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Grinding of Thermal Spray Coated Aircraft Engine Parts

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Abstract

Aircraft engines that must be certified separately from the platform should comply airworthiness and remain unchanged for all types of operations and in all environments. Together with this, they might only be preferred by airlines if they are competitive in terms of several aspects such as fuel efficiency, speed, and maintainability. These requirements are met by an interdisciplinary effort including engine design, component materials, manufacturing techniques and electronic control. An illustrative example to this is the critical components designed and manufactured of titanium or superalloys and coated afterwards to resist various wear causes and to facilitate easy, cost-effective maintenance by keeping the component itself only via renewing the coating after certain flight hours. Although this solution sounds reasonable and feasible, it needs a considerable know-how level to apply a proper coating and subsequently to size it to an acceptable level of dimensional quality and surface integrity. In order to meet researchers' and engineers' know-how needs on the subject, this paper presents a systematic review on grinding of thermal spray coated aircraft engine parts. In this paper, spray coatings, which offer the widest substrate material range are explained in detail regarding their materials, application methods and characterizations. Later on, grinding of these is narrated considering tools and process parameters such as cutting speed, feed, and depth of cut. Finally, the influence of grinding conditions on dimensions, surface quality, hardness, residual stresses, and microstructure is discussed. The paper is concluded with a state-of-the-art summary and emphasis on research gaps and future perspectives on the subject.

1. Introduction

Commercial and military aircraft are powered by a variety of engine types, such as diesel-propeller, gasoline-propeller, turboshaft, turbofan, and turbojet. These so-called engines, especially the ones that are used for commercial aircrafts transporting humans, should be certified separately from the platform and should comply airworthiness for all types of operations and in all environments. In addition to this, airline operators and/or aircraft manufacturers purchase and use competitive engines in terms of several aspects such as fuel efficiency, speed, and maintainability. In order to meet these demands, aircraft engine developers and manufacturers put an interdisciplinary effort starting from material selection phase to engine design and component manufacturing. Critical components made of nickel and titanium alloys that are subsequently coated to withstand different wear causes and enable simple, economical maintenance by preserving the component itself by simply renewing the coating after a set number of flight hours serve as an illustrative example of this. These special materials include but are not limited to aluminum alloys, composite materials, alloyed and stainless steels, superalloys and titanium (Sjöberg, 2008). Aircraft engine designers might have different aims during the selection of these materials and these aims are mostly related to the function of the component, the temperature that the component is exposed, the rotation speed and the gas pressure. As mentioned before, the designers' aims are shaped by market demands and the safety of the part is dictated by international agencies' certification specifications. For example, a high-pressure turbine disc of the LEAP engine powering all up-to-date narrow-body aircrafts like Airbus A320Neo, Boeing 737-Max and Comac C919 should deliver more than 140kN take-off thrust, should rotate approximately at 20000RPM, should withstand an overall pressure ratio of 50:1 and should not exceed 14.4g/kN/s thrust-specific fuel consumption (EASA, 2018). On the other hand, the same part, as an equipment with high-energy rotors, shouldn't failure significantly to demolish engine's containment and should have an acceptable level of design integrity (EASA, 2020). The conflicting nature of aligning with market demands and safety regulations poses a significant challenge in developing a design solution that relies solely on specific material properties. At this point, the need for enhancing these materials' properties with additional special processes becomes prominent, and these processes might be used of core properties of materials like heat treatments or for surface properties of materials like coating.

Among the different type of aircraft engines, turbines which work in the harshest environments in terms of temperature, centrifugal forces and pressure, display the widest variety of coating materials and techniques. In order to select and apply this wide variety of coating techniques on turbine engine parts, researchers and engineers should pay sufficient attention to several criteria including coating purpose, coating material, coating technique as well as substrate part function, material, and pre or post surface condition. Previous researchers (Rhys-Jones, 1990) introduced a coating classification including wear control coatings, clearance control coatings, thermal barrier coatings, overlay coatings, and gas seal coatings. During the last decade, MTU Aero Engines AG (2017) expanded this classification to include corrosion/oxidation protection coatings, titanium fire protection coatings, abradable/sealing coatings and dimensional adjustment coatings. Further classification of these coatings can be made according to the material state being gaseous, solution and molten. While chemical vapor deposition (CVD) and physical vapor deposition (PVD) can be classified in the gaseous state, electroplating and electrochemical deposition belongs to solution state, and thermal spraying, laser cladding and electro discharge coating belongs to molten state (Tyagi et al., 2022). Within these coating methods, thermal spraying has the widest application area for aircraft turbine engine parts (Fauchais and Vardelle, 2012) and it is sub- classified to detonation gun, flame spray, high velocity oxy-fuel (HVOF), plasma spray and warm spray (Ahmed et al., 2021). There is a considerable material range difference between different thermal spray techniques and plasma spray method offers the broadest material range to include metals/intermetallic, cermets and ceramics. Fig. 1 shows the available materials for different type of thermal spray methods together with feedstock size and temperature (Ahmed et al., 2021).

