The Effect of Grinding Process on Surfaces After Cutting Processes

Eng. Mohammad Dashti

Abstract— The paper is a review of the effect of the grinding process on surfaces after cutting. Grinding is a critical process in manufacturing because it increases the precision and durability of products. The review was based on evidence from published studies about the benefits and challenges of grinding. As a finishing process, grinding is applied to workpieces to improve accuracy, surface quality, texture, and value. Accuracy is critical for the machination of large and small parts while improvement of surface quality and texture helps to increase the functionality and efficiency of products. However, while grinding was linked to these benefits, some challenges were reported. The challenges were attributed to thermal damage resulting from the heat generated from the frictional resistance when the workpiece met the grinding wheel. The drawbacks of the process were oxidation burn, re-hardening burn, and residual stress. These challenges reduced the quality and functionality of workpieces.

Key Words: Grinding, Oxidation Burn, Residual Stress, Re-Hardening Burn

1. INTRODUCTION:

Grinding is a surface improvement process in engineering. The goal of this procedure is to increase the quality of products. Malkin (2013) describes grinding as a collective term referring to various machining processes in which hard abrasive particles are employed to cut and shape surfaces. Indicative in this definition is the notion of a subtractive manufacturing technology. Other technologies related to grinding are milling, drilling, and turning. However, unlike drilling, for instance, which utilizes drill bits for boring holes in metallic material, grinding is reductive by abrasion. Moreover, while the goal of drilling is to generate boreholes in the material, grinding is a finishing procedure used to increase the quality and appeal of a surface. The objective of this activity is to increase surface attractiveness, but manufacturers should be aware of certain drawbacks. These challenges arise because of the excessive heat generated during the process attributed to the high friction generated as the workpiece rubs against the grinder's wheel. While grinding helps manufacturers improve the quality of surfaces, effort should be taken to reduce thermal damages, such as residual stress, oxidation burns, and re-hardening burns.

Benefits of Grinding

Accuracy

Manufacturers rely on grinding for accuracy and straightness of workpieces. According to Rowe (2014), the machination of large parts requires increased accuracy since the functionality of finished products is not tolerant to uneven surfaces. In other words, manufacturers need to produce precise products and compute errors within specified parameters. Moreover, as Rowe (2014) continues to explain, accuracy is not limited to large parts since precision is needed for small parts, such as needles, lenses, and rolling bearings. In these parts, accuracy levels are higher compared to the degree required for large parts because error tolerance reduces to the nearest submicron level rather than the micron level.

The need for accuracy in manufacturing has directed attention toward various aspects of grinding, such as precision monitoring and machine tool spindle error tests (Hu et al., 2020). The goal is to pre-define the parameters of the grinding process to achieve a final product with geometrical properties within the desired range. However, while accuracy is critical, the focus is also on cost control. The aspect of cost is critical since grinding is a finishing process, and mistakes resulting in damages may compel manufacturers to work pieces with all accumulated value. To increase the efficiency of grinding while achieving accuracy, Sato et al. (2017) proposed the idea of constraint force control. This approach involved moderating the force being applied by the robot arm with an attached grinder to a workpiece to ensure the target is ground into the desired shape and with sufficient accuracy. Hence, grinding helps manufacturers produce precise products, and researchers have directed attention toward increasing accuracy while lowering wastage-related costs.

Surface Quality and Texture

The quality of a workpiece is related to the parameters of surface texture and surface form. These two properties increase the functionality of the final product. According to Rowe (2014), grinding can improve the quality of a workpiece by producing an even surface for fluid functioning. While the integrity of a workpiece at the ground surface may not be obvious, this property is vital to the performance of the final product. Ground products comprise constituent parts in larger machines with high precision demands. Grzesik et al. (2014) compared the characteristics of surface topography between ground and turned surfaces, and, based on their findings, the researchers classified both processes under precision machining mechanisms since the quality of workpiece surfaces was high and their surface topography parameters were within range of each other. The quality of ground surfaces was also higher because of the low incidence of microgrooves and valleys and smaller values of surface bearing index (Grzesik et al., 2014). Grooves and valleys, for instance, result in workpieces with poor texture and rough surfaces. A low surface bearing index, on the other hand, is associated with reduced peak wear. The summits of a ground surface present even elevation points, indicating workpieces with smooth textures. However, analysis of ground surfaces, as Grzesik et al. (2014) explain, reveals geometric irregularities with higher slopes. While these slopes are not noticeable to the eye, they interfere with the performance and efficiency of the workpiece. Motif examination of unfiltered ground surfaces with a focus on roughness, spacing of roughness, and highest points of elevation have led researchers to associate deeper pits with grounding compared to turning. However, this conclusion does not dismiss the effectiveness of grinding since no research has ascertained

