FAISAL, N.F. and PRATHURU, A. 2024. Sustainable development goals and circularity in thermal spray coating manufacturing and value chain. *Spraytoday* [online], 4(2), pages 8-11. Available from: https://www.inscience.in/files/SPRAYTODAY%20Q2%20Full%20Issue_June2024.pdf

Sustainable development goals and circularity in thermal spray coating manufacturing and value chain.

FAISAL, N.F. and PRATHURU, A.

2024

Sustainable Development Goals and Circularity In Thermal Spray Coating Manufacturing and Value Chain

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Summary

Thermally sprayed coating manufacturing utilizes a range of feedstock materials to develop thick layers on high-value solid and conformal structures which provide a wide range of qualities to components or parts. Due to the combination of environmental, economic, social, and regulatory factors, there is compelling need for thermal spray coating manufacturers and those associated with the value chain to embrace the United Nation's Sustainable Development Goals (UN SDGs) and circularity to stay competent in the international market. This could lead to a significant increase in the demand for sustainable and circular manufacturing practices, and potential increase in business opportunities, market size and the economy. There is a need to understand the challenges and identify opportunities for circularity in thermal spray coating manufacturing and value chain.

Thermal spray coating

Thermal spray is regarded as a key surface manufacturing technique that underpins the competitiveness of critical manufacturing and engineering industries. Considering the global thermal spray market size, it is expected to grow from USD 10.91 billion in 2023 to USD 13.41 billion by 2028, at a CAGR of 4.22% (during 2023-2028) (Report Linker, April 2023). It is widely used in engineering for aerospace, industrial gas turbine, automotive, medical, printing, oil & gas, steel, pulp & paper, others as well as other new applications [1-2].

Various thermal spraying processes exist (e.g., air plasma spray, cold spray, detonation spray, flame spray, electric arc spray, high velocity oxy-fuel (Fig. 1), and more) [3] and all are used to produce thick-film coatings to combat surface degradation of engineering components or to bring in functional features, for example wear resistance, catalysis, electromagnetic wave absorption or hydroxyapatite for tissue regeneration. The materials that can be deposited through thermal spray include pure metals, metallic alloys, ceramics, and a mix of ductile and brittle materials. During spraying, several variables and process parameters have a direct impact on coating properties, which can be quantified. The process of such coating deposition involves complex phenomena occurring with overlapping timelines. The temporal evolution of overall coating formation constitutes splat formation, cooling, and subsequent layer deposition followed by cooling to room temperature post-deposition (Fig. 2). Such coatings are vital to improve the performance of components and industrial products to maximise their life cycle.

Value chain in thermal spray sector can be split into the following fields: materials and processes pre-spraying (materials mining, feedstock processing and their manufacturing), during spraying (consumables, coating manufacturing, equipment's), post-spraying (coated part finishing and handling), during use or in-service operations (coating degradation), and then the end-of-life and circularity of coated parts. The materials and manufacturing vision as well as the entire value chain should be guided by sustainable development goals (SDGs) and circularity imperatives. Due to barriers within this sector, such as lack of understanding, skills, experience, as well as training, resources, strategy, regulations, and environmental awareness on the part of suppliers, clients, or end users, the circularity within the thermal spray value chain is currently at a nascent stage.

Sustainable Development Goals (SDGs) and thermal spray sector

To bring prosperity, peace, and partnership to all people on the planet by 2030, the United Nations enacted a set of 17 goals in 2015, called Sustainable Development Goals (SDGs), which have economic, social, and ecological

