OPTIMIZING SURFACE QUALITY AND DEFORMATION IN GRINDING OPERATIONS OF STAINLESS STEEL

Yogesh Dileep Lande[1], Dr. Nitin Yashwant Patil[2], Dr. Gaurav D. Sonawane[3]
[1]*Research Scholar, Sri Satya Sai University of Technology and Medical Sciences, Sehore, M.P., India*
[2]*Professor, Mechanical engineering department, S S J C E T, Asangaon, Maharashtra, India*
[3]*Associate Professor, Sandip Foundation's SITRC, Nashik, Maharashtra, India*

ABSTRACT

The obtained findings may serve as a guide for selecting suitable grinding settings in the process of machining 304L. Additionally, they can contribute to the comprehension of the failure mechanism of ground austenitic stainless steel components during their operational use. The crucial correlation between the surface quality and deformation in grinding operations of stainless steel. The topic is on the difficulties presented by the hardness and ductility of stainless steel, highlighting the significance of selecting the best grinding settings, suitable wheel choice, and efficient cooling systems. The main causes of deformation during grinding are residual strains and heat impacts. It is recommended to use innovative technology for monitoring and controlling the process in real-time. The investigation into alternate grinding techniques underscores the industry's dedication to surmounting obstacles and attaining accuracy in the production of stainless steel parts, which is essential for satisfying contemporary requirements in many fields.

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I. INTRODUCTION

The surface quality and distortion in grinding operations of stainless steel are crucial factors that have a major impact on the performance and functioning of the end product. Grinding is a commonly used machining technique in several sectors to obtain accurate forms, narrow tolerances, and enhanced surface qualities. Stainless steel, renowned for its resistance to corrosion and long-lasting nature, is widely used in several fields, including aerospace engineering and medical equipment manufacturing. The complex correlation between surface quality and deformation in stainless steel grinding processes is crucial for guaranteeing the integrity and functioning of the final components. Attaining the appropriate surface quality in stainless steel components is a challenging task within the field of production and machining. The grinding process has distinct problems due to the inherent hardness and high ductility of stainless steel. The fundamental objective of grinding operations is to eradicate surface abnormalities, such as scratches and tool marks, while concurrently preserving the structural integrity of the material. Obtaining an ideal surface texture is essential for situations when appearance, cleanliness, and protection against rust are of utmost importance, as is often the scenario with stainless steel parts in medical devices, food processing machines, and architectural constructions. The selection of suitable grinding settings is a crucial component that significantly affects the surface quality in grinding operations. The parameters include wheel speed, feed rate, depth of cut, and coolant application. Attaining the intricate equilibrium among these factors is crucial in order to avoid problems like as combustion, changes in the workpiece's metallurgical properties, and excessive elimination of material. The selection of the grinding wheel also has a crucial impact on the surface quality. The effectiveness of material removal and the final surface polish are influenced by the use of abrasives with different grit sizes and bonding compounds. The careful examination of these factors is essential for optimizing the grinding process for stainless steel, guaranteeing the required surface quality and dimensional accuracy of the end product.

Deformation is a significant issue in grinding processes, particularly when working with very robust materials like stainless steel. Grinding may cause many types of deformation, such as residual stresses, warping, and changes in microstructure, due to the mechanical forces and heat impacts it produces. Residual stresses, caused by uneven material removal, may weaken the structural integrity of stainless steel parts, possibly resulting in early failure or decreased resistance to corrosion. The task at hand is to efficiently handle these remaining stresses in order to minimize the danger of deformation while preserving the acceptable surface quality. Moreover, the heat impacts that occur during the grinding process may have a substantial impact on the deformation of stainless steel. Heat produced at the grinding contact may cause localized temperature spikes, resulting in thermal expansion and contraction. Uncontrolled thermal cycling may cause dimensional errors and modify the mechanical characteristics of the material. Utilizing efficient cooling systems, such as coolant application, is crucial for dispersing heat and reducing thermal impacts during grinding operations. Moreover, the progress made in grinding technologies, such as cryogenic cooling, has shown potential in further reducing thermal deformation in stainless steel components. A thorough comprehension of the metallurgical characteristics of stainless steel is crucial for understanding the processes involved in deformation during the grinding process. The material's proneness to undergo phase transitions, work hardening, and grain refinement due to mechanical and thermal stresses requires a meticulous approach when choosing grinding settings. Scientists and engineers are actively investigating novel methods, including as adaptive control systems and in-process monitoring, to dynamically modify grinding settings and address deformation problems in real-time. Surface quality and deformation issues are most noticeable when working with complex and very accurate components, such as those utilized in medical implants or aerospace applications. Advanced grinding techniques and a thorough knowledge of material behavior are necessary in these sectors because to the strict demands for surface quality and dimensional precision. Furthermore, the need for making things smaller and more detailed in current applications increases the difficulties in attaining excellent surface quality while maintaining the strength and stability of stainless steel parts.

