Thermal Spray Technology White Paper
Prepared by the
Thermal Spray Society
Affiliate of ASM International

Mission

This document is to better educate government, industry and academia as to the benefits of Thermal Spray Technology. Critical aspects of this document are to highlight the importance of education, training and internships of students, research in applied science/ engineering/ fundamental science and in collaboration efforts between academia, government and universities to advance technology from theory to practice. It is anticipated that greater understanding and appreciation of the value of thermal spray for improved sustainability will lead to government and public funding for additional growth.

The Value of Thermal Spray Technology

Thermal spray technology helps to sustain our way of life by reducing energy consumption, providing environmental benefits, supporting human comfort, and reducing material waste.

What is Thermal Spray?

Thermal spray is an established industrial method for the surfacing and resurfacing of engineered components.[1,2] Metals, alloys, metal oxides, metal/ceramic blends, carbides, wires, rods, and various composite materials can be deposited on a variety of substrate materials to form unique coating microstructures or near-net-shape components. Thermal spray coatings provide a functional surface to protect or modify the behavior of a substrate material and/or component. A substantial number of the world's industries utilize thermal spray for many critical applications.[2] Key application functions include restoration and repair, protection against corrosion and various forms of wear such as abrasion, erosion and scuff, heat insulation or conduction, oxidation and hot corrosion prevention, electrical conductors or insulators, near-net-shape manufacturing, seals, engineered emissivity, abradable coatings, decorative purposes, and more.
Thermal spray processes are easy to use, cost relatively little to operate, and have attributes that are beneficial to applications in almost all industries. The benefits of this environmentally friendly process are typically lower cost, improved engineering performance and/or increased component life (Figure 1).

- Resist Wear
- Retard Corrosion
- Manage Thermal Efficiency
- Enhance Electrical Properties
- Control Dimensions & Clearances
- Salvage Worn Components

Reduce Cost Through

- *Better Performance*
- *Longer Component Life*
- *Decreased Maintenance*

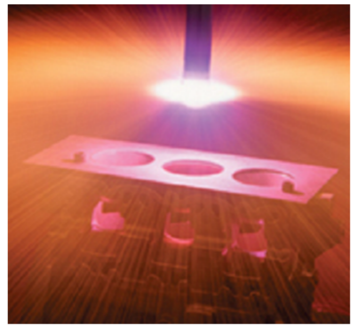

Figure 1: The benefits of Thermal Spray technology leading to better performance, longer component life, and decreased maintenance.

How It Works

Figures 2a and 2b show the requirements for thermal spray: a heat / energy source and consumable materials.[2] Gases, along with air in some cases, are needed to inject materials into the thermal spray gun/torch and to generate the necessary heat for melting. The high gas velocities associated with these processes cause material to be propelled as fine molten droplets which impinge on the part, solidify, and adhere. The mechanism of bonding is mostly mechanical, but in some cases is also metallurgical. The result is that each layer bonds tenaciously to the previous layer, forming a lamellar “pancake-like” splat structure. The coating properties are directly dependent on the combination of kinetic and thermal energy.