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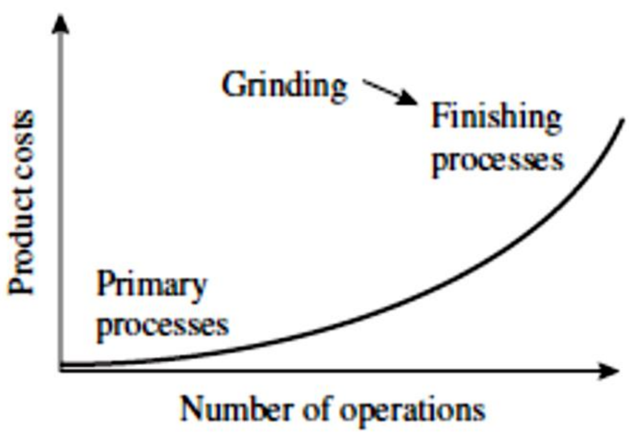
the impact of the pits on the quality of the workpieces. In other words, while the pits may be noticeable when comparing grinding to turning, their effect on the effectiveness and performance of workpieces or final products may be negligible. Hence, grinding significantly improves the surface quality and texture of products because the process generates even surfaces with a low incidence of grooves, valleys, even slopes, and points of elevation.

The Value-Added Chain

Grinding is a value-addition exercise manufacturers perform at the end of the production cycle. The position of this process at the end of this cycle has notable cost implications. In other words, the procedure is conducted when the value of the workpiece is already high and any mistake translates to expensive costs. The accumulation of production costs during grinding is illustrated in Figure 1 below.

Figure 2

The Buildup of Costs and Value-Added in Product Manufacture



Note. The buildup of costs and value-added in product manufacture. From Principles of modern grinding technology, Elsevier, Boston MA. p.6. Copyright 2023 by Elsevier

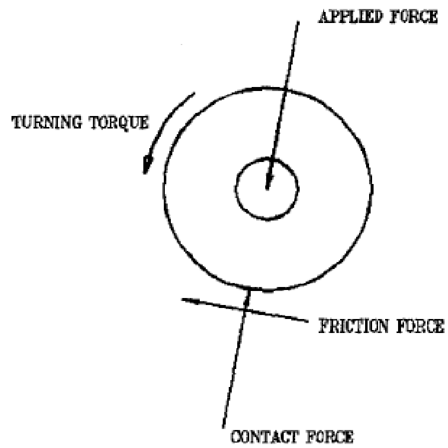
Challenges of Grinding

Thermal Damages

As the hard abrasive material on a grinder's wheel rubs against a workpiece, excessive heat linked to thermal damage is generated. Gu et al. (2004) present a mathematical model of the heat generated during grinding, reiterating the role of frictional force in production of the excessive temperatures. The rotating grinding wheel produces a force applied to the workpiece to counterbalance the turning torque with the resistance from the workpiece. A pictorial representation of these forces is presented in Fig. 2 below.

Figure 1

Equilibrium of forces on the grinding wheel

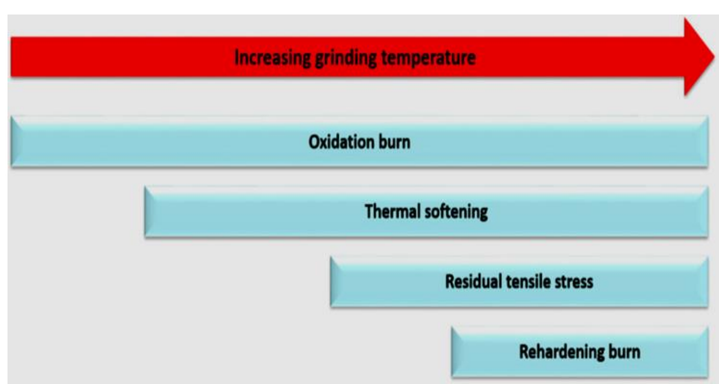


Note. Equilibrium of forces on the grinding wheel. From "Thermal analysis of the grinding process" by Gu et al. 2004, Mathematical and Computer Modelling. 39. p.993. (https://doi.org/10.1016/j.mcm2003.07.009). Copyright 2023 by the Journal of Mathematical and Computer Modelling

