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Applications of Thermal Spray Coatings: A Review

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ABSTRACT

Thermal spray coatings techniques are groundbreaking solutions for a multitude of stumble blocks in various industries. In this article authors reviewed various applications of thermal spray coatings such as automotive, biomedical, power generation and aerospace industry to overcome problems like tribological aspects, corrosion, heat losses, etc. Thermal spray coating will enhance the operating life of the components like in gas turbine industry and mechanical properties of components, increase the thermal efficiency by insulation in engines. It also helps to avoid allergic reactions to patients in orthopedic implants. Moreover, after thermal spray coating waste packages and canisters suitable to sustain the nuclear criticality for transportation, aging and disposal and reduction in friction and wear to increase the life of components in quagmire situations. These are various coating techniques i.e. HVOF, TWAS, FS, APS, CGS and VPS used in different applications to enhance or restore material/mechanical properties of particular component.

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Introduction

Thermal spraying is a process in which molten, semi-molten or solid particles are deposited on a substrate. Consequently, the spraying technique is a way of generating a 'stream' of such particles. Coatings can be generated if the particles can plastically deform at impact with the substrate, which may only happen if they are molten or solid and sufficiently rapid. Their heating and/or acceleration are practical if they occur in a stream of gas [1]. Thermal spray is a technology that involves a group of techniques and coating processes that improve the performance of a component by adding functionality to surfaces. Thermal spray techniques aim at increasing the lifetime of materials compared to their structural mechanisms of breakdown or to provide them with a specific property (e.g. optical and electrical). Thermal spray is a very versatile technology that can be used in many types of applications and virtually almost on any component. This is why it has grown to become a large worldwide market of several billion dollars since the first produced coatings in the early years of the twentieth century. Its versatility makes this technology suitable for use against wear, corrosion and aggressive and high-temperature environments and for repair and restoration of components .The infusion of thermal spray coating into the industry problems has made it possible to achieve targeted results and optimization in various applications like the automotive sector, power generation (wind, gas and steam turbines), biomedical arena and many more without compromising with the quality and standards and inducing desired characteristics into components using various techniques and coating materials [2].

The extremely heterogeneous range of materials that can be employed to develop coatings, is a massive benefit of thermal spray processes. Almost any material that melts and fails to decompose can be used. A second significant advantage is that majority of the thermal spray processes can implement coatings to substrates without making substantial heat input. As a direct consequence, materials with extremely high melting points, such as tungsten, can be applied to finely machined, fully heat-treated parts without reconfiguring their properties or causing excessive thermal distortion. An added advantage to the above stated, is the ability to eliminate and recoat worn or deteriorated coatings without modifying part properties or dimensions across most cases [3]. There are numerous techniques developed based on the material of coating, coating methods and applications. The timeline of development of the same is shown in Figure 1. The broad spectrum of materials used to produce desired coating and the ability of most of the techniques to coat the substrate for desirable characteristic enhancement without thermally affecting it, is the major cause of thermal spray coating seeping into the root of multitude of industries. The various coating techniques used have also been reviewed along with their advantages and disadvantages in Table 1 making them a suitable choice for an application based on their characteristics.

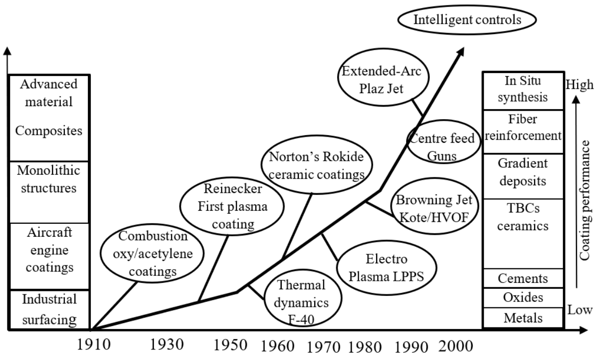

Figure 1: Timeline of thermal spray developments, equipment, processes, and material [3]

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Table 1. Coating techniques used in different applications