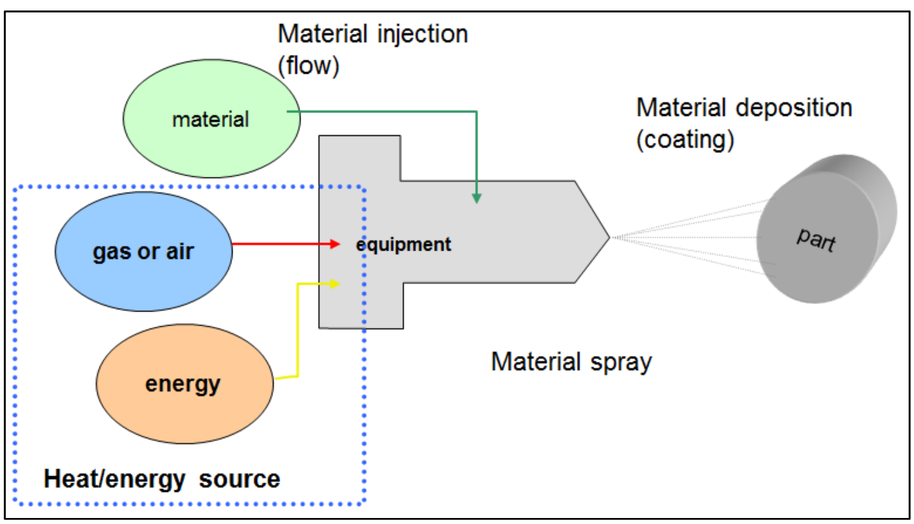

Figure 2a: Heat / Energy Source Requirements

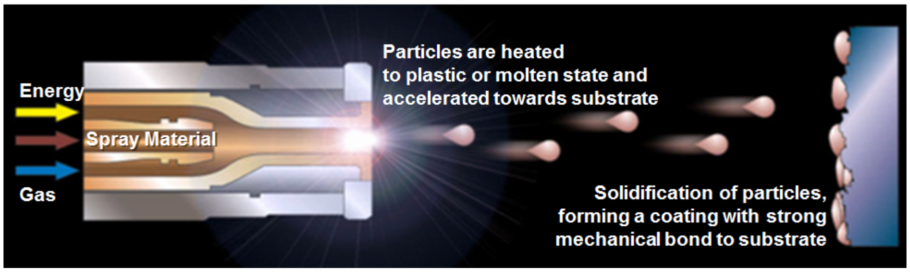

Figure 2b: Principle of Thermal Spray Coatings

Figure 3 shows the various types of thermal spray processes in the marketplace today. A summary of typical temperatures and velocities of the sprayed particles/droplets for the various processes and materials are shown in Figure 4a and 4b. Addendum 1 gives more specific details about each process.

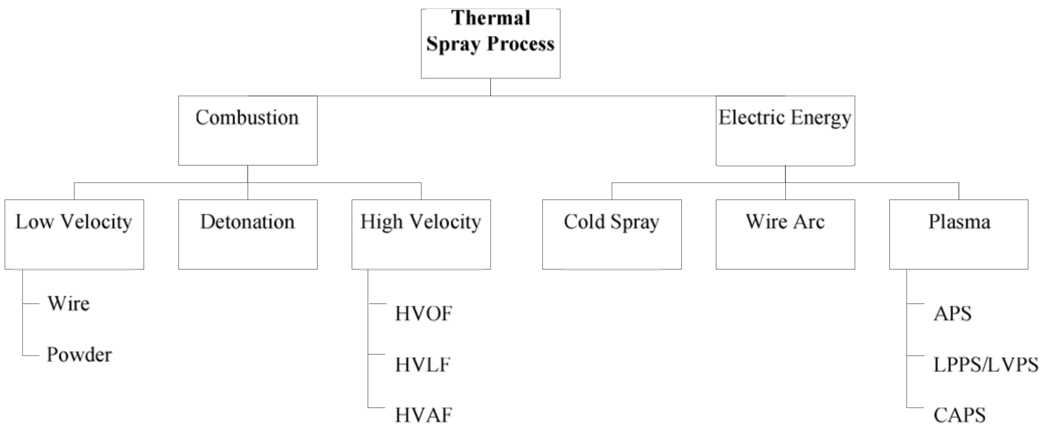

Figure 3a: Types of Thermal Spray Processes (HVOF: High Velocity Oxy-Fuel; HVLF: High Velocity Liquid-Fuel; HVAF: High Velocity Air-Fuel; APS: Air Plasma Spray; LPPS/LVPS: Low Pressure Plasma Spray/ Low Vacuum Plasma Spray; CAPS: Controlled Atmospheric Plasma Spray)