As the abrasive particles exert pressure on the workpiece, the latter produces a reactionary force in the form of contact pressure on the rotating wheel. Researchers find it difficult to determine this pressure because of the numerous factors involved. In other words, the role of the cooling fluid and particles generated from the process need to be accounted for; hence, the heat dissipation capacity of the material being ground is difficult to compute. This heat may adjust the properties of the workpiece in undesirable ways. According to Malkin (2013), in grinding, the workpiece absorbs three-quarters of the heat generated from the process while the grinding wheel and the chips falling from the material's surface absorb the remaining portion. Therefore, the surface under preparation absorbs a notable share of the heat capable of changing its structure and properties. The resulting changes may be detrimental to the quality of the workpiece, which is counterproductive to the original objective of improving the appeal of the material. According to Malkin (2013), thermal damages comprise surface oxidation, thermal softening, residual tensile stress, and re-hardening burn (Fig.3).

Figure 3

Onset of different grinding burns at different grinding temperatures



Note. A graphical representation of the role of temperature on the occurrence of thermal damages. From “A comprehensive review on the grinding process: Advancements, applications and challenges” by K. Kishore et al., 2022, Journal of Mechanical Engineering Science, 236(22), p.5. (https://doi.org/10.1177/09544062221110782). Copyright 2023 by the Journal of Mechanical Engineering Science.

Oxidation Burn

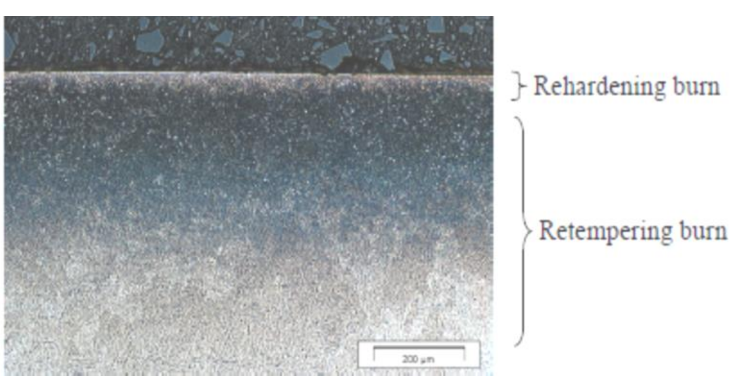
An oxidation burn compared to other forms of thermal damage, such as thermal softening, residual tensile stress, and hardening burns, occurs at lower temperatures. The different types of thermal damage interfere with the integrity of the work-material’s structure and reduce its quality. One can identify oxidation burns appearing as dark blue stripes on the surface of a workpiece, and, according to Kishore et al. (2022), the discoloration is attributed to slow grinding speeds. Therefore, at lower speeds, the heat generated from the high friction ignites combustion on the surface of the material under preparation, leading to discoloration. The attribution of oxidation burns to slow grinding speed led Sinha et al. (2016) to propose increasing the speed of grinding as a way of reducing oxidation burns. Hence, while oxidation burns threaten the integrity and quality of workpieces during grinding, this problem can be avoided by increasing grinding speed; however, researchers need to improve the prediction of burns by integrating artificial intelligence (AI) solutions, for instance, neural networks capable of predicting burn time.

Re-hardening burn

The grinding of steel is also associated with re-hardening burns. Steel has a high hardening temperature. However, the friction at the contact zone between the grinding wheel and the workpiece generates excessive heat higher than the hardening temperature of steel. According to Kishore et al. (2022), the temperature differences result in the formation of a white residue at the interface of the work surface and the grinding wheel. More importantly, the white residue generates secondary residual stress higher than the original workpiece, resulting in re-hardening. Grinding is linked to high surface transient temperatures, weak compressive stress, and the emergence of tensile stresses (Champagne et al., 2010). Therefore, workpieces affected by the re-hardening burn are subject to wear resistance since their fatigue strength is low. In other words, products or parts made from such pieces are prone to premature failure. Fig. 4 below presents evidence of a re-hardening burn caused by the grinding of an X2M specimen. According to Huang et al. (2015), high grinding speeds are directly correlated with the thickness of the white residue on the surface of the workpiece. Therefore, as the temperature rises due to the high grinding speed, it results in tempering and thermal softening of the workpiece, leading tthe thickening of the white residue. Fig. 5 (b-i) below illustrates the thickness of the white layer at different speeds (Jiang et al., 2022). While moderating the speed of grinding is likely to resolve the re-hardening burn problem, this approach still raises the question of oxidation burn observed at low grinding speeds.