Technique	Advantages	Limitations
Cold Spray	• Allows homogenous and very dense coatings • Decreased surface prep: • No bulk particle melting • Cold spray is fast and portable	• Plastic deformation process, which leads to a loss of ductility of the coating
High Velocity Oxy Fuel Spraying	• Higher density (lower porosity) due to greater particle impact velocities • Higher strength bond to the underlying substrate and improved cohesive strength within the coating • Lower oxide content due to less in-flight exposure time • Retention of powder chemistry due to reduced time at temperature • Smoother as-sprayed surface due to higher impact velocities and smaller powder sizes • Better wear resistance due to harder, tougher coatings • Higher hardness due to less degradation of carbide phases • Improved corrosion protection due to less through thickness porosity • Thicker coating due to less residual stresses	• HVOF sprayed coatings can be extremely complex, with their properties and microstructure • Powder sizes are restricted to a range of about 5 - 60µm, with a need for narrow size distributions. • HVOF spraying requires experienced, qualified personnel to ensure safe operation and to achieve consistent coating quality. • As with all the thermal spraying processes, particular health and safety issues should be addressed. HVOF spraying usually needs to be undertaken in a specialized thermal spray booth, with suitable sound attenuation and dust extraction facilities. • HVOF equipment requires more investment than other thermal spraying processes, for example flame and arc spraying. • Manual operation of an HVOF spray gun is not recommended and automated manipulation of the gun is usually needed. • Deposition of coatings is difficult or impossible to achieve on to internal surfaces of small cylindrical components, or other restricted access surfaces, because HVOF spraying needs line of sight to the surface and a spray distance of 150-300 mm.
Twin Wire Arc Spraying	• This coating provides an excellent barrier layer to protect components from deterioration while enhancing their lifespan against factors like corrosion etc.	• High porosity (%) and uneven grain size in the coating layer which causes low adhesive strength, hardness, and fracture toughness
Flame Spraying	• Cost effective • Lower dust and fume levels • Coat complex geometry with ease • Portable and easy to use	• Lower-quality coatings • Difficult to coat restricted surfaces • Powder flame sprayed coatings tend to have high porosity (10-20% vol), low density and high oxide levels (10-20% wt) for metal deposits, and lower bond strength than coatings prepared by other thermal spraying processes.
Atmospheric Plasma Spraying	• Its ability to spray a wide range of materials, from metals to refractory ceramics, on both small and large components • High deposition rate and the applicability of various metallic and oxide coatings. • Many types of substrate material, including metals, ceramics, plastics, glass, and composite materials can be coated using plasma spraying. • The high temperature of a plasma jet makes it particularly suitable for spraying coatings of refractory metals and ceramics, including $ZrO2$, $B4C$ and tungsten. • A broader powder particle size range can be used, typically 5-100µm, compared with HVOF spraying. • Plasma spraying is a well-established coating process that is widely available and well understood.	• Air plasma spraying equipment is generally very expensive to buy and use. • It is a line-of-sight process, similar to all other thermal spraying processes, making it difficult to coat internal bores of small diameters or restricted access surfaces. • The plasma spray gun usually experiences rapid deterioration of the inner gun electrodes and other internal components. This leads to frequent replacement of gun electrodes, and the need for quality control to maintain coating consistency. • The high temperatures associated with the plasma jet can result in carbide decomposition or excessive oxidation when spraying in air, giving carbide coatings with lower hardness or metallic coatings with higher oxide levels compared with HVOF sprayed coatings. • The equipment is not suitable for manual operation and requires use of automated gun manipulators
Arc Spraying	• Arc spraying has the highest deposition rate • Power input is very low	• The process can be used to spray only electrically conductive materials that are available in a

	• Low heating of the substrate makes arc spraying useful in metallizing thermally sensitive substrates such as capacitors and similar electronic components. • It is possible to spray two dissimilar wires and produce an intimately mixed coating • Arc spraying does not require use of combustion gases or produce a high-energy plasma, and consequently poses fewer Health & Safety risks than other thermal spray processes.	suitable wire form. • It is not suitable for spraying cermets or ceramics, although hard particles can be introduced via the use of cored wires.
Detonation Gun Spraying	• Provides extended life to parts. • It gives dependable wear and corrosion-resistant surface on machine parts under difficult service conditions.	• Detonation spraying creates a coating that is mostly mechanically bonded as opposed to being metallurgically bonded, which is a much stronger type of bond. • Detonation spraying is a 'line of sight' process meaning that components generally need to be coated before being put to use or assembled. This is because the detonation gun needs to be able to access the surface to be able to apply an effective coating. • The coatings despite being considerably strong in compression are weak under tension, meaning they can't be applied to malleable or expanding components. • The coatings tend to fatigue under pinpoint loading. • Detonation guns are quite large and loud. • Detonation spraying has to be performed at a location specifically designed for it, as the gun is reasonable large and it is a loud process that produces substantial noise. For this reason, it is usually installed in a sound-proof room (with concrete walls 45 cm thick). • The process involves a considerable amount of mechanization and automation because the operator can't be in the room whilst the D-gun is in operation
Electron Beam Physical Vapour Deposition	• Coating PVD is safe • PVD can be used on almost any type of inorganic material. • Coating PVD is still one of the most effective methods of improving a surface's strength and durability.	• Coating PVD is expensive • The process requires complex machines that need skilled operators. • The rate at which coating PVD operates is relatively slow.