Progress in grinding technologies, such as the use of abrasive belts, electrochemical grinding, and abrasive flow machining, provide alternative methods to tackle surface quality and deformation problems in stainless steel. These techniques, often used with conventional grinding procedures, provide supplementary means to improve accuracy and minimize the effects of deformation on the end result. Electrochemical grinding is a process that combines the use of electricity and mechanical forces to produce smooth surfaces without any burrs and to decrease the production of heat, therefore decreasing the likelihood of thermal deformation. The assessment of surface quality and deformation during grinding processes of stainless steel is of utmost importance for manufacturers and engineers in many sectors. To achieve the precise combination of a high-quality surface finish and accurate dimensions, a comprehensive strategy is necessary. This strategy should include several factors such as material properties, process variables, and advanced technologies. The industry's dedication to addressing the obstacles presented by the distinctive properties of stainless steel is seen in its continuous efforts to develop cutting-edge grinding methods and include sophisticated monitoring and control systems. With stainless steel's continued popularity in many applications, achieving accuracy in grinding operations is crucial. This ensures that the end products not only meet but surpass the high-quality requirements required by contemporary industries.

II. REVIEW OF LITERATURE

Mizobuchi, Akira &Tashima, Atsuyoshi. (2020). Due to its impracticality and difficulties, dry grinding of large stainless steel sheets is not an option, hence this study focuses on wet grinding instead. Stainless steel may easily experience thermal deformation and grinding burn when wheeled dry without any cooling effect because of its high coefficient of thermal expansion and low heat conductivity. Wet grinding is hence the best choice. Manufacturing several grinding wheels, wet grinding stainless steel sheets, and selecting the best wheels for the job were all part of this study. Our investigation led to the development of a novel attachment for use with wet grinding workpieces. During the process, the attachment may keep the pressure, rotational velocity, and supply of grinding fluid constant. Various experiments were conducted on a stainless steel sheet workpiece (SUS 304, as per the Japanese Industrial Standards: JIS) to ascertain the effect of various grinding conditions on the surface roughness. According to the study, a polyvinyl alcohol (PVA) grinding wheel with 150 rpm of rotational speed, an attachment pressure of 0.2 MPa, and tap water as the grinding fluid may decrease the sheet's roughness. A surface roughness of up to 0.3 µm in terms of the arithmetic average height may be produced while wet grinding, provided that the requirements mentioned above are fulfilled. The surface roughness reached a final value of 0.03 µm after the completion of the polishing process using buffing. This article will be a great reference as it delves into the intricate aspects of wet grinding steel, a topic that has not been well explored.

Bardhan, Prasanta et al., (2020) When studying the grinding process, the surface topography of the machined work-piece is an important consideration since it greatly affects the work-piece's fatigue properties. The purpose of this research is to find the sweet spot for surface roughness and material removal rate while grinding AISI 304 stainless steel using an abrasive wheel made of Al_2O_3. Many factors are considered here, including feed rate, table speed, and depth of cut. By fine-tuning the process parameters using the Taguchi optimization approach, we may get the best surface finish possible during grinding. The two most critical process variables for maximizing surface roughness and material removal rate (MRR) are table speed and depth of cut. The findings indicate that 0.5 mm of feed rate, 16 m/min of table speed, and 0.02 mm of depth of cut are optimal for attaining the target surface roughness.