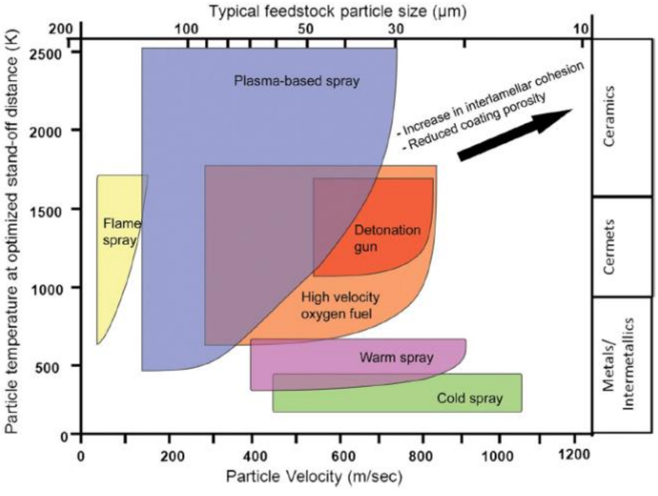

Figure 1. Spectrum of Thermal Spray Processes by Ahmed et al. (2021) licensed under Creative Commons Attribution 4.0

This broad material spectrum also leads to turbine engine part diversity and today plasma sprayed coatings are used for liners, seals, hubs, supports, guide vanes, stators and so on. Fig. 2 shows plasma spray coated parts on aircraft turbine engine section (Fauchais and Vardelle, 2012).

Still, plasma sprayed coatings might have some drawbacks. One of the main drawbacks of plasma spray coatings is the coating thickness. Of course, depending on the part/substrate and coating material, the thickness of plasma spray coatings is indicated to be between 50μm to 100μm, whereas the thickness of CVD and PVD coatings can be as low as 3μm (Fauchais and Vardelle, 2012 and Vardelle et al., 2015). Another common drawback of these plasma spray coatings is their surface quality. Their surface quality can only be as low as Ra 0.51μm, while the surface quality of CVD and PVD coatings can be as low as 0.03μm.

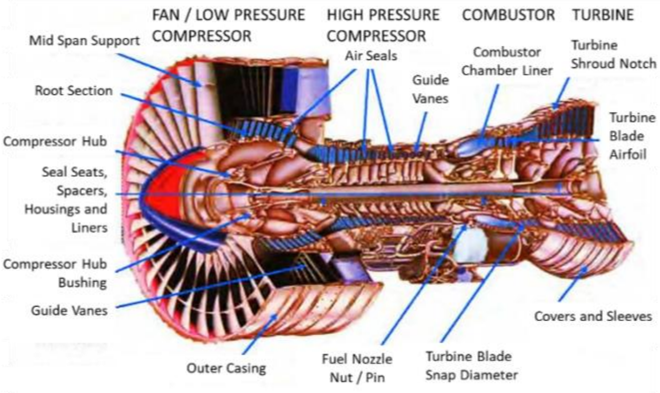

Figure 2. Plasma-sprayed coatings on aircraft turbine engine parts, reproduce from Fauchais and Vardelle (2012) licensed under Creative Commons Attribution 4.0

A widely employed practice to reduce the disadvantages of these plasma spray coatings is to grind them posterior to coating process. However, there are many aspects to consider for grinding of plasma spray coated aircraft engine parts including part/substrate material, coating material, coating method, coating characterization, grinding tool, grinding process parameters, and post grinding inspection and evaluation. Furthermore, some of these elements are hard to locate in scientific literature, while others are present but randomly distributed among numerous papers or proceedings. In this regard, this review paper aims to fill this gap in the current literature and gather all the relevant or important information on grinding of thermal spray coated aircraft engine parts.

2. Thermal Spray Coating of Aircraft Engine Parts

Plasma spray coatings can be applied on to various aircraft engine parts including spacers, liners, seals, vanes, casings, covers and sleeves. Depending on the engine module that each part exists and in accordance with the part's function and service conditions, the substrate material might be various alloys such as bearing steels, stainless steels, nickel-based superalloys, titanium alloys. These effects the selection of coating materials, coating parameters and the necessary coating characterization techniques (Rhys-Jones, 1990, Molak et al., 2017). For this reason, the following sub-sections are focused on the coating materials, coating methods and characterization techniques before jumping on the grinding of these coatings.