Five basic thermal spray processes are available commercially, and one new process is still in its infancy. Flame spray powder/wire, detonation, and **H**igh **V**elocity **O**xygen **F**uel (HVOF) are three of the basic processes associated with combustion. Plasma and wire arc are two other processes that utilize electric energy to melt the consumable materials. Of the five processes, HVOF and detonation spraying are two that result in high bond strength with extremely dense microstructures. Plasma coatings are also known to have high bond strength with relatively dense oxide-free microstructures when sprayed in either **L**ow **P**ressure **P**lasma **S**pray (LPPS) or **V**acuum **P**lasma **S**pray (VPS) systems. “Cold Spray” is a new process that relies more on high velocity and kinetic energy and less on thermal energy. Actually it is a solid state process, that is to say, the particles are not molten during spraying. Particle temperatures are lower than HVOF, but velocities are higher, enabling coating structures that resemble bulk wrought materials.

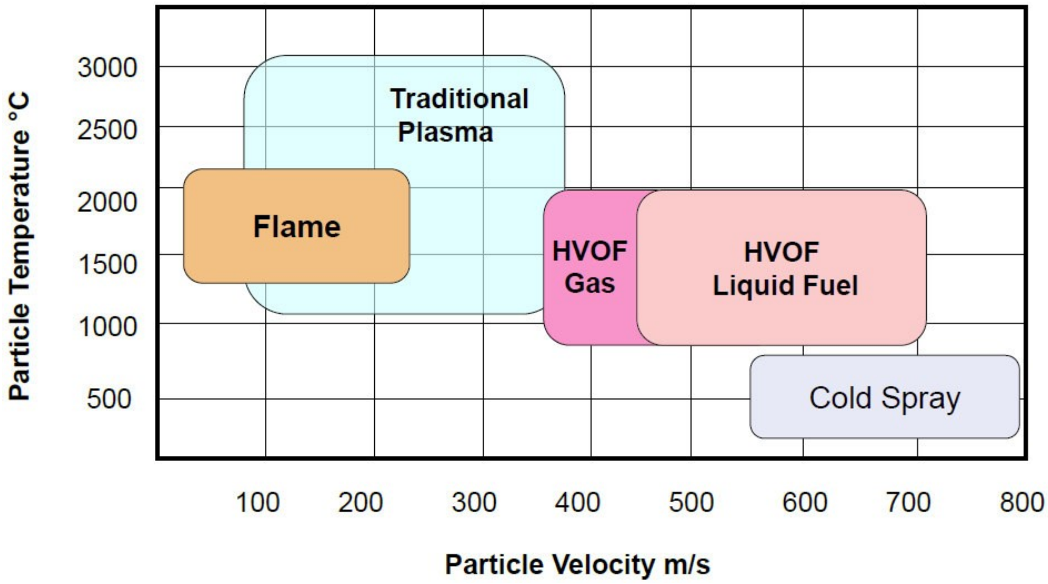

Figure 4a: Overview of Particle Temperature versus Particle Velocity for Different Processes

Figure 4b is a general overview of relative particle temperatures versus velocities for various thermal spray materials. This fundamental understanding is critical for spray parameter optimization of process and material. For example, metal oxide ceramics with high melting points and low thermal conductivity typically require high enthalpy and particle temperatures with slow flame velocities for optimum performance and application cost. Carbide cermets require the opposite conditions, low particle temperature and high particle velocities. This results in optimized wear resistance with minimum decarburization and brittle phases being formed in the coating. As can be seen in Figure 4b, other material types fall somewhere in between metal oxides and carbide cermet's.