Tien, Dung et al., (2017) Finding the sweet spot for the grinding wheel diameter while surface grinding stainless steel is the subject of this article's study. Examining the process's related costs forms the basis of the optimization. The ideal grinding wheel diameter is determined by minimizing the cost function. The optimal diameter was determined by analysing the effects of several input technological parameters on it. These parameters included the initial wheel diameter and width, the total dressing cut depth, the workpiece's Rockwell hardness, the wheel life, the radial grinding wheel wear per dress, and the cost components, which included the machine tool hourly rate and the grinding wheel cost. An explicit equation was obtained from the regression study, which could be used to determine the mathematical model's ideal diameter. The reliability of the mathematical model is confirmed by the results of the experiment. In terms of ideal diameter, there was a 1.7% discrepancy between the model and the experiment. This model has the potential to improve the technical and economic efficiency of surface grinding by calculating the ideal switched grinding wheel.

Kumar, Anish. (2013). Surface grinding is a prevalent technique used in the industrial industry to get a polished surface on flat objects. In the grinding process, it is crucial to take into account the surface quality and metal removal rate as the key performance indicators. The primary objective of this research is to investigate the impact of abrasive tools on the surface of EN24 steel. This will be achieved by examining three key parameters: the speed of the grinding wheel, the speed of the table, and the depth of cut. The investigation was done with a surface grinding machine. This study included the development of empirical models to analyze the relationship between surface roughness and metal removal rate.

Dirviyam, Philip Selvaraj& Palanisamy, Chandramohan. (2010). In this research, the method of dry turning Austenitic Stainless Steel (AISI) 304 is examined. In this study, we look at how different cutting parameters affect the surface roughness of austenitic stainless steel during dry turning. These factors include cutting speed, feed rate, and depth of cut. An experimental strategy based on Taguchi's method has been used to gather data. Using an orthogonal array, the signal-to-noise ratio (S/N), and analysis of variance (ANOVA), the cutting qualities of AISI 304 austenitic stainless steel bars are examined using a tungsten carbide cutting tool coated with TiC and TiCN. Its effectiveness in assessing surface roughness was confirmed by confirmation studies that aimed to align the predicted values with the observed ones.

III. RESEARCH METHODOLOGY

Material

This study's substance was austenitic stainless steel 304L (UNS S30403). By weight, it included the following elements: carbon (0.19 percent), silicon (0.32%), manganese (1.55%), phosphorus (0.29 percent), sulfur (0.001%), chromium (18.22 percent), nickel (8.11%), niobium (0.11 percent), copper (0.31%), cobalt (0.16%), nitrogen (0.071 percent), and iron (the rest). In its original state, the material was heated to 1100 °C for solution annealing, then cooled by forced air and quenched in water. To restore the object's corrosion resistance and remove the oxide layer that developed during annealing, it was then submerged in an acidic solution. The material was then roll leveled to make it smoother. At room temperature, the main mechanical characteristics measured in a perpendicular direction to the rolling direction were Rm = 642 MPa, elongation = 54%, hardness = 170 HB, and yield strength (RP0.2) = 230 MPa. The 400 × 150 × 2mm test coupons contained the substance.