2.1. Substrate and coating materials in grinding research

Previous researchers and engineers have practiced various materials as substrate and reported their findings accordingly. In this context, practiced substrate and ground materials exhibit a diverse metallic alloy range including 1040 and 1050 steels (Gullu, 1995), Ti6Al4V titanium alloys (Tao et al., 2017), and Inconel 718 nickel-based superalloys (Yastikci, 2016). Still, before progressing to the grinding of coated materials, scientific and research know-how expanded by just grinding the ceramic materials themselves and it presented a considerable contribution to the further research on grinding of ceramic coatings and also other hard coatings. Pioneer researchers Mayer et al. (1995) focused on hot pressed silicon nitrides (HPSN) in their study and by reporting the surface characteristics of those being influenced by grinding parameters and also grinding wheel grit sizes. Other researchers Hwang and Malkin (1999) have investigated hot pressed silicon nitrides (HPSN) too, together with reaction bonded silicon nitride (RBSN), silicon carbides (SiC) and aluminum oxides ($A1_20_3$). In addition to these Sun et al. (2015) published a grinding force model for brittle and hard ceramic materials such as $A1_20_3$ and SiC. Although it is not the focus of this paper, research is still ongoing for the grinding of hard ceramics and for the current state-of-the-art, researchers focus on minimum quantity lubrication (MQL) techniques (Choudhary et al., 2018). A very good and relatively recent study by Kumar et al. (2018) exploits discrepancies between grinding of ceramic substrates and ceramic coatings and come up with results showing that ceramic was free from residual stress whereas in ceramic coatings, tensile residual stresses were observed.

The material range is obviously more varied when it comes to coating grades. Grinding experts started to focus on grinding of coatings in the beginning of 2000s and one of the comprehensive articles was published by Liu & Zhang (2002) on the grinding of n-Al_2O_3/13TiO_2 and n-WC/12C coatings. They have revelated important results stating that the difference of material properties of the two coatings used for the study influenced the subsurface cracks. It was also proven that different from bulk samples, large quantities of defects inherited from the thermal spray process play a significant role (Liu & Zhang, 2002). As for the further grinding research on coatings, Deng et. al. (2006), investigated the grinding forces for nanostructured WC/12C coatings and concentrated to predict grinding forces per unit area and per grit. Researchers who have carried coating grinding research to upper levels benchmarked a diverse range of coating materials (Kar et al., 2016). Kar et al. (2016) benchmarked an extensive grade of coating materials including Al_2O_3, Al_2O_3–13 wt% TiO_2, Cr_2O_3, TiO_2, YSZ and evaluated residual stresses for critical depths. They have demonstrated that surface topography and microstructures had the signs of plowing and rubbing only. In addition, their study revealed residual stresses that were linked to the ceramic coating's retention of the material's characteristics rather than heat gradients.

To summarize this section, it can be concluded that previous grinding research focused on many substrate and coating materials including steels, titanium, nickels as well as Al_2O_3, Cr_2O_3, TiO_2, WC/12C and YSZ coatings. On the other hand, while some of the published research focuses on a single substrate-material combination, other ones focus on benchmarking of different materials with a single set of process parameters.

2.2. Thermal spray coating

As discussed in the previous section, some of the published papers from the current state-of-the-art clearly related some results to the coating materials and/or coating conditions. In this respect, it would be beneficial to present a brief overview of different coating technologies here in this review article.

The main purpose of thermal spray coating techniques is to enhance the surface quality of solid materials by applying heated or melted materials to the surface under study. This co-called surface improvement can offer the product resistance to wear, abrasion, cavitation, corrosion, erosion, heat and wear (Łatka et al., 2020). Different type of energy sources can be used to melt the materials such as electricity for plasma and arc spraying or chemical energy for high velocity oxy-fuel (HVOF) or high velocity air fuel (HVAF). A second aspect to be included in the classification of this method can be the feedstock used for melting or heating. Even though there are several varieties of the feedstock, two common forms are powder and wire. Fig. 3 shows a detailed classification of thermal spray coating methods (Tejero-Martin et al., 2019).

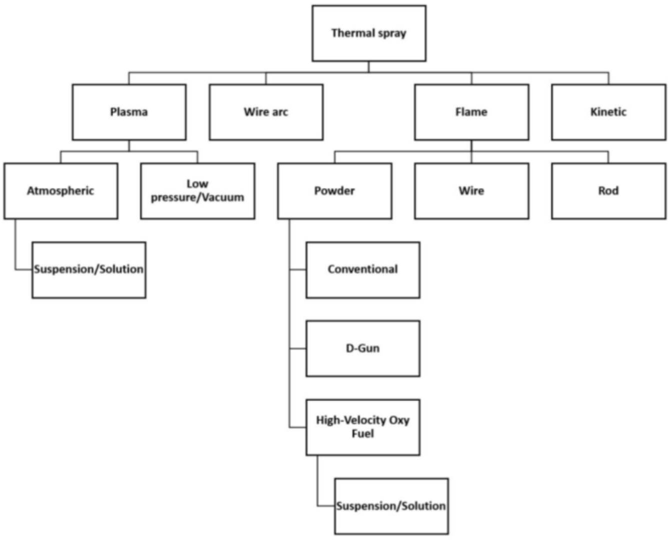

Figure 3. Classification of Thermal Spray Methods by Tejero-Martin et al. (2019) licensed under Creative Commons Attribution 4.0

Despite the fact that thermal spray methods have many different classes, a typical thermal spraying system may include major components like power supply, material feeder, spraying torch or gun, automated or manual manipulator and a control system. While the material feeder provides and moves the raw material in powder or wire form, the torch or the gun melts it through various energy sources such as arc, HVOF or plasma. Following to melting of material and spraying it onto a certain location of the part surface, the torch or gun is moved by manipulator and the manipulator is managed by control system for automated thermal spray methods. Fig. 4 shows schematic of a sample thermal spraying method which uses plasma as energy source (Łatka et al., 2020).