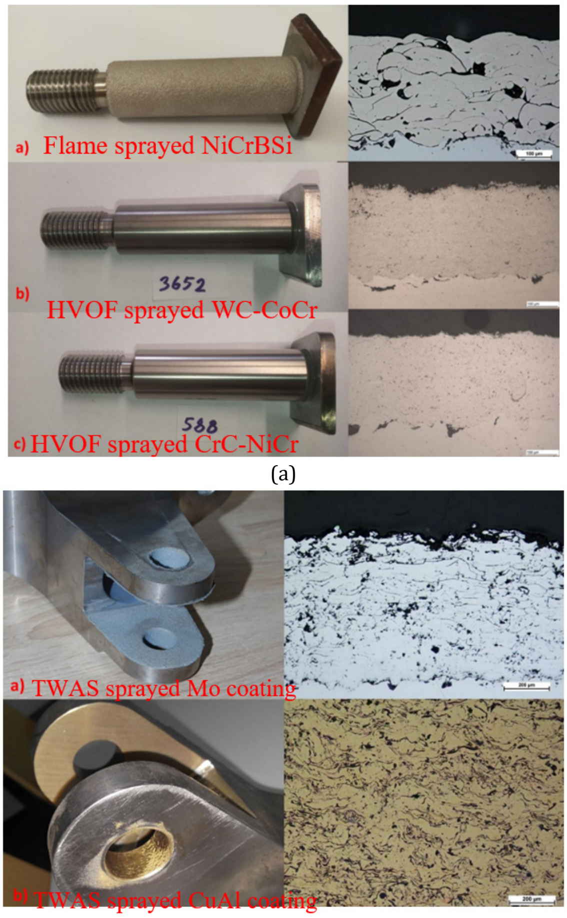
Applications

Automotive application

[4] implemented the amorphous iron-based coating through powder and wire frame to study the wear resistance. Authors compared the thermal spray, flame spray / amorphous iron-based coating, showed that the microstructure, hardness and face content depend largely on the spraying parameter incorporated. Permanent magnets from an NdFeB-Al composite powder mixture with high coercivity and raw theoretical remanence made by [5]. The acquired magnetic characteristics show that cold spray additive manufacturing can be used to effectively create motor parts without the need for further assembly procedures. It was demonstrated that by selecting the magnetic powder/binder powder pre-mix ratio, binder granulometry, and process temperature optimally, a high magnetic volume fraction could be achieved. A maximum remanence of 0.49 T was obtained using these values. Despite having a lower value than sintered magnets, cold spray magnets have better mechanical characteristics and more shape flexibility. Advanced toolpath programming was utilized to deposit a self-standing hollow hourglass-shaped rotor (as shown in Figure 2.) made of soft and hard magnetic materials to demonstrate that final characteristic.

Figure 2: Hourglass shaped rotor made from NdFeB-Al composite and pure iron [5].

Vostřák et al. [6-7] attempted to enhance the resistance and service life of rail vehicle parts by applying thermal spray coatings such as High Velocity Oxygen Fuel (HVOF), Twin Wire Arc Spray (TWAS), Flame Spray (FS), and Atmospheric Plasma Spray (APS) with various materials like iron, nickel, zinc, molybdenum-based alloys and WC and CrC cermet. Authors applied the HVOF/ FS sprayed coating on rail vehicle components which require high wear and corrosion resistance (handle to secure wheelset during lifting of chassis), whereas they used TWAS/APS thermal spray techniques to protect (from weather, erosion by stones and walking) large surfaces located outside the rail vehicles (walkable footplates). One of the key properties of these coatings must be resistance against corrosion in the salt environment, as they need to protect the part for the whole life span in climatic conditions. The two components the "Pivot" and the "Roll Holder" are taken [7] for HVOF and TWAS spray respectively to enhance the life span of these component. The pivot has high demands on corrosion resistance, hardness, and resistance against abrasion as presented in Figure 3(i). The chosen coatings were (a) Flame sprayed NiCrBSi (FST 771.33), (b) HVOF (High-Velocity Oxygen Fuel) sprayed WC-CoCr (Woka 3652) coating and (c) HVOF sprayed CrC-NiCr coating (Amperit 588.074) as shown in Figure 3 (a-c). Roll holder has high demands on friction properties due to the geometric complexity and economic considerations as given in Figure 3(ii).