Grinding operations

The grinding operations were performed using a Chevalier FSG-2A618 grinding machine, as seen in Figure 1. The image illustrates the use of grinding belts with typical aluminum oxide grits, which are 50 mm wide and 473 mm long. These belts are put on the grinding wheel. Test coupons, measuring 400 × 150 × 2mm, are secured to the working table throughout the grinding process using screws. The grinding wheel used was a 150 mm diameter and 50 mm breadth Kemper Radix Go series wheel. This wheel is an expanding roller composed of 20-mm-thick rubber. The grinding operations were performed parallel to the rolling direction of the material. The grinding speed, vs, was set at a constant value of 23m/s, and the feed rate, vw, was also set at a constant value of 8m/min, as advised by the material source. While grinding, the grinding wheel spun in a clockwise direction, while the working table was reciprocated, allowing for both vertical and horizontal grinding movements. The grinding parameters that were altered included the size of the abrasive grit, the power of the machine, and the lubricant used during grinding. In an industrial grinding operation, these parameters, together with cutting speed and feed rate, may be altered to provide a variety of grinding results. To drive the grinding belt, the machine draws power equal to a certain proportion of the total motor power, which is 1 kW. During the grinding process, we manually adjusted the grinding force using a hand wheel to acquire the required amount of machine power. Mobilcut 321, a synthetic fluid with a specific gravity of 1.10 at 20 °C and a pH value of 9.4.0020, was used as a 3% component in the grinding liquid. Three sets of ground samples were created to evaluate three variables: (I) abrasive grit size, (II) machine power, and (III) grinding lubrication. The material supplier's recommendations informed the selection of the specific grinding settings and procedures, as shown in Table 1.The grinding process started with a coarse grit (60#) for a duration of 5 minutes in order to eliminate the first surface. Subsequent grinding was performed incrementally using progressively finer grit at each stage until the required level of surface smoothness was achieved. Each phase included the application of a fresh abrasive and the grinding process was carried out for a sufficient duration to eliminate the distortion caused by the previous step.