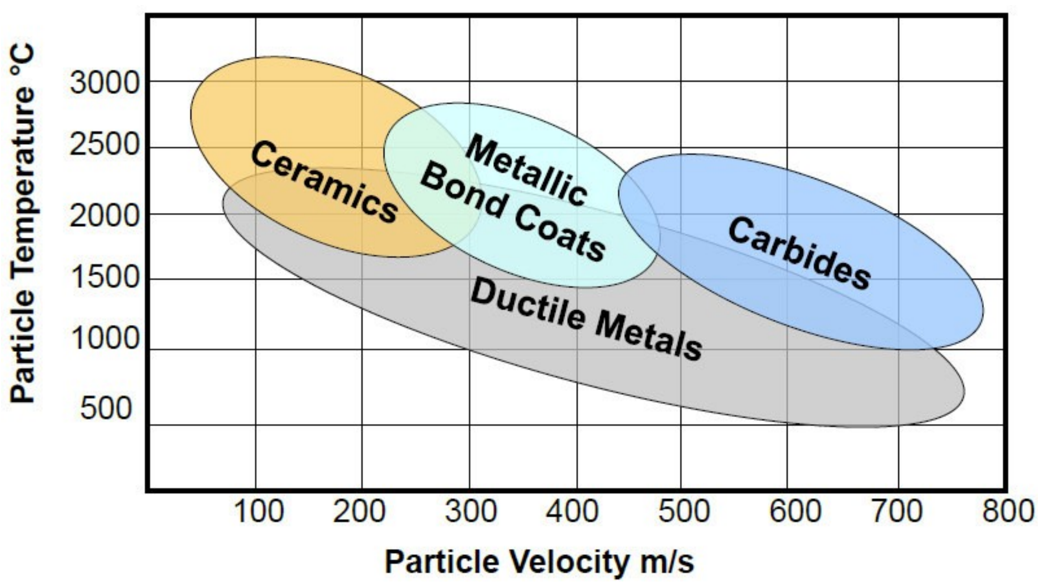

Figure 4b: Overview of particle temperature versus particle velocity for different materials systems

Market Size and Growth Areas

The market size for Thermal Spray is an estimated \$6.5 billion[3]. Key market segments are in aerospace and industrial gas turbine industries. Here it is estimated that 60% of revenue is generated in these industries[4]. Equipment and material suppliers see approximately 20% of this market with the balance attributed to coating applicators and finishers. Historically, the most active regions for thermal spray technology have been in North America and Europe. However, developments over the last few years have shown higher market growth in Asia and South America. China, for example, has seen tremendous growth due to the high degree of professional engineers graduating yearly and its overall economic growth. Traditional markets such as aerospace, although strong, will see additional growth in alternative energy sectors, semi-conductor/electronic, steel and paper and pulp.[5]

The Value of Thermal Spray Technology: Typical Examples of Application Success Stories

A few examples where thermal spray technology has helped to sustain our way of life by reducing energy consumption, providing environmental benefits, supporting human comfort, and reducing material waste are seen below. More examples of application success stories can be found in the ASM Handbook Volume 5A : Technology of Thermal Spray Handbook[(6)]. This handbook captures the value and benefits thermal spray provides to society with examples from the following industries: turbine, marine and atmospheric corrosion, renewable energy, oil sands, automotive, electronic and semiconductor, biomedical applications, landing gears (replacement of hard chrome with thermal spray), primary metals/steel, paper, printing, nuclear, petrochemical, and textile. Addendum 2 also summarizes many of the applications highlighted in this handbook. A few applications critical to thermal spray and market growth are briefly discussed below:

a. Aerospace and Industrial Gas Turbine Industries [(6,7)]: Aerospace and industrial gas turbines will continue to expand as thermal spray technology and reliability improve. Important areas of growth are in advanced heat insulation materials (thermal barrier), wear resistant coatings, clearance control coatings, and oxidation/hot corrosion resistant alloys. The value of these coatings is higher operation temperatures leading to more efficient engines, reduced energy cost, reduced CO_2 emissions resulting in less green house effects to the environment and less material waste due to reduced maintenance times.
b. Energy/Alternative Energy[(6,7)]: With a world population of over 7 billion at the time of this writing and growing, emerging countries, as well as technically advanced countries, will continue to need new and improved energy solutions. Hydroelectric, wind, fuel cells, bio-fuels, biomass, and solar are just a few examples of where thermal spray can play a role in renewable energy solutions in addition to the more traditional fossil fuel areas such as coal, gas and oil. Turbine manufactures and energy producers are aware of these sources of energy and have started to synergistically integrate multiple technologies when cost appropriate.
c. Biomedical[(6)]: As medical technology helps to extend human life spans, medical implants will become more common and thermal spray applications will play a bigger role. One key area where thermal spray technology is playing a role is as an inert surface for bone and tissue growth. Coatings have been used to support the advancement of knee and hip implants.
d. Automotive[(6)]: New environmental regulations imposed by governments on car mileage have forced manufacturers to look at alternative solutions to reduce car weight and improve engine efficiency. One area of growth has been the use of