(a)

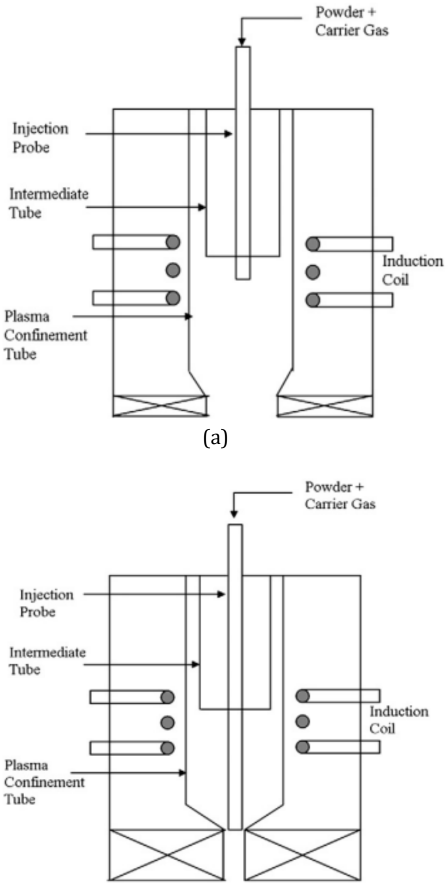
(b)

Figure 3: The component (a) pivot roller and (b) roll holder treated by thermal spraying [7]

The author conducted experiment to study the corrosion behavior in salt spray condition for 1000 hours for the two rail vehicles components with and without thermal sprayed coatings. The first component "Pivot" requires apart from high corrosion resistance also high hardness and wear resistance. Voyer concluded that the HVOF sprayed WC-CoCr coating displayed the best performance from selected variants. The second component "Roll holder" requires apart from corrosion resistance suitable friction properties. The TWAS sprayed CuAl and Mo coatings were tested and the CuAl shows better behavior in salt spray and conducted an additional analysis of corrosion product on the interface and detailed analysis of friction behavior to choose a more suitable coating for roll holder. The thermal insulation technology was employed [8] to increase the thermal effectiveness and decrease the heat losses in automotive vehicles. Through the use of plasma spray suspension techniques, authors demonstrated thermal shock resistance as well as changes to microstructural and thermal characteristics. Additionally, they observed various stages of degradation in the specimens, including microcracking, fracture propagation, and crack growth on coated surfaces.

Biomedical application

Highly crystalline nano hydroxyapatite (HA) coating on commercially pure titanium (Cp-Ti) was prepared [9] using inductively coupled radio frequency (RF) plasma spray and studied there in vitro and in vivo biological response. The author investigated the possible effects of plasma nozzle designs, plate power, and working distance on coating crystallinity, phase decomposition, and mechanical properties of plasma sprayed HA coatings as presented in Figure 4 [9] and experimental conditions are given in Table 2.



(a)

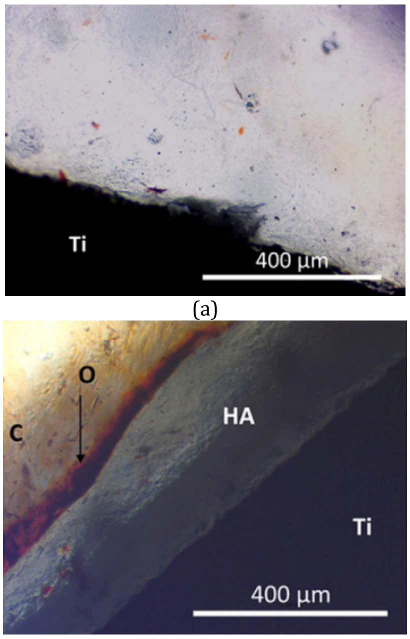
(b)

Figure 4: Schematic representation of (a) normal and (b) supersonic plasma nozzle [9].