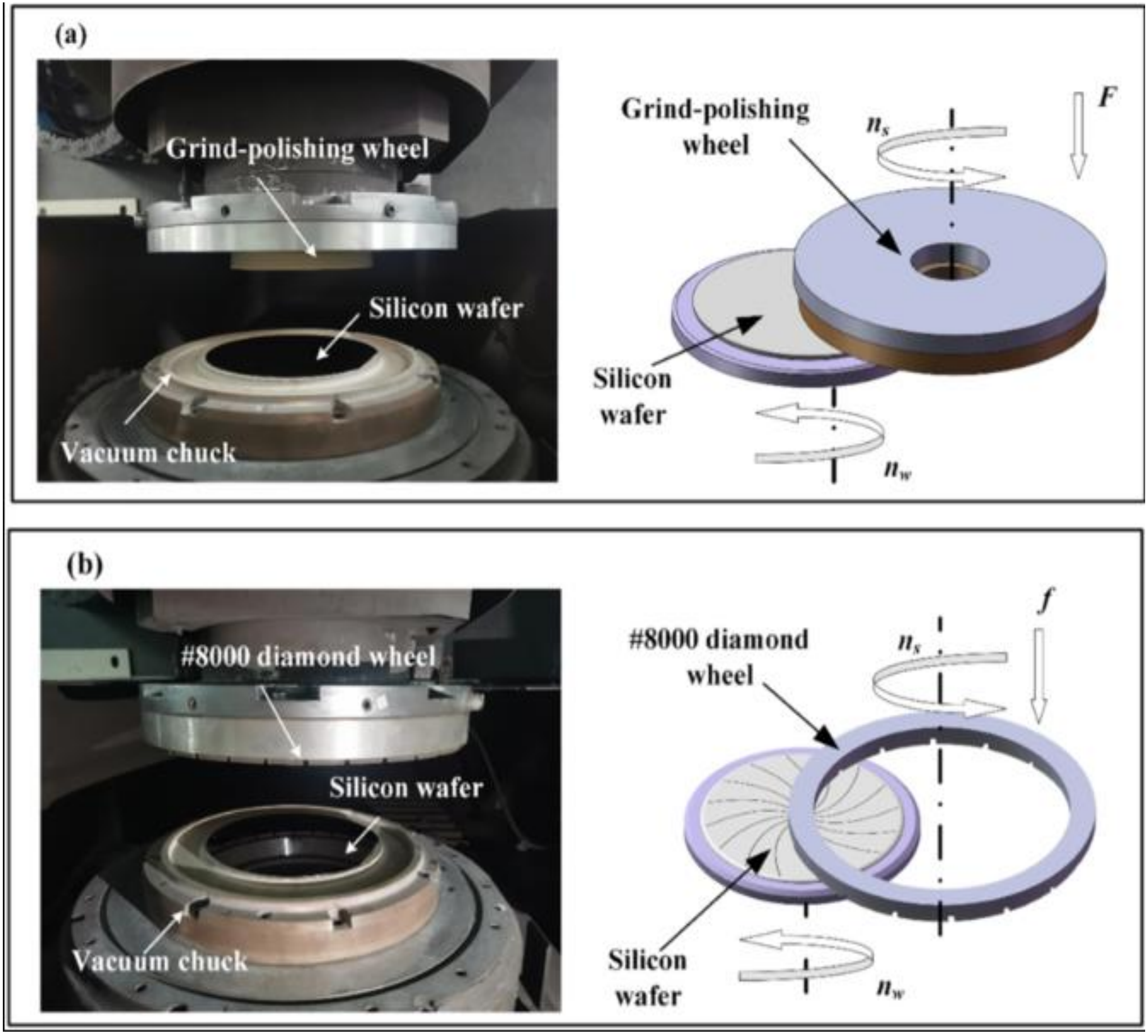

Figure 2. Grinding set-up

DATA ANALYSIS AND INTERPRETATION

Grinding force and measured surface temperature

Table 1 compares the impact of grinding parameters on both grinding force and surface temperature measurements. The findings indicate that increasing the machine's power leads to a proportional rise in the necessary normal grinding force. Observations revealed that the use of grinding lubrication resulted in a significant reduction in the typical grinding force, decreasing it from 110 N to 50 N, although using the same machine power (50%).

The present authors had previously noticed a similar phenomenon while grinding duplex stainless steel 2304. Applying lubrication during grinding operations may assist maintain the sharpness of abrasive grit, decrease friction between the abrasive and the work piece material, and promote a favorable way of creating chips, ultimately decreasing the normal force.

Table 1. Measured grinding force and surface temperature by different grinding conditions

Group no	Comparison	Grinding parameters			Measured normal grinding force (±10 N)	Measured surface temperature
		Final surface finish	Machine power	Lubrication		
I	Abrasive grit size	50	59 %	Without	99 N	59^0 c
		170			99 N	68^0 c
		300			88 N	69^0 c
II	Machine Power	175	29 %	Without	59 N	49^0 c
			59 %		99 N	67^0 c
			89 %		149 N	84^0 c
III	Lubrication	174	59 %	Without	99 N	67^0 c
				With	39 N	34^0 c

Figure 3 shows the results of the surface temperature monitoring close to the work piece material/grinding wheel interaction. Considering that the ground surface's properties are mainly affected by the temperature in the grinding zone and that the infrared camera's settings and surface conditions affect the measured temperature values, the results given here are only meant to show how the temperature varies over time for various grinding parameters.

A significant increase in surface temperature was seen when using a more powerful machine. When the machine's power was increased, the grinding force was magnified right away. This caused the friction between the abrasive and the work piece material to noticeably increase, which in turn caused the grinding heat to rise significantly. Using a finer final surface for grinding (group I) resulted in somewhat greater surface temperatures, which goes against what one may predict.

The most probable explanation is that the total grinding time increased since more grinding processes were required for a more polished finish. There was a little increase in surface temperature, which was explained by the buildup of heat from each grinding operation. However, the power of the machine significantly affects temperature.

The cooling effect of the lubricating process is substantial. Keep in mind that the metal surface temperature may not be the same as the lubricant temperature while taking temperatures during lubrication. Lubrication helps to remove grinding heat and reduces friction between the work piece and abrasive grits. In this study, the average temperature of the grinding surface close to the grinding region is quite low.

