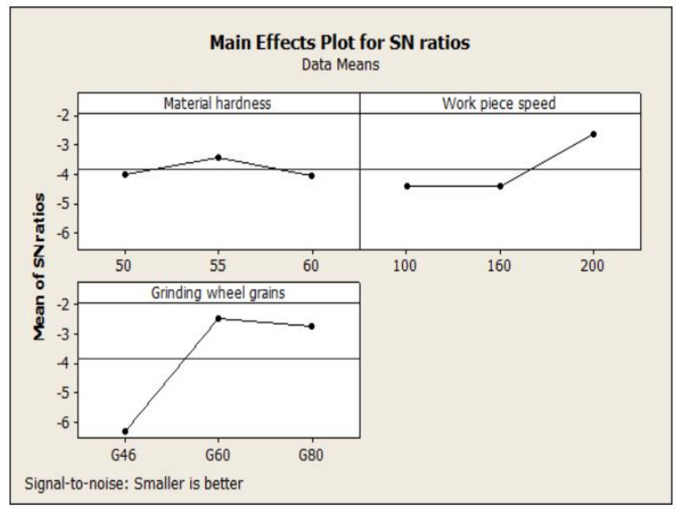

Figure 6. Main Effect Plot for SN Ratios [12]

Demir, H. et al. [13] investigated the relationship between SR of AISI 1050 steel and grinding force values and the size of the grinding disk grain. It was observed that the grinding force increased with an increase in grinding wheel grain size. The Ra measurement and grinding forces increase as the grinding wheel grain size increases. Luo, S. Y., et al. [14] investigated the effect of the diamond grain size, the wheel rotation speed, table rotation speed, and applied pressure on surface roughness using Taguchi L9 orthogonal array The abrasive particles acquired on the Si wafer during exact grinding had a tight presence in the middle with a slimmer chip, resulting in a smaller number of pits. The most significant factor for the consequence of Si wafer SR was the diamond grit size. The diamond grit shape had a significant impact on the SR of the wafer generated by grinding. According to the response of the S/N ratio figure. 7, using the slightest diamond grit shape of 1000 mesh produced silicon wafers with the least amount of roughness.

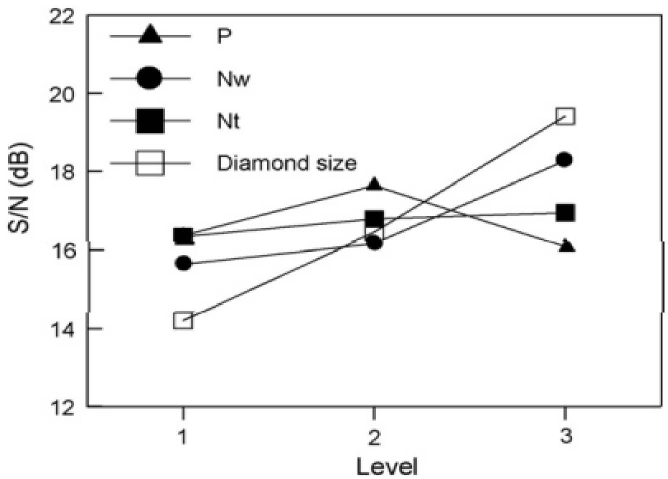

Figure 7. S/N ratio effects for each factor on surface roughness of silicon wafers produced. P: pressure; N_w: wheel rotation speed and N_t: table rotation speed. [14]

Tang, J., Du, J., and Chen, Y. [15] introduced a novel mathematical model to predict grinding forces during surface grinding operations. Their work analyzed how various grinding parameters influence the dynamic mechanics of metal cutting, as well as the frictional interactions between the workpiece and the grinding disk. The model emphasizes the relationship between grinding settings and the mechanics of material removal, offering a detailed framework to better understand the forces at play during the grinding process. To calculate the grinding force accurately under the same grinding disk and component metal circumstances. This grinding force model saves money and reduces experimentation when compared to the conventional model. Izman, S., & Venkatesh, V. C. [16] produced Plano surfaces on glass by surface grinding. It was studied crystal chips that gel up cause the grinding wheel to load up and need frequent dressing. Using a center chamber stops this self-defeating activity along with zero velocity tracks and halting. At varied grinding factors and coolant flow rates, they tested with grinding pins with and without center chambers (figure. 8).