Table 2: Experimental conditions [9]

Central gas flow rate (slpm)	25 Ar
Sheath gas flow rate (slpm)	60 Ar + 6 Hz
Carrier gas flow rate (slpm)	10 Ar
Power	22, 25, 28
Working distance (mm)	90, 110, 130
Chamber pressure (Psig)	5

Roy acquired a coating thickness of 300 and 400 m with bond strengths ranging from 4.8 MPa to 24 MPa, depending on the plasma processing settings. Author cultured human foetal osteoblast cells (hFOB) on surfaces with HA coatings to investigate the cytotoxicity of those materials. Roy also compared the uncoated and coated Ti in rat femur for two weeks as shown in Figure 5.



(a)

(b)

Figure 5: Optical photomicrograph of a longitudinal section of (a)Uncoated Ti and (b) HA coated Ti , implanted in rat femur at 2 weeks showing (O) nonmineralized osteoid and (C) collagen matrix with Putative Mesenchymal Cells (Goldner's Masson Trichrome Stain) [9].

In his research, [10] examined the impact of strontium (Sr) dopant on the kinetics of protein release in vitro and the osteogenic qualities of plasma-sprayed hydroxyapatite (HA) coatings in vivo as presented in Figure 6. The creation of crystalline and amorphous HA coatings on commercially pure titanium (Cp-Ti) utilizing inductively linked radio frequency (RF) plasma spray were carried out [10]. On HA implants, osteoid new bone started to form 12 weeks after implantation; but, on Sr-HA samples, bone mineralization had not yet begun. While no osteoid was formed on bare Ti surfaces, bone mineralization was complete on HA and Sr-HA coatings 16 weeks after implantation. Vahabzadeh et al. demonstrated the effects of plasma spraying parameters and coating composition on crystallinity, dissolution, protein release behavior, and in vivo bone regeneration, which can be tailored to meet specific clinical application needs, and that crystallinity significantly reduced coating stability in both neutral and acidic environments in Figure 6.

Since the rejection reaction cases of inflammation and allergies were observed in a large number of patients with implants as they react with the host environment, surface modification of implants has emerged indispensable. In order to overcome these drawbacks, [11] attempted composite coating on implants. The authors used HVOF to incorporate bio inert ceramics such as stabilized zirconia, titanium, and alumina into a hydroxyapatite (HA) matrix to create coatings with improved mechanical properties and no rejection reactions, overcoming the shortcomings of conventional coatings.

Harjit Singh [12-13] worked on the challenges in fabrication and solutions for implementing Ti alloy in biomedical industry and reported bibliometric analysis, revealing the implementation of HA coating on Ti alloy using plasma spray technique in orthopedic implants and its surface modification. The research included enhancement of the biomechanical property of HA coating with biocompatible elements like CNT, TiO2, ZZO2 and Al2O3, as they reduce the brittleness of HA thereby improving the overall mechanical properties. The author concluded that HA-TiO2 coating has been the best combination to provide required characteristics for the implant (Fig. 7).

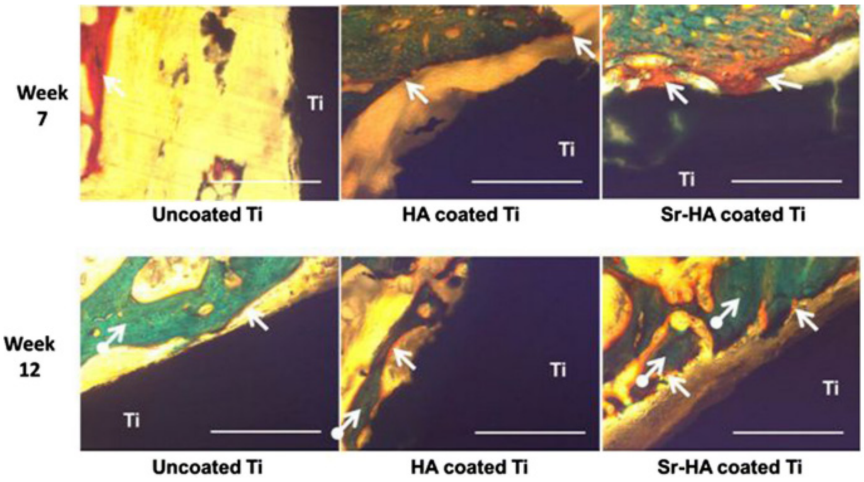


Figure 6: Optical photomicrograph of a longitudinal section of uncoated Ti, HA coated Ti, and Sr-HA coated Ti implants showing the development of new bone formation on the surface of implants after 7 and 12. Modified Masson Goldner's trichrome staining of transverse section. Color description: orange/red = nonmineralized osteoid (indicated by arrow), green = mineralized bone (indicated by circled arrow). The scale bar represents 400 lm [10].