Figure 5:

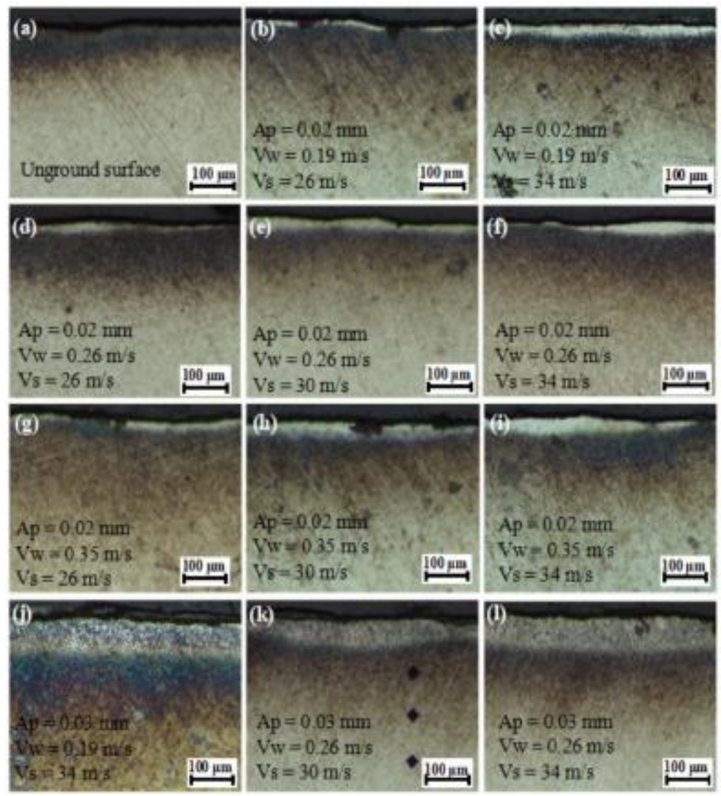
Re-hardening and Re-tempering Grinding Burns on X2M Steel Sample



Note. A graphical representation of the role of temperature on the occurrence of thermal damages. From “Detection of thermal damage in X2M gears steel using Barkhausen noise analysis” by V. Champagne et al., 2022, AIP Conference Proceedings, 1211(1), p.1456 (https://doi.org/10.1063/1.3362239). Copyright 2023 by ResearchGate

Figure 4:

The Ground Surface Layer at Different Parameters



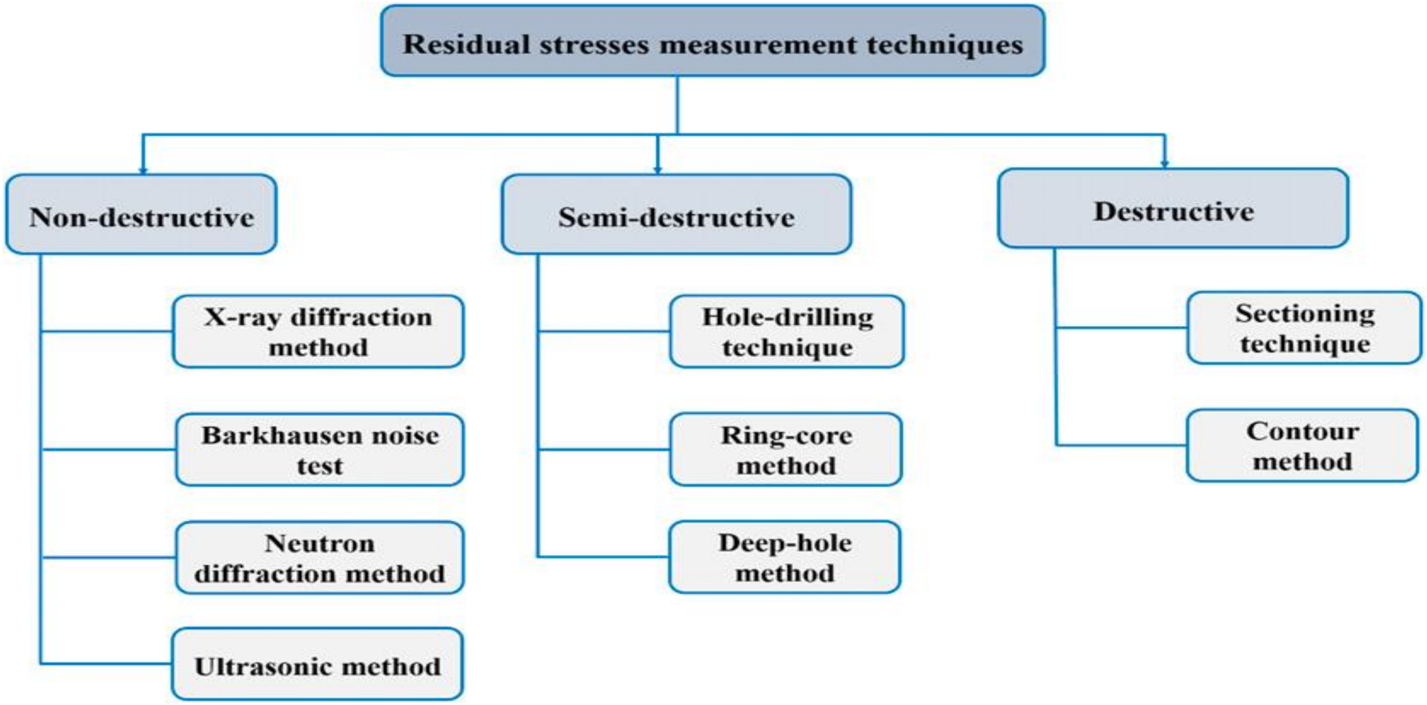
Note. From “Grinding temperature and surface integrity of quenched automotive transmission gear during the form grinding process” by X. Jiang et al., 2022, Materials, 15(21), (https://doi.org/10.3390/ma15217723). Copyright 2023 by MDPI

Residual Stress

Residual stress is a property of the work material in grinding. Kishore et al. (2022) define this type of stress as the result of microstructural tensions in the workpiece even after external thermal and mechanical loads applied during grinding are removed. In other words, residual stress refers to the after-effects of the tension induced by grinding. Whereas mechanical loads on the workpiece are associated with compressive residual stress, thermal loads are linked to tensile stress. As Figure 5 below illustrates, residual stresses are categorized into three clusters based on their degree of destructiveness. Due to the negative effect of this stress on the material, some studies have focused on the correlation between thermal stress and surface grinding conditions (Huang et al., 2019; Kohls et al., 2021). Results from studies correlate residual stresses with temperatures at the zone of contact. Overall, the properties of a ground workpiece are affected by the thermal and mechanical loads, reducing the quality of the material.

Figure 6

List of Residual Stresses Measurement Techniques



Note. A graphical representation of the role of temperature on the occurrence of thermal damages. From “A comprehensive review on the grinding process: Advancements, applications and challenges” by K. Kishore et al., 2022, Journal of Mechanical Engineering Science, 236(22), p.6. (https://doi.org/10.1177/09544062221110782). Copyright 2023 by the Journal of Mechanical Engineering Science.

Conclusion

Grinding is associated with quality improvement in manufacturing, but the process generates challenges related to thermal damage. Manufacturers grind cut material to improve the accuracy and straightness of workpieces. However, while the process leads to improved precision in the final product, manufacturers are exposed to the risk of increased costs associated with disposing of valuable products damaged during grinding in the final phase of production. Grinding also improves the surface texture and quality of work material. These two properties are critical since they improve the functionality of the workpiece. However, despite the benefits of grinding, the process is also linked to various challenges related to thermal damage. These challenges comprise the problems of oxidation burns, re-hardening burns, and residual stress. These effects reduce the quality of the final product by compromising its performance and functionality. Anecdotal evidence supports moderating grinding speed to overcome the challenges. However, the evidence from the research is not conclusive. Therefore, future studies should analyze how AI can be deployed to overcome the thermal destruction of workpieces during grinding.

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