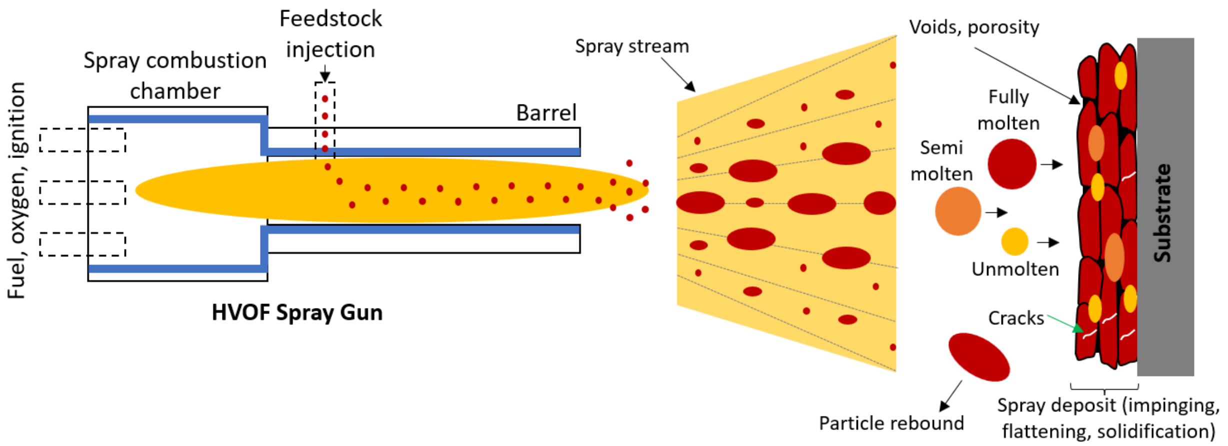

Figure 1: Various stages of thermal spraying

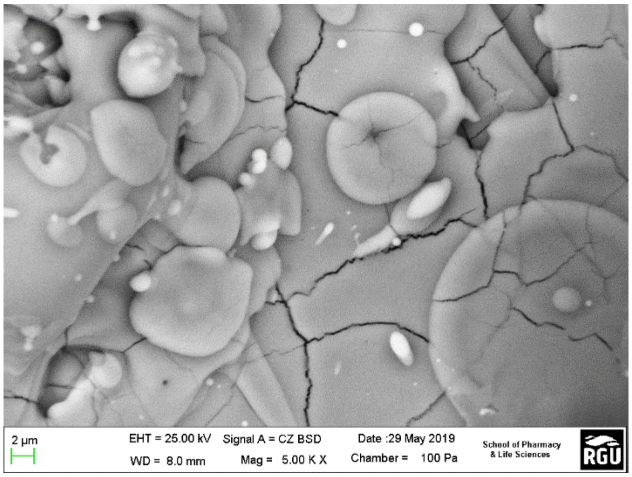

Figure 2: Air plasma sprayed TiO2 coatings on mild steel, showing splats and microcracks

dimensions. Given the size of the thermal spray value chain and market, it has an important role to play in reaching relevant SDGs. Relevant SDGs could be SDG7 (affordable and clean energy), SDG8 (decent work and economic growth), SDG9 (industry, innovation, and infrastructure), SDG12 (responsible consumption and production), SDG13 (climate action), and SDG17 (partnership for the goals) (Fig. 3).

Like other manufacturing sectors, the thermal spray sector could create a sustainable framework for the industry which could help meet its social responsibility goals. There is very limited data, however, in certain practices associated to thermal spray value chain, there is overexploitation of resources, including creation of huge material waste. There is a need to provide incentives of the SDGs to thermal spray value chain stakeholders, including encouragement to transition to circular economies (reuse, recycle, remanufacture, and recover), and support various framework directives related to waste (e.g., EU's Waste Framework Directive, 2023 [4]). Overall, such directives require the stakeholders and businesses to protect human health and the environment, by reducing waste and its adverse effects through efficient management.

Figure 3: Relevant SDGs appropriation for thermal spray value chain

Circularity opportunity

Competitiveness in thermal spray manufacturing is highly dependent on the ability of such manufacturing sector to provide high-quality, innovative products through enhancing circularity, and facilitating decarbonization [5]. This would mean a range of modern tools need to be employed to achieve the systemic circularity of the thermal spray sector. The transition to circular manufacturing requires a new mindset, resources, and expertise in the sector. All the technological improvements of the manufacturing process should always support the human aspect to uptake these improvements through upskilling and reskilling of the manufacturing workforce. Currently, there is a skill gap within professionals with knowledge of circular manufacturing processes. The workforce should be engaged in the realization of circular approaches.

Considering the future requirements of thermal spray coating manufacturing, there is need to forecast the environmental impact, quantify state of products after their use, develop simulation and modelling software or build on existing solutions fostering new circular manufacturing capabilities with a view to be more efficient and more sustainable product design. There is a need to enable the manufacturers to implement the Digital Product Passport initiatives [6], and focus on gathering relevant data, material and product tracking and tracing, certification protocols for secure re-used materials and components among sectors.