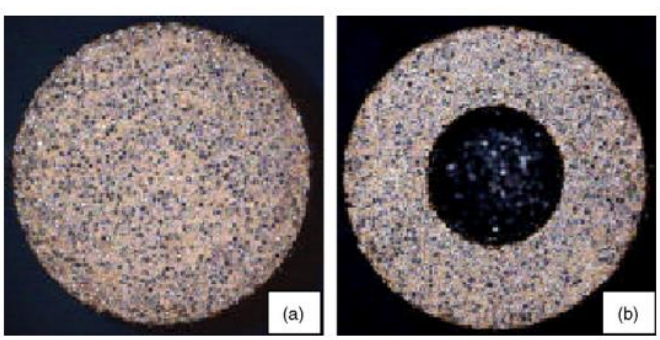

Figure 8. Grinding face of a resinoid diamond pin. (a) Original condition. (b) After ultrasonic drilling to produce central cavity [16]

Young, H. T., et al. [17] explored the influence of grinding parameters on subsurface damage in silicon wafers. Their findings indicated that larger grit sizes led to deeper cracks, with grit size being the primary contributor to crack formation. Additionally, the rotational speed of the chuck was found to exacerbate crack depth, although higher wheel rotation speeds reduced the severity of cracks. The study also assessed silicon chip particle details during grinding to identify factors contributing to surface fractures. Young, H. T., and Chen, D. J. [18] examined the online dressing of conventional aluminum oxide grinding wheels (WA120K8V, GC90U9V, 180 mm×13 mm) while grinding advanced carbide steel (S45C, HRB105). Their research highlighted that the sharpness of the grinding disk could be restored with minimal dressing passes, as determined by the power ratio. The dressing process was complete once the dressing force ratio stabilized. Kwak, Jae-Seob [19] analyzed geometric inaccuracies in surface grinding using response surface methodologies. The study revealed that cutting depth was the most significant factor affecting geometric errors, followed by grain size. Percentage distributions of errors were also mapped to illustrate the influence of these parameters on dimensional precision.

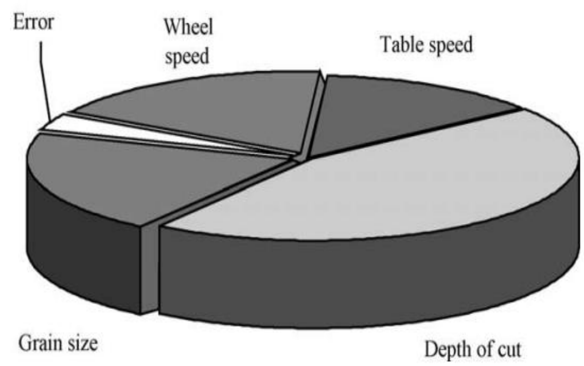

Figure 9. Circulation of grinding domains for the dimensional error [19]

Agarwal, S. et al. [20] highlighted that surface roughness is a major quality of the ground product. A novel scientific model for roughness forecast has been matured. Along with other grinding variables, the intersecting effect is included in the model. Further realism has been added by including the overlapping effect, helping to accurately guess the SR as well as to form ceramic grinding repeatable. Surface roughness is predicted by the chip thickness model. Shaji, S., & Radhakrishnan, V. [21] analyzed surface roughness in surface grinding with graphite as lubricant using the Taguchi method. In comparison to conventional grinding, the tungsten carbide implementation, tangent pressure, and SR have been found to be lower, whereas the normal pressure is higher. Based on the results of the current study, a more thorough investigation can be conducted to characterize the performance of the suggested grinding method.

3. Conclusion and Future Scope

This literature review examined the influence of various essential variables like grinding wheel velocity, bench travel velocity, and cutting depth on the responses i.e., SR and MRR in case of surface grinding machines. Because of the wheel's relatively high surface velocities and greater contact area with the workpiece, a rigid boundary layer forms around wheel periphery, restricting the flow of cutting fluids into the grinding zone. The values were predicted by Response Surface Methodology (RSM) Taguchi, and the experimentally obtained values showed close agreement and showed better fit. The SR of surface grinding is better than the surface roughness of cylindrical grinding. They were observed or considered with different factors, for example, wheel speed, cutting depth, table feed, coolant, and so forth. All of this was done with many materials such as EN8, EN10, and EN24 on grinding machines such as surface grinding and cylindrical grinding [2][7]. After thoroughly reviewing numerous research studies on surface grinding, it is evident that this process is highly intricate, requiring careful control of various parameters to achieve an optimal surface finish. Researchers have employed a wide range of methods and techniques to enhance outcomes, with each approach tailored to address specific challenges. However, there remains significant potential for exploring and adopting advanced optimization strategies to further refine the process and consistently achieve superior results. A lot of work can be done on optimization methods such as TOPSIS and GRA using ANOVA. In addition to characterization, process control, and optimization of titanium alloys, stainless steel, etc., important research and understanding are required in terms of material preparation. CBN grinding axles have greater productivity and machining capacity with low surface roughness than traditional grinding wheels with good cutting capacity and high heat capacity.

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***Cite this article as*:** Radhey Shyam Mishra, Ranganath Muttanna Singari, Neeraj, A comprehensive review of advancements in surface grinding techniques and parameters, International Journal of Research in Engineering and Innovation Vol-8, Issue-4 (2024), 162-166. *https://doi.org/10.36037/IJREI.2024.8404*.