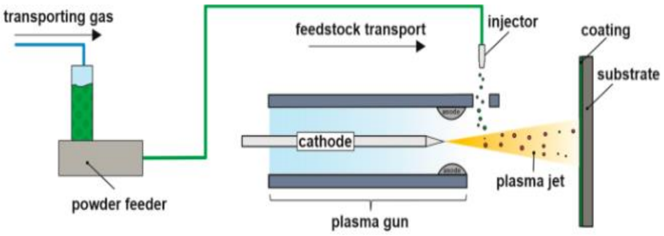

Figure 4. Schematic for Thermal Spray Method Using Plasma by Łatka et al. (2020) licensed under Creative Commons Attribution 4.0

As can be appreciated through explanations and schematic in Fig 4., this method can deposit coating materials up to several millimeter thickness and since the melted materials are sprayed in the form of droplets, the microstructural characteristic of the coating might consist of splats, pores and voids. Moreover, these splats can take lamella form when other splats stack on the previous one and deforms it from being a sphere to a flat like melted liquid. Fig. 5 shows cross-sectional morphology of a thermal spray coated specimen including lamella and pore formations (Si et al., 2020).

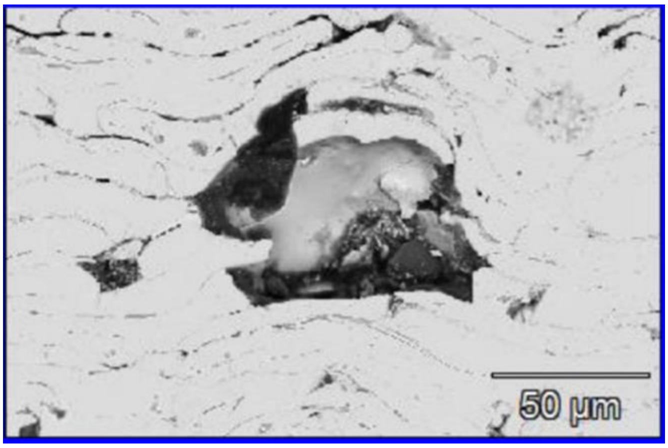

Figure 5. Cross-sectional Morphology of A Thermal Spray Coated Specimen by Si et al. (2020) licensed under Creative Commons Attribution 4.0

The phenomena seen during and after thermal spray processes may alter surface roughness and dimensional accuracy of the part on top of the microstructural condition. In this regard and depending on several issues such as substrate preparation and existence of a bond coat, the surface roughness of the thermal sprayed parts can take values between Sa 34.9µm – Sa 119µm (Curry et al., 2015). Presumably, these surface roughness values which show the average distance between the peak and valley of the surface topography may have a considerable effect on the part's dimensional accuracy. Remembering the dimensional accuracy and surface quality requirements of aircraft engine parts to change within +/-10µm (Poyraz & Yandi, 2021), the use of thermal spray coated parts in as-deposited condition cannot be expected. And due to the fact that the thermal spray coating microstructures have lamella forms with pores and irregularities, cutting processes cannot be practiced as they might lead to separation. For this reason, abrasive processes are mostly preferred being kind to the coating and grinding, which is the subject of this paper is commonly employed.

3. Grinding of Thermal Spray Coated Parts

Before going into the grinding process details and parameters used for finishing thermal spray coating faces, it would be beneficial to present an overview on the principles of this method to enhance readers' understanding. In this context, next sub-section gives a brief overview of grinding method, process parameters and terms used.

3.1. Overview of grinding and process parameters

Grinding is a subtractive process where a cylindrical grinding wheel rotates and abrades part material with the help of hard abrasive particles in order to form the part shape and comply necessary dimensional accuracy and surface quality. Grinding process is usually performed on manually or computer numerically controlled (CNC) machines. These machines which consist of a machine bed to hold the part and a machine spindle to hold the grinding wheel, might have cartesian or polar configurations depending on the need.

The used grinding wheels, which are regarded as one of the crucial technique inputs, are identified by a number of characteristics and labelled appropriately. The initial attribute emphasized for a grinding wheel is the type of abrasive it includes. Two common abrasive types used for grinding wheels are aluminum oxide and silicon carbide. Grain size comes as the second major attribute and changes between 10-600 going from coarse to finer. Of course, the level of bonding plays a critical role on the wheels' performance and is expressed as soft, medium or hard. The types of these bonds can be vitrified, silicate, resinoid, rubber, shellac or oxychloride. Among these wheel compounds, bond type is selected according to processing strategy. While resin bonds which can be more flexible in the case of epoxy grades might be used for rough grinding applications, vitrified bonds having low-impact resistance are used for relatively lower speed grinding operations (Ault, 1989).