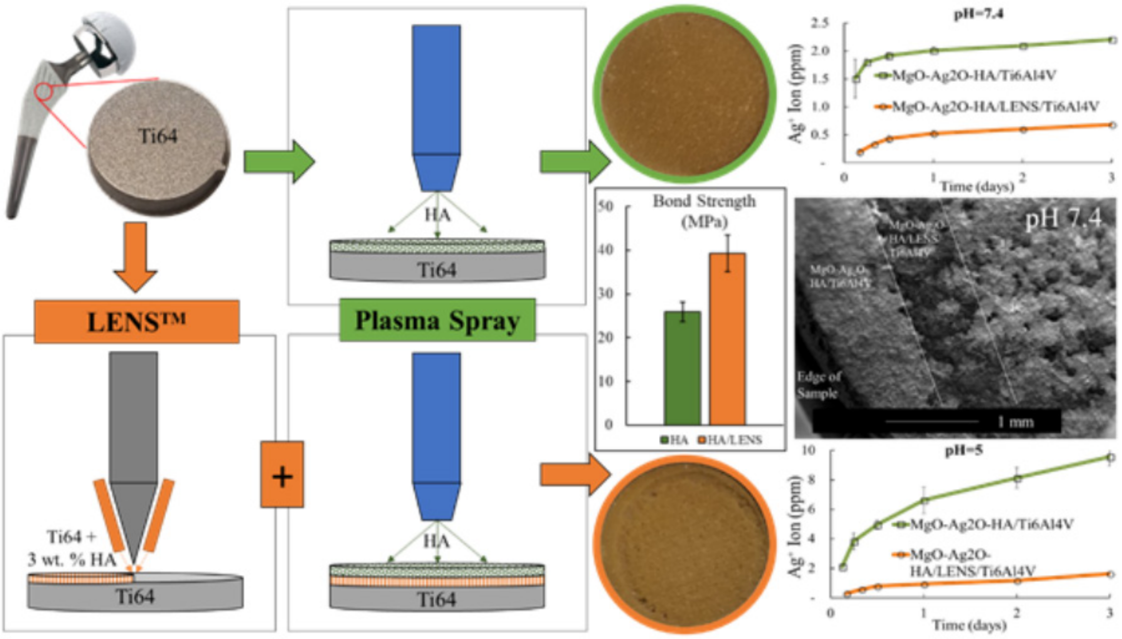


Figure 7: Deposition of functional graded MgO/Ag2O alloyed HA-coating on the Ti-surface using laser and plasma spray process [13]

Power generation application

Gas turbine industry

For gas turbine applications, Miller [14] used a plasma-sprayed Zr02—(6% - 8%) Y203 ceramic layer over a plasma-sprayed MCrAIY (M Ni, Co, or NiCo) bond coat layer. Miller emphasized that the advantages of thermal barrier coatings include lower metal temperatures, moderation of thermal transients, reduced cooling air requirements, and/or higher gas temperatures were supreme and that the roughness can eventually lead to coating failure. There are two types of ceramic coating development: compositional modifications and structural modifications. As a result, performance and efficiency are improved, component lifetimes are extended, designs are simplified, and in some cases, less expensive metallic substrates are substituted. Vaßen [15] attempted to increase and improve the temperature capability and microstructure, as well as optimize optical properties, by developing thermal boundary coatings for use in protecting structural parts in gas turbines. The authors used a NiO/YSZ coating for anodes, a YSZ coating for electrolytes, and various chromium coatings for interconnects created using the Atmospheric Plasma Spray coating technique. APS is a cutting-edge technology in modern gas turbine systems, as it improves the overall mechanical and thermal properties, as well as the operation life of components used in gas turbines subjected to harsh operating conditions. Mauer [16] identified various pyrochlores, perovskites, doped yttria-stabilized zirconia, and hexa-aluminates as promising candidates as TBC for gas turbines due to their temperature and cyclic capabilities, corrosion resistance and erosion performance, prompting the development of new materials and coating systems.

Thermal barrier coatings (TBCs) made of YSZ (yttria stabilized zirconia) were frequently used to prevent superalloy blade failure in industrial gas turbine engines. The main cause of TBC failure was YSZ coating spalling. Typically, this failure occurs within the YSZ coating, near the YSZ/bond coat interface. Tailor [17] used a Ni718 superalloy substrate with a NiCrAlY-20%YSZ- MoSi2 top coat in his investigation, to create a novel robust multilayer TBC using atmospheric plasma spray (APS). Moreover, Fiebig [18] emphasized the importance of restoring worn out and deteriorated components related to gas turbine maintenance and overhaul since they are subjected to harsh operating conditions. The authors demonstrated the potential for coating repair using Cold Gas Spraying (CGS) and Vaccum Plasma Spraying (VPS) for polycrystalline and single crystal components.