cylinder bore coatings on aluminum blocks. Aluminum blocks help reduce the weight of a vehicle while the porous nature of the coating helps to reduce friction between the cylinder and piston ring.

e. Additive Manufacturing (Cold Spray Applications) [6,8]: In addition to improvements in traditional processes, the industry continues to see growth in cold spray. This will result in the growth of salvage and repair applications for critical and expensive components. The U.S. military is developing specifications written and implemented for critical components. Examples of key materials being studied include aluminum, zinc-aluminum, aluminum-magnesium, copper, titanium, and NiFeCr alloys. Potential area for growth in cold spray is in materials development and in material manufacturing processes.

f. Environmental Health and Safety [6,9]: Thermal spray has already been shown to be a more environmentally friendly and sustainable technology[6]. At present, HVOF sprayed carbide coatings are being used as replacement for chromium electroplating for aircraft landing gears and hydraulic rods in industrial applications . Such examples of environment friendly, sustainable manufacturing, are desirable for gaining support for market growth.

What Industry, Government, and Academia is Doing to Grow Applications and Technology

Addendum 3, Thermal Spray Resources and Links, is a good overview of many of the key professional and trade associations, research organizations, international conferences, and Environmental, Health and Safety (EH&S) and Accepted Practice documents related to the Thermal Spray industry.
Key highlights from this addendum are:

1. **Professional and Trade Societies/Assoications**: ASM International's Thermal Spray Society (TSS), Germany's Welding Society (DVS), Japan Thermal Spray Society (JTSS), European Thermal Spray Society (ETSA), Thermal Spray Committee of China Surface Engineering Association (TSCC), Japan Thermal Spray Association (JTSA), Korean Thermal Spray Association (KTSA), International Thermal Spray Association (ITSA), German Thermal Spray Association (GTS) as well as many other associations and societies are dedicated to expanding thermal spray applications, improving the technology and promoting the industry. Toward this end, annual international and regional conferences are sponsored by leading professional societies such as the International Thermal Spray Conference (ITSC) sponsored by the ASM's affiliate: Thermal Spray Society, along with its partner the German Welding Society. This conference rotates every year between Asia, Europe and North America. In addition, TSS publishes the Journal of Thermal Spray Technology and the Handbook on Thermal Spray Technology. These documents, along with international conferences such as ITSC and smaller topical events, help the growth and promotion of emerging technology and applications.

Other organizations in Asia also promote conferences such as the Asian Thermal Spray Conference (ATSC) which links countries such as Japan, China, Korea, India and Singapore.

The European Thermal Spray Society, Chinese Thermal Spray Society, Japan Thermal Society, Korean Thermal Spray society all sponsor their own activities and events. Trade organizations such as the German Thermal Spray Association (GTS); International Thermal Spray Association (ITSA) , Japanese Thermal Spray Association (JTSA) also hold their own events to support market growth.