Efforts are necessary to consider recycling and reuse in the thermal spray sector and to continue drawing the advantage of thermal spraying being a relatively green technique. To achieve a circularity or circular economy of thermal spray coated products after use (i.e., end-of-life), there is a need to start looking at value retention processes [7]. This includes practices such as choosing repair and overhaul (where possible) over buying new or purchasing remanufactured equipment as opposed to new. It is not new, but thermal spray industries have been using the practice of rebuilding and remanufacturing for reuse or recycling (either through removing damaged materials via machining or rebuilding the surface of coated components through mix of thermal spray techniques, through using heat, depending upon the metallurgical properties of the coating and structural part material). The key advantage of such remanufacturing are its cost-effectiveness and a process that can be done multiple times [8], and importantly it is an accepted practice as the sector has been able to achieve original equipment manufacturers (OEMs) specification through remanufacturing [9]. However, some aspects of reuse and recycling are currently not possible in thermal spray industry (e.g., reusing coating materials which are removed from the coated parts). As an example, thermally sprayed thermal barrier coatings (TBC's) could be removed using techniques such as grit blasting, chemical stripping (autoclaving, aqueous stripping), water jet (abrasive, non-abrasive), and laser ablation. With varied degree of removal efficiencies, all these coating processes are useful only to remove the coatings, but these does not help in recovering the removed materials. It would be quiet a cumbersome and costly process (with very low yield) to recover the useful part of the removed coatings, as the removed mass would have contaminants, rusts, stains, and high toxicity, which can be a less attractive offer for many businesses.

Thermal spray processing generally requires feedstock in the form of fine powders. These powders are made using methods such as atomisation, spray drying, and solid-state reduction. All these processing methods require some level of energy to either melt the raw material or to enable a chemical reaction process. Efforts should be put in place to achieve carbon neutrality in such feedstock manufacturing processes to reduce the overall carbon footprint. To understand the circularity of thermal spray process and its overall carbon footprint, it is important that the background processes be accounted for too. One possible way to implement the concept of circularity is to evaluate how waste or by product material from other industries can be used in thermal spray. For example, copper waste from the electronics and electrical (WEE) industries could be a possible source of copper feedstock for electrically conductive coatings. In addition, low melting point metals such as zinc and aluminium can be recycled for reuse with minimal heat input. However, in such cases, particle oxidation in the spray plume is a potential hurdle.

Overspray is seen extensively in most thermal spray shops. The general operational philosophy of such facilities is the collection of the overspray dust to be either sent to a landfill or selling to a waste buyer who separates the individual powder materials and reprocesses them to be resold. Understanding the cost benefit of recycling instead of discarding into a possible landfill provides the basis for formulating the business case of introducing circularity in thermal spray manufacturing value chain. Classifying the materials according to the ease of recycling is one way of understanding and creating a circularity framework. For instance, being able to collect the overspray dust in separate bins according to the material type makes it easier for the buyer to recycle the waste material at a later stage. This could also increase the sale value of the dust and could present a cost recovery opportunity to the thermal spray manufacturer. Creating an implementation plan around the product life cycle, not just of the coated product but also the feedstock could be an effective way of reducing waste while increasing the overall cost return.

One excellent demonstrator of the reuse of thermally sprayed feedstock overspray dust is the LIFE ReTSW-SINT project [10] funded by the European Commission (EC). The objective of the project was to establish the processing methods to use thermal spray waste in other industries. The project was able to successfully demonstrate the reuse of nickel metal powders in creating sintered products using the spark plasma sintering (SPS) method. In addition, the project also established the process of incorporating YSZ waste powder into ceramic frits and tiles. This project also demonstrated the critical aspect of environmental safety consideration while developing a recycling process. Given that most of the materials of commercial interest used in thermal spray are hazardous, it is critical that the reuse process isolates these materials and reduces their interaction with the environment. Most ceramics exhibit leaching behaviour where the constituent metals are slowly released into the environment creating environmental contamination.

Concluding remarks

Since the invention of the thermal spray process by Dr. Max Ulrick Schoop of Zurich in 1911, a lot has changed in the sector. Thermal spray market is experiencing significant growth as the sector is seeking advanced coating solutions to enhance the performance and longevity of coated parts, including emergence of new ways to deposit coatings and applications. Quality and affordable thermal spray products will be the future growth opportunities in coming decades. There is a need to drive low-carbon processes in thermal spray coating manufacturing and value chain through efficient resource utilisation, enhanced performance, and waste minimisation, strategically address critical (social, economic, environmental) needs sustainably, develop global centre of excellence and achieve high quality, multidisciplinary research, engage (co-create/co-deliver) with partners, and create opportunities for staff and end user skill development, and embed equality, diversity, and inclusion (EDI) within the sector through specific action plans. There is a need of new entrants (entrepreneurs) in thermal spray value chain who can focus on the deployment of next generation technology solutions at scale to meet short and medium-term targets, including meeting sustainable development goals and transition to circular economies. Such strategies could also help improve loyalty of the buyer and influence the brand.

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