Nuclear industry

Transportation, ageing and disposal of spent nuclear fuel are critical parameters for employing a nuclear industry for power generation application. Blink [19] investigated the use of TSC to improve the corrosion resistance of drip shields, waste packages, and canisters for the aforementioned applications, thereby reducing nuclear criticality. For this, Fe-based amorphous metals with Cr, Mo, and W were used. The high boron content of rare earth metals, combined with their stability at high neutron doses, allows them to be used as neutron absorbers with very low critical cooling rates. Blink also gave a cost model to quantify economic benefit possible with these new materials, thereby highlighting the rise of TSC in the nuclear industry.

A promising solid-state, powder-based deposition technique for coating production, near-net-shape manufacturing, and component repair is cold spray technology. This technique has recently being looked into for a variety of uses in the nuclear energy industry. For instance, it has been investigated for the deposition of corrosion and oxidation coatings on zirconium-alloy fuel claddings in light water reactors (LWR) for (ATF) cladding, as well as in claddings of oxide dispersion-strengthened (ODS) steels and for the mitigation and repair of potential chloride induced stress corrosion cracking in used fuel storage canister systems. Yeom [20] has examined this infusion and the hole that has to be filled in the future as shown in Figure 8. The Author has also highlighted cold spray near-net shape manufacturing for advanced nuclear reactors, fuel storage and repository; moreover explained the challenges this technology faces in its implementation.

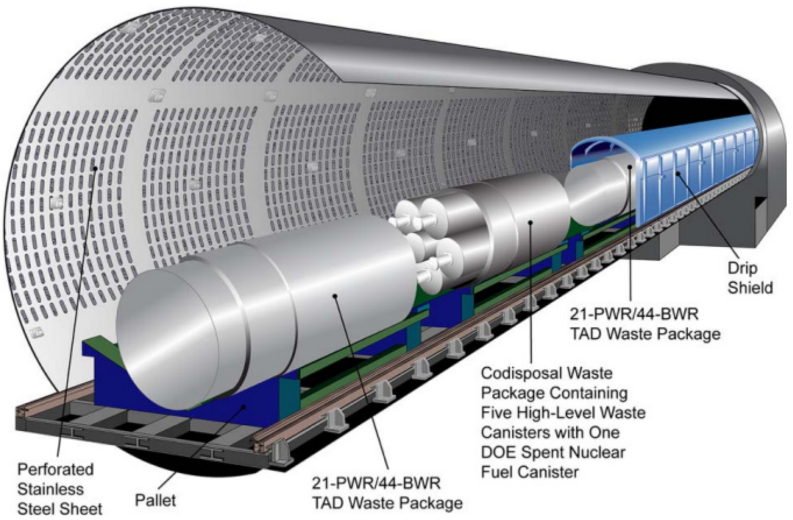


Figure 8: Three-dimensional illustration of waste packages for spent nuclear fuel and high-level radioactive wastes in a typical drift (tunnel) at the Yucca Mountain site. Waste packages were protected from dripping water and falling rocks by the drip shield. A SAM coating on the exterior of the waste packages or drip shields could improve repository performance [20].

Table 3: Process conditions of SPS coatings [21]

Process	Flame	Arc	D-Gun	Plasma
Consumable material	Powder or wire	Wire	Powder	Powder
Heat source	Chemical reaction	Electric arc	Controlled explosion	Inert gas plasma
Flame temperature (deg C)	2—4000	4000	3300	4500-20000
Particle velocity (m/s)	90-180	240	730	240-600