While essential grinding parameters consist of grinding wheel speed, worktable traverse feedrate and depth of cut, special grinding operations might have more parameters like workpiece speed for cylindrical grinding or dressing infeed speed for creep feed grinding (Poyraz et al., 2019). Fig. 6 shows essential grinding parameters together with the workpiece and grinding wheel.

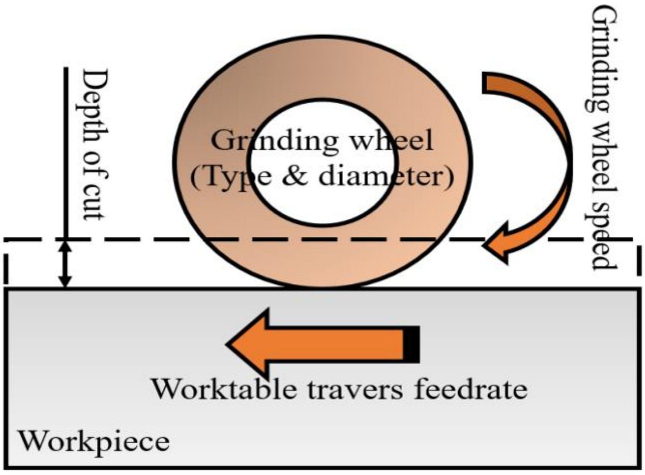

Figure 6. Essential grinding parameters

3.2. Effect of grinding parameters on thermal spray coatings

Liu et al. (2002) have investigated the aforementioned grinding parameters and highlighted the depth of cut as the most influential parameter increasing the grinding forces for nanostructured ceramic coatings on low alloy steel substrates. Furthermore, *n*-WC/12Co coatings were also reported to expose higher grinding forces comparing to other ceramics such as *n*-$Al_2O_3/13TiO_2$ (Liu et al, 2002). Furthermore, they came up with the conclusion that the increase in feedrate increases the surface roughness (Liu et al., 2002). The same relationship between depth of cut and grinding forces were also observed by Deng et al. (2006). In addition to depth of cut, Deng et al. (2006) also revealed the fact that under same grinding conditions, the decrease in grinding wheel grit size increases the cutting forces. Another adverse effect reported on the grinding depth of cut was local and sharp temperature rises on nano-zirconia ceramics (Li et al., 2011). Even though all pioneer researchers on the subject emphasized the cutting force effects for the depth of cut, Masoumi et al. (2014) conducted multi-factorial parametric studies and found that the forces depend not only on the depth of cut, but also on the depth of cut and feedrate interaction.

Kar et al. (2016) benchmarked superabrasive grinding of various ceramic coatings on low carbon steel. They demonstrated that the nature of the chips did not vary with change in grinding parameters. On the other hand, it was shown that ground surface topographies of Al_2O_3 and TiO_2 coatings have clear dissimilarities (Kar et al., 2016). The same group of researchers continued their evaluations by benchmarking high speed and precision grinding of plasma sprayed oxide ceramic (Kar et al., 2017). Their studies conducted on low carbon steel substrates and various ceramic coatings exhibited that surface residual stresses of samples produced during high-speed grinding are lower than those of samples using precision grinding (Kar et al., 2017).

Ghosh et al. (2018) achieved a reduction of areal surface roughness from Sa 5.04µm to Sa 53nm by applying chemical assisted shape adaptive grinding on high velocity oxy-fuel sprayed WC-Co coatings. On top of this achievement, no fracture or WC disintegration was observed on the surfaces. In a recent study by same researchers, HVOF sprayed and shape adaptive ground WC-Co coatings were exposed to wetting tests by analysing the static contact angle, sliding angle, and contact angle hysteresis (Ghosh et al., 2020). Finished coatings exhibited a lower sliding angle and contact angle hysteresis and the water droplets get completely released from the surface.

Zoei et al. (2016) investigated the effect of depth of cut, cutting speed and feedrate on high velocity oxy-fuel sprayed WC–10Co–4Cr coatings and came up with the results showing that wear resistance and the compressive residual stresses increase after grinding. In their study, increase of the depth of cut and feedrate and the decrease of the cutting speed led to higher residual stresses and improved wear resistance (Zoei et al., 2016). The same coating material's grinding have also been investigated by Pishva et al. (2020). In the scope of their research, the effect of different grinding depth of cuts were evaluated in terms of porosity, surface roughness and microhardness. It was concluded that grinding decreases surface quality while increasing microhardness and porosity (Pishva et al., 2020). Furthermore, an increase in depth of cut led to microcracks and decreased corrosion resistance.

In an interesting study by Boccarusso et al. (2022), Metco 204 NS and Amperit 421.761 commercial coating grades were applied onto Inconel 718 via air plasma spray method. Later on they were repaired by grind g and water jet processes, and their surface qualities were evaluated by different parameters. Rather than commonly used Ra and Rq parameters, better correlation was shown between less commonly used Rdq / Rlo parameters and tensile adhesion strength (Boccarusso et al. 2022).