Globally some of the key Professional and Trade associations can be found via the following websites:

a) Thermal Spray Society (www.asminternational.org/tss)
b) The German Welding Society (www.dvs-ev.de/en)
c) German Thermal Spray Association (www.gts-ev.de)
d) European Thermal Spray Society (www.etsa-thermal-spray.org)
e) International Thermal Spray Association (www.thermalspray.org)
f) Japan Thermal Spray Society (www.jtss.or.jp/index-e.htm)
g) Thermal Spray Committee of China (www.chinathermalspray.org/htm)
h) Chinese Thermal Spray Association (CTSA) (www.chinaspray.com/english/index.asp)
i) Korean Thermal Spray Association: (http://www.thermalspray.or.kr/)
j) Thermal Spraying and Surface Engineering Association (www.tsseu.co.uk)
K) Asian Thermal Spray Society(www.asiantss.com/member.php)
l) Thermal Spray Committee of China Surface Engineering Association (TSCC@chinathermalspray.org)

2. **Industry Supported Research, Training and Application Development**: Key objective is to bridge the gap between research and commercialization with the goal of accelerating technology transfer to the market. The secondary goal is to demonstrate technological solutions to real problems. The third goal is education and training of students in industrial environments. Since there are many levels of support globally, it is suggested that the reader review the above websites and information in Addendum 3 on various professional and trade associations. for more information as to specific industry supported programs in a given country.

3. **Government Funded Organizations/Institutes**: Addendum 4 highlights many more research organizations supporting the growth of thermal spray technology. A few key institutes from around the world are shown below to highlight that Thermal Spray is indeed recognized globally as a critical surface engineering science. Readers should also go to http://tss.asminternational.org/portal/site/tss/ for a detailed list of academic and research institutions involved in Thermal Spray research.

a. National Research Council of Canada http://www.nrc.gc.ca
b. National Institute for Materials Science (NIMS) www.nims.go.jp/eng/
c. Forschungszentrum Julich GmbH, IEK-1, Germany www.fz-juelich.de
d. NASA Glen Research Center www.nasa.gov/centers/glen/
e. Korean Institute of Science and Technology http://eng.kist.re.kr
f. Beijing General Research Institute of Mining and Metallurgy, Beijing China
g. International Advanced Research Center for Powder Metallurgy & New Materials, Hyderabad, India (www.ARCI.RES.in)
h. Commonwealth Scientific & Industrial Research Organization (CSIRO), Center for Materials Science and Engineering (http://www.csiro.au/org/CMSE)
i. URAL Welding Institute (www.ustu.ru/en/home)
k. Centre national de la recherche scientifique (CNRS) http://www.cnrs.fr/index.php
l. Commissariat à l’énergie atomique et aux énergies alternatives (CEA), http://www.cea.fr/english-portal
j. State University of New ork (SUNY) (www.suny.edu)
k. Aachen University of Technology (www.rwth-aachen.de)
l. Université de Limoges (www.unilim.fr)

Key Research Areas

Many of these research organizations and universities on the five continents are exploring new ways to improve human life through Thermal Spray technology. Key research areas include but are not limited to improving the reliable and robustness of process, expanding materials and equipment technology, and advancing applications in energy and transportation sectors. Solution precursor and suspension thermal spray, cold spray, diagnostics and modeling are examples of such innovative research areas. Addendum 4 provides an overview of the key challenges and solutions that must be addressed to stimulate the development of the thermal spray science and technology.

References:

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4. P. Hanneforth, “The Global Thermal Spray Industry-100 years of Success: So What’s Next?”, iTTSe, Vol 1, No1, ASM International, Materials Park, May 2006, P 14-16.
5. M. Fukumoto, “The Current Status of Thermal Spray in Asia”, Journal of Thermal Spray Technology, 2008,17(1), p5-13.
6. R.C Tucker Jr, “ASM Handbook, Volume 5A: Thermal Spray Technology”, Published by ASM International, 2013.
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9. N. Krishnan, A.Vardelle, and J.G. Legoux, “A Life Cycle Comparison of Hard Chrome and Thermal Spray Coatings: Case Example of Aircraft Landing Gears”, International Thermal Spray Conference 2008: Cross Boarders”, DVS-ASM, Hamburg, 2008, P212-216
10. http://tss.asminternational.org/portal/site/tss/