Table 4. Various application of thermal spray coating

Authors	**Spray coating**	**Applications**	**Remarks**
Voyer (2010)	Wire spray and powder spray coatings	Automotive vehicles	Amorphous iron based coatings wear resistance is similar to plasma / HVOF spray techniques and it is easy to use on-site for small components.
Lamarre (2019)	Cold spray technology	Electric Vehicle (Automotive vehicle)	Manufacturing permanent magnets from an NdFeB-Al composite powder mixture for better magnetic properties.
Vostrak *et al.* (2021a)	High Velocity Oxygen Fuel (HVOF), Twin Wire Arc Spray (TWAS), Flame Spray (FS), and Atmospheric Plasma Spray (APS)	Rail vehicle components	HVOF/ FS sprayed coating component require high wear and corrosion resistance. TWAS/APS thermal spray techniques to protect environment conditions on large area.
Vostrak *et al.* (2021b)	Flame spraying technique HVOF	Rail vehicle components	Coatings for Pivot and roll holder developed based on the mode of failure of the same
Jeon *et al.* (2021)	Thermal insulation	Automobile vehicles components	To enhance the thermal efficiency and reduce the heat losses.
Roy (2011)	Inductively coupled radio frequency (RF) plasma spray technique	Orthopedic implants	Generation of coating on the implants by changing the nozzle to optimize the implant life
Vahabzadeh (2015)	Inductively coupled radio frequency (RF) plasma spray technique	Orthopedic implants	Compared HA coated , uncoated and uncoated Ti implants for stability under various conditions
Prashar (2020)	HVOF and plasma spraying techniques	Composite coated implants	Surface modification of implants by composite coating on implants to improve the mechanical properties of the implants.
Singh (2021)	Plasma spray coating(PST)	Orthopedic implants	HA coating on Ti alloy using PST on orthopedic implants to improve the properties and comfort of the patient.
Miller (1987)	Plasma spray coating(PST) and Electron beam—physical vapor deposition (EB—PVD)	Gas turbine coating	TBC for gas turbine blades.
Vaßen(2008)	Atmospheric Plasma Spray technique(APS)	Gas turbine coating	APS technique for improving the mechanical and thermal properties and operation life of gas turbine
Mauer (2012)	Electron Beam-Physical	Gas turbine coating	Comparison of different materials used for TBC

	Vapor Deposition (EB-PVD) and atmospheric plasma spraying (APS)		with their strengths and limitations
Tailor(2016)	Atmospheric plasma spray (APS)	Gas turbine industry	Protective top coat layer of MoSi2 to prevent spalling, oxidation and improve mechanical properties, thermal insulation and prevent damage to the turbine
Fiebig (2020)	Cold Gas Spraying (CGS) and Vacuum Plasma Spraying (VPS)	Restoration of gas turbine coating	Repair the coating on gas turbine for restoration and hence improve the life and performance of the gas turbine subjected to harsh conditions.
Blink (2009)	HVOF	Nuclear industry	Enhance the corrosion resistance of drip shields, waste packages and canisters for safer transportation, aging and disposal of the used fuel.
Yeom (2020)	Cold spray technology	Nuclear industry	CST for LWR and AFT cladding, nuclear reactor, fuel and storage repository.
Rhys-Jones (1990)	Flame spraying , Arc , D-Gun and Plasma spraying technique	Aerospace industry	Coating material and technique depending on the various applications like wear , oxidation and corrosion, thermal barrier control etc. for aero engine components
Koutsomichalis (2009)	Atmospheric plasma spray technique	Aerospace industry	Reduction of the deterioration caused by friction and wear on the operating life of aircraft systems by TSC coatings

Aerospace industry

Rhys-Jones [21] emphasized the then-existing principal and new thermal spray and the use of coatings in aero engine compressor, combustion chamber, and turbine applications. Coatings were used to protect engine components from wear, erosion, corrosion, and oxidation, to provide thermal insulation to allow for higher material operating temperatures and/or less use of cooling air, and to control clearance. Various spray process conditions are given in Table 3 as expressed by [21].

Koutsomichalis [22] investigated stresses and their effects on the tribological behavior of the conventional WC 12% Co coating deposited by atmospheric plasma spray technique using four different test loads. Author also investigated the tensile characteristics and corrosion resistance of coated and uncoated specimens and concluded with the superiority of coated substrate with satisfactory wear, high hardness and good adhesion with respect to the latter. Various application of thermal spray coating with remarks is given in **Table 4**.

Conclusions

In this paper , we have studied the four major areas of application of the thermal spray coating in namely the automotive , biomedical , power generation and aerospace industry to appreciate how seamlessly has TSC been able to solve a multitude of industrial problems including enhancement of mechanical properties, decreasing heat losses by insulation, restoration of components, nuclear criticality, allergic reactions and life of implants and considering the tribological aspects of various components based on the application and environment of operation. The paper also highlights the various TSC technologies providing a helping hand to achieve these goals in a variety of problems. Over decades, technology has certainly made it possible to find ground breaking solutions for problems once seemed impossible to crack .Technology is accrescent and hence many more such advancements are yet to come.

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