As already narrated in Section 3.1 and Section 3.2 of this article, grinding methods have many process parameters as inputs and they have considerable influence on the results. Having that in mind the so-called parameters and the related results can differ according to substrate material, coating material and coating application, it would be beneficial to have the previous data in a tidy form. For this reason, all the reviewed data in this article is compiled, tabulated according to materials, and essential grinding parameters as depth of cut, speed, and feed, and presented in Table 1.

Table 1. State-of-the-art summary on coating grinding parameters

Reference	Substrate material	Coating material and method	Depth of cut	Speed	Feedrate
Liu et al. (2002)	Low carbon steel	WC/12Co, $Al_2O_3/13TiO_2$ - HVOF	2, 5, 15, 30µm	33m/s	1, 4, 8mm/s
Liu et al. (2003)	Low carbon steel	n-$Al_2O_3/13TiO_2$, n-WC/12Co - HVOF	2, 5, 15µm	33m/s	4 mm/s
Deng et al. (2006)	Not given	n-WC/12Co - HVOF	5-30µm	31.4m/s	20, 30, 50mm/s
Li et al. (2011)	Not given	n-ZrO2 - HVOF	1, 3, 6, 10µm	30m/s	6m/min
Masoumi et al. (2014)	Low carbon steel	WC–Co–Cr - HVOF	4-22µm	20-35m/s	142-550mm/s
Kar et al. (2016)	Low carbon steel	Al_2O_3, TiO_2, Cr_2O_3, YSZ, Ni-Al, NiCrAlY – Plasma spray	1.2-3µm	26m/s	6-12m/min
Zoei et al (2016)	AISI1010	WC-10Co-4Cr - HVOF	4-16µm	25-35m/s	273-550mm/s
Kar et al (2017)	Low carbon steel	Al_2O_3, TiO_2, Cr_2O_3, YSZ, Ni-Al, NiCrAlY-Plasma spray	1.2-3µm	30-150m/s	1-4m/min
Kumar et al (2018)	Low carbon steel	Al_2O_3 NS, Al_2O_3 SFP – Plasma spray	45µm	40-160m/s	1m/min
Ghosh et al (2018)	Low carbon steel	WC-%12Co - HVOF	5µm	25m/s	0.1m/s
Ghosh et al (2020)	Low carbon steel	WC-%12Co - HVOF	5µm	25m/s	0.1m/s
Pishva et al (2020)	Carbon steel	WC–10Co–4Cr - HVOF	4-22µm	35m/s	550mm/s
Boccarusso et al (2022)	Inconel 718	Metco 204NS (ZrO_2-%7Y_2O_3), Amperit 421.761 (NiCoCrAlTaReY)	Not given	Not given	Not given

4. Evaluation of Results

Similar to the situation with the grinding parameters, evaluated outputs, evaluation methods and reporting of results, units, etc. drastically changes according to the researchers or engineers performed the published studies in the current literature. As an example outputs such as grinding force, surface roughness as surface topography were evaluated by many previous researchers including Liu et al (2002), Liu et al (2003), Kar et al. (2006), and Kumar et al. (2018). Still, the units of the practiced evaluations show a diversity. While Liu et al. (2002) reported the cutting forces per unit area in N/mm^2, Kar et al. (2016) reported total cutting forces in N. Parallel differentiation also exist for hardness values. While Gosh et al. (2018) used GPa units to assess microhardness, Pishva et al. (2022) applied HV unit instead. A final distinction can be observed on surface roughness. Even though most of the researchers practiced Ra units to report the surface roughness values, Boccarusso et al (2022) tried varied units including Ra, Rq, Rdq, Rlo. Moreover, they showed better correlation between less commonly used Rdq / Rlo parameters and tensile adhesion strength. That's why this review article presents all the employed methods in Table 2 in order to provide aggregated know-how to prospective researchers of the subject.

Table 2. State-of-the-art summary on evaluation methods

Reference	Evaluation method
Liu et al. (2002)	Grinding force (N/mm^2), grinding pressure (N/grit), surface roughness (Ra), surface topography
Liu et al. (2003)	Grinding force (N), surface topography, subsurface damage depth (µm)
Deng et al. (2006)	Grinding force (N/mm^2)
Li et al. (2011)	Temperature (°C)
Masoumi et al. (2014)	Specific grinding energy (J/mm^3), surface topography
Kar et al. (2016)	Grinding force (N), surface topography, surface roughness (Ra), subsurface microstructure
Zoei et al (2016)	Compressive residual stresses (MPa), wear loss (mg), surface topography
Kar et al (2017)	Grinding force (N), surface topography, surface roughness (Ra), Specific grinding energy (J/mm^3), subsurface microstructure
Kumar et al (2018)	Grinding force (N), surface topography, surface roughness (Ra), Specific grinding energy (J/mm^3), subsurface microstructure
Ghosh et al (2018)	Microhardness, nanohardness (GPa), surface roughness (Ra), surface topography
Ghosh et al (2020)	Microhardness, nanohardness (GPa), surface roughness (Ra), surface topography, static wetting, dynamic wetting
Pishva et al (2020)	Microhardness (HV), surface roughness (Ra), surface topography, electrochemical behaviour
Boccarusso et al (2022)	Surface roughness (Ra, Rq, Rdq, Rlo), surface topography, tensile adhesion strength (MPa)

