ENVIRONMENT AND PERSONNEL PROTECTION AT THERMAL SPRAYING

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Abstract: An overview is presented of problems related to the environment and personnel protection during thermal spraying. Some of the main categories of solid noxes generated at thermal spraying are presented, depending on the sprayed materials, together with some usual applications and characteristic values of the noxes types for some common spraying methods. The main hazards associated with the thermal spray process are enumerated, as well as some of the measures to be taken for the safety control of the operators during manual operation.

1. INTRODUCTION

Essentially, thermal spraying is a process that involves melting and atomization of the functional material using a concentrated thermal source, and than depositing it (using aerodynamic principles) on the substrate. Thermal spraying may be used to obtain layers that present different properties: thermal barriers, corrosion or wear resistant, thermal or electrical insulators, biocompatible, etc.

2. NOXES AT THERMAL SPRAYING

Noxes that result during the thermal spray process of metallic or ceramic materials are the result of the physical process in which the material to be deposited is melted (sometimes vaporized) and than atomized in molten state by a compressed air jet or gas and projected to the base material (substrate).

An important part regarding the quantity of noxes that are formed is played by the following: thermal spray method, filler material and working procedure (process parameters). This is why in the functional system of the thermal spraying one can find three noxes sources:

- the concentrated thermal source;
- the contact with the working environment by atomization in gas jet (active or neutral gases);
- functional (sprayed) material.

The working environment is considered to be active when it reacts with the sprayed material. Characteristics to concentrated thermal sources used for thermal spraying are:

- high temperatures;
- activity towards the functional material in molten state;
- distance and atomization speed.

Since the phenomena taking place have accentuated thermal and dynamic character, they are accompanied by radiation emissions, from which one can distinguish infrared and ultraviolet radiations, noise and fumes (figure 1).

Because of the elements that were mentioned above, maximum values of the noxes types are characteristic to each spraying method; some elements are, in particular, characteristic to each family of sprayed materials.

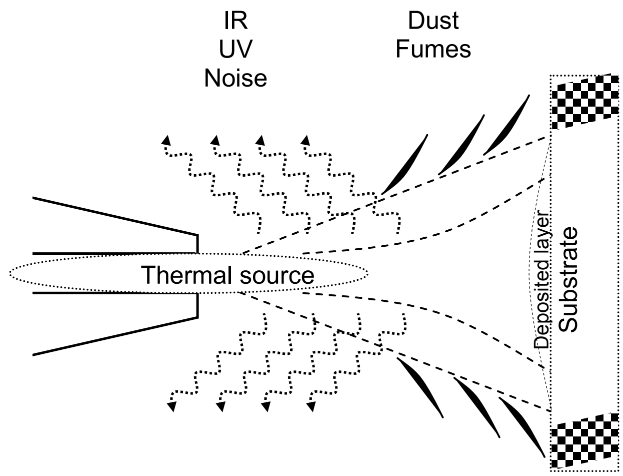

Fig. 1. Noxes types at thermal spraying

Table 1 presents typical operating conditions for different thermal spray processes.

Table 1. Typical operating conditions for different thermal spray processes [1]

	LVOF[1]	HVOF[2]	Arc	Plasma arc	Induced plasma
Temperature, ^oC	max. 2760	max. 3350	2220-8300	2220-8300	max.16500
Speed, cm/s	60-215	765-1220	235-335	235-550	235-550
Spray distance,cm	10-25	15-45	5-15	5-15	7-20
DB (sound level)	110	150	115	132	132

[1]LVOF-Low Velocity Oxy-Fuel
[2]HVOF-High Velocity Oxy-Fuel

Gas jet atomization generates solid noxes by three routes:
- vaporization of the components of the functional material;
- forming of reaction compounds (chemical reaction between the spreyed material and working environment);
- scattering of the sprayed material by the carrying agent.

3. VAPORIZATION OF THE FUNCTIONAL MATERIAL