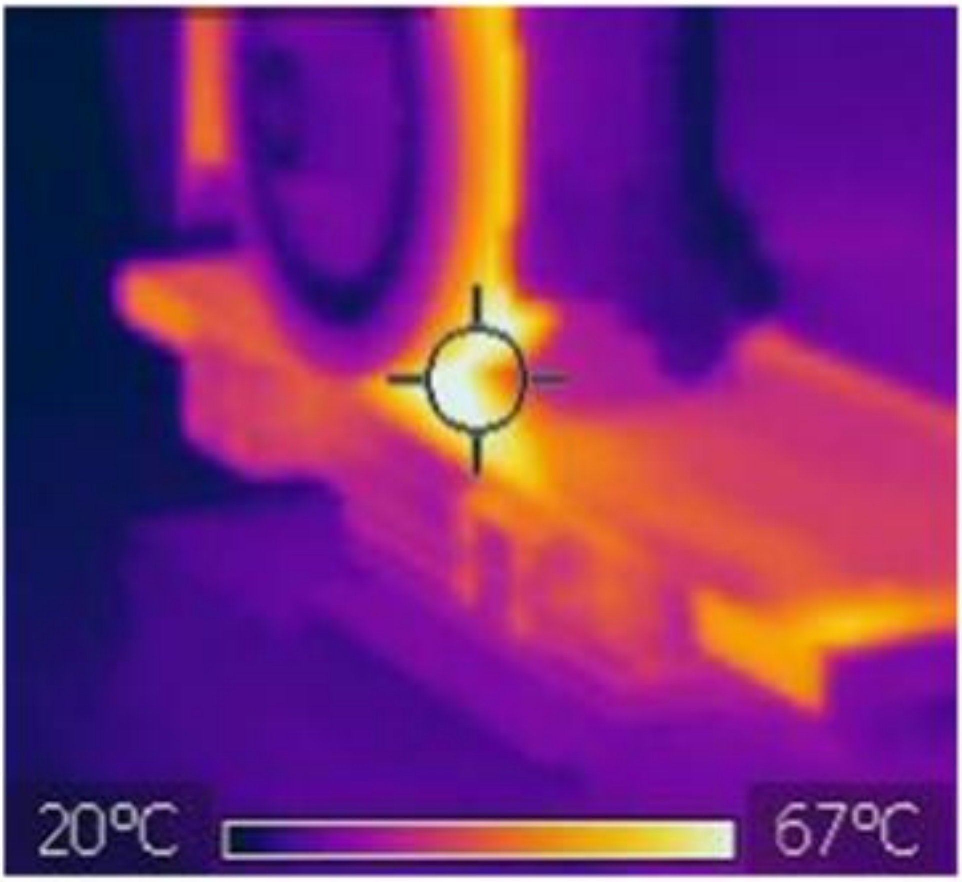

Figure 3. Temperature measurement during grinding operations, showing the measured area, 304L ground by 170# abrasive grit size, 50% machine power, and without using grinding lubrication.

Ground surface roughness and topography

Surface roughness was measured using Ra and Rz values as part of the experiment. The results for different abrasive grit sizes (group I) are shown in Figure 5, with the error bars for each sample indicating the standard deviations of the five measurements taken.

Using an abrasive with a finer grit size for the final surface finish lowers the Ra and Rz values, as seen in the figure. With 50# abrasive grit, the Ra value was 1.81 µm and the Rz value was 18.4 µm. Ra was measured at 0.77 µm and Rz at 10.66 µm, both of which were reduced by about half when a lesser grit size of 170# was used.

Using the minimum grit size of 300# also caused a precipitous drop in Ra to 0.34 µm and Rz to 5.66 µm. Using scanning electron microscopy (SEM), the surface topography and defects caused by different abrasive grit sizes (group I) are shown in Figure 4. Indentations, adhesive chips, deep grooving, and smearing are the main surface flaws seen, as shown in Figure 4a. These same problems have been identified by the writers before while grinding duplex stainless steel 2304.

These defects develop because of a number of interactions that take place during grinding between the abrasive particles and the work piece's surfaces. Deep grooves were cut into the ground surfaces as a consequence of the uneven metal removal process, which includes both plowing and chip generation.

Material is displaced and moved across the surface at the interface where the abrasive grit tips meet the work piece's surface. This process creates smearing zones and chips. Turley and Doyle (1975) detailed the redeposition procedure, which led to the creation of sticky chips.

Friction welding returned the material to the ground surface once it had bonded to the grits. Scratching the surface of the work piece with abrasive grits or ground chips caused indentations to form. Using abrasives with a reduced grit size greatly improved the surface quality, as shown in the photograph.