5. Conclusions and Future Prospects

This article presents a review on grinding of thermal spray coatings which is exquisitely used of aircraft engine parts. In this respect, spray coatings, which offer the widest substrate material range are explained in detail regarding their materials, application methods and characterizations. Later on, grinding of these is narrated considering tools and process parameters such as cutting speed, feed, and depth of cut. Finally, the influence of grinding conditions on dimensions, surface quality, hardness, residual stresses, and microstructure is discussed.

Although spray coatings are applied on to various aircraft engine parts including spacers, liners, seals, vanes, casings, covers and sleeves of stainless steel, titanium and nickel alloys (Fauchais and Vardelle, 2012), most of the current literature is focused on low alloy and carbon steels as substrate materials. This gap can be considered and filled by prospective researchers on the subject.

On the contrary, coating materials in the published literature show a diverse range including Al_2O_3, WC-%12Co, WC–10Co–4Cr, NiCrAlY and their nano grades. Coating methods also cover high velocity oxy-fuel (HVOF), high velocity air fuel (HVAF) and plasma spray.

Even though most of the research reports surface roughness and/or quality values, dimensional accuracy of the ground coatings has been barely mentioned. Considering the accuracy demand on aircraft engine parts to be below 10µm tolerance (Poyraz and Yandi, 2021), this research question should be addressed by the future researchers or engineers.

Hardness can be focused on as a last highlight on the subject. Despite the fact that a considerable increase on the hardness was reported by one of the previous researchers on the ground samples and was related to depth of cut process parameter, number of current publications reporting this result is less. In the future, this gap can also be filled by other researchers.

Ethical approval

Not applicable.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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References

Ahmed, R., Ali, O., Berndt, C. C., & Fardan, A. (2021). Sliding wear of conventional and suspension sprayed nanocomposite WC-Co coatings: an invited review. Journal of Thermal Spray Technology, 30(4), 800-861.

Ault, W. N. (1989). Grinding Equipment and Processes. In ASM Metals Handbook Vol 16, edited by Davis, J.R, ASM International, United States of America.

Boccarusso, L., Durante, M., Formisano, A., Langella, A., & Minutolo, F. M. C. (2022). Thermal Barrier Coatings (TBCs) Produced by Air Plasma Spray: Repair by Grinding and Waterjet (WJ) Processes. Key Engineering Materials, 926, 1746-1755.

Curry, N., Tang, Z., Markocsan, N., & Nylén, P. (2015). Influence of bond coat surface roughness on the structure of axial suspension plasma spray thermal barrier coatings—Thermal and lifetime performance. Surface and Coatings Technology, 268, 15-23.

Choudhary, A., Naskar, A., & Paul, S. (2018). Effect of minimum quantity lubrication on surface integrity in high-speed grinding of sintered alumina using single layer diamond grinding wheel. Ceramics International, 44(14), 17013-17021.

Deng, Z. H., Zhang, B., & Cheng, F. (2006). Investigations of grinding forces for nanostructured WC/12Co coatings. Key Engineering Materials, 304, 151-155.

EASA, (2018) Type-Certificate Data Sheet for Engine LEAP-1A & LEAP-1C series engines, Paris, France, 1-15.

EASA, (2020) Certification Specifications and Acceptable Means of Compliance for Engines, Amendment 6, 41-79.

Fauchais, P., & Vardelle, A. (2012). Thermal sprayed coatings used against corrosion and corrosive wear. Advanced plasma spray applications, 10, 34448.

Ghosh, G., Sidpara, A., & Bandyopadhyay, P. P. (2018). High efficiency chemical assisted nanofinishing of HVOF sprayed WC-Co coating. Surface and Coatings Technology, 334, 204-214.

Ghosh, G., Sidpara, A., & Bandyopadhyay, P. P. (2020). Fabrication of mechanically durable slippery surface on HVOF sprayed WC-Co coating. Surface and Coatings Technology, 394, 125886.

Gullu, A. (1995) Computer aided optimisation of the grinding parameters in cylindrical grinding order to get required surface roughness, Gazi University, Institute of Sciences, Ankara, Turkiye.

Hwang, T. W., & Malkin, S. (1999). Grinding mechanisms and energy balance for ceramics. Journal of Manufacturing Science and Engineering, 121, 623-631.

Kar, S., Bandyopadhyay, P. P., & Paul, S. (2016). Precision superabrasive grinding of plasma sprayed ceramic coatings. Ceramics International, 42(16), 19302-19319.

Kar, S., Bandyopadhyay, P. P., & Paul, S. (2017). High speed and precision grinding of plasma sprayed oxide ceramic coatings. Ceramics International, 43(17), 15316-15331.