Deep grooves, broad smearing regions, and adhesive chips were far less common when 170# grit size abrasive was used instead of 60# grit size abrasive. Using the sharpest grit size (300#) greatly reduced surface imperfections. Every one of the three samples has surface indentations.

Both surface roughness and surface quality are greatly impacted by the choice of abrasive grit size. These two areas benefit greatly from the use of an abrasive with a lower grit size. While grinding, only a small fraction of the abrasive grits on top actually remove metal, while the remaining grits glide and rub against the workpiece's material. The bigger the abrasive particles of coarser grit size abrasives, the more surface area there will be to rub against while grinding.

Another issue with abrasives with coarser grit sizes is that the grains are not uniform in size or distribution. The use of abrasives with larger grit sizes results in a worse surface quality and more flaws.

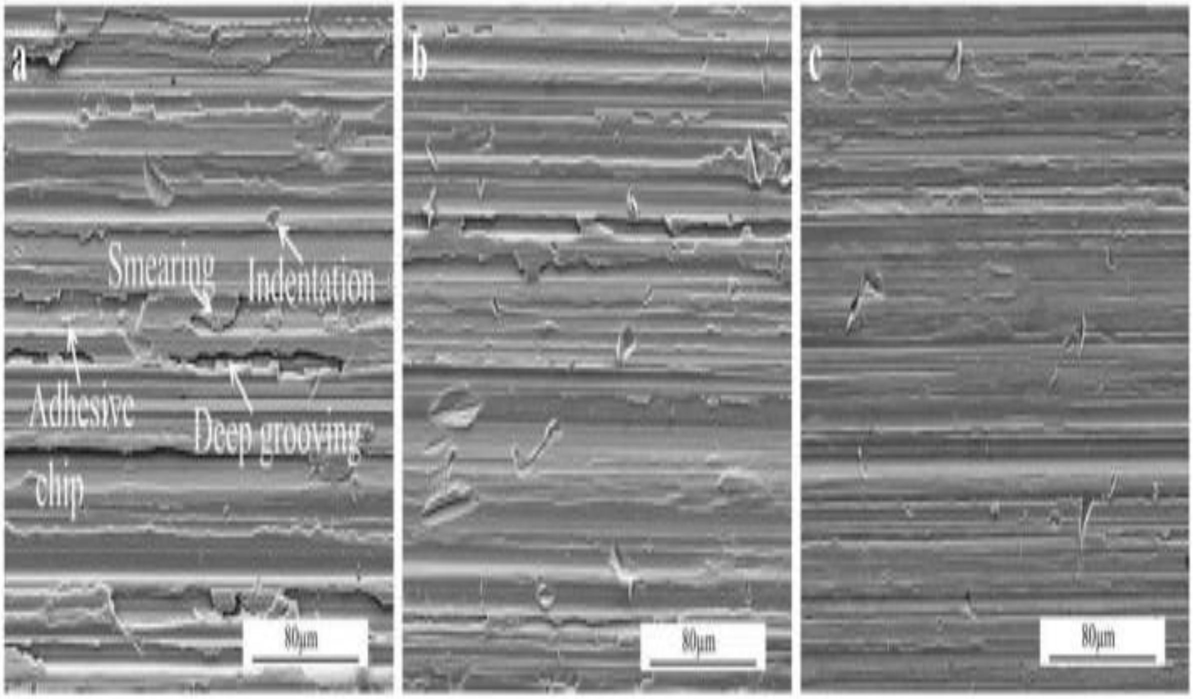

Figure 4. Surface topography and surface defects by different abrasive grit size (group I). a 50#. b 170#. c 300#

CONCLUSION

The complicated relationship between the quality of the surface and the deformation in stainless steel grinding processes highlights the difficulty of obtaining accuracy in production. To achieve the required surface smoothness and minimize deformation, it is essential to carefully adjust grinding settings, have a deep grasp of material characteristics, and make use of latest technology. Continual research and innovation in grinding processes will be crucial in addressing the increasing demands of sectors for improved aesthetics and functionality. The industrial sector's passion to delivering exceptional goods that excel in both form and function is evident in their commitment to overcoming the difficulties presented by stainless steel's distinctive qualities.

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