Kumar, A. S., Kar, S., Bandyopadhyay, P. P., & Paul, S. (2018). Grinding of ceramics–sintered ceramics versus ceramic coatings. Advances in Materials and Processing Technologies, 4(4), 538-547.

Łatka, L., Pawłowski, L., Winnicki, M., Sokołowski, P., Małachowska, A., & Kozerski, S. (2020). Review of functionally graded thermal sprayed coatings. Applied Sciences, 10(15), 5153.

Li, C. H., Hou, Y. L., Liu, Z. R., & Ding, Y. C. (2011). Investigation into temperature field of nano-zirconia ceramics precision grinding. International Journal of Abrasive Technology, 4(1), 77-89.

Liu, X., Zhang, B., & Deng, Z. (2002). Grinding of nanostructured ceramic coatings: surface observations and material removal mechanisms. International Journal of Machine Tools and Manufacture, 42(15), 1665-1676.

Liu, X., & Zhang, B. (2003). Grinding of nanostructural ceramic coatings: damage evaluation. International Journal of Machine Tools and Manufacture, 43(2), 161-167.

Tejero-Martin, D., Rezvani Rad, M., McDonald, A., & Hussain, T. (2019). Beyond traditional coatings: a review on thermal-sprayed functional and smart coatings. Journal of Thermal Spray Technology, 28, 598-644.

Masoumi, H., Safavi, S. M., & Salehi, M. (2014). Grinding force, specific energy and material removal mechanism in grinding of HVOF-sprayed WC–Co–Cr coating. Materials and Manufacturing Processes, 29(3), 321-330.

Mayer Jr, J. E., & Fang, G. P. (1995). Effect of grinding parameters on surface finish of ground ceramics. CIRP annals, 44(1), 279-282.

Molak, R. M., Araki, H., Watanabe, M., Katanoda, H., Ohno, N., & Kuroda, S. (2017). Effects of spray parameters and post-spray heat treatment on microstructure and mechanical properties of warm-sprayed Ti-6Al-4V coatings. Journal of Thermal Spray Technology, 26, 627-647.

MTU Aero Engines (2017) Coatings in the engine, Aerport Magazine, https://aeroreport.de/en/good-to-know/coatings-in-the-engine

Pishva, P., Salehi, M., & Golozar, M. A. (2020). Effect of grinding on surface characteristics of HVOF-sprayed WC–10Co–4Cr coatings. Surface Engineering, 36(11), 1180-1189.

Poyraz, Ö., Ozaner, O., & Subaşı, L. (2019, November). Comparative review on the manufacturing of turbine blade fir-tree roots. In Proceedings of the 10th International Congress on Machining (UTIS 2019), Antalya, Turkey (pp. 7-9).

Poyraz, Ö., & Yandı, N. (2021). Investigations on the Fixture Designs of Compressor and Turbine Blades with Parametric Analysis and Finite Element Simulations. European Journal of Science and Technology, (28), 97-105.

Rhys-Jones, T. N. (1990). Thermally sprayed coating systems for surface protection and clearance control applications in aero engines. Surface and Coatings Technology, 43, 402-415.

Si, C., Duan, B., Zhang, Q., Cai, J., & Wu, W. (2020). Microstructure, corrosion-resistance, and wear-resistance properties of subsonic flame sprayed amorphous Fe–Mo–Cr–Co coating with extremely high amorphous rate. Journal of Materials Research and Technology, 9(3), 3292-3303.

Sjöberb, G. (2008), Aircraft Engine Structure Materials, Technical Report, NATO, RTO-EN-AVT-207, 13-24.

Stewart, S., & Ahmed, R. (2002). Rolling contact fatigue of surface coatings—a review. Wear, 253(11-12), 1132-1144.

Sun, L., Yang, S., Yang, L., Zhao, P., Wu, P., & Jiang, Z. (2015). A new model of grinding forces prediction for machining brittle and hard materials. Procedia Cirp, 27, 192-197.

Tao, Z., Yaoyao, S., Laakso, S. & Jinming, Z., (2017). Investigation of the effect of grinding parameters on surface quality in grinding of TC4 titanium alloy. Procedia Manufacturing, 11, 2131-2138.

Tyagi, R., Mandal, A., Das, A. K., Tripathi, A., Prakash, C., Campilho, R., & Saxena, K. K. (2022). Electrical discharge coating a potential surface engineering technique: A State of the Art. Processes, 10(10), 1971.

Vardelle, A., Moreau, C., Themelis, N. J., & Chazelas, C. (2015). A perspective on plasma spray technology. Plasma Chemistry and Plasma Processing, 35, 491-509.

Yastıkcı, B. (2016). Investigation of tool wear in grinding processes, Sabanci University, Istanbul, Turkiye.

Zoei, M. S., Sadeghi, M. H., & Salehi, M. (2016). Effect of grinding parameters on the wear resistance and residual stress of HVOF-deposited WC–10Co–4Cr coating. Surface and Coatings Technology, 307, 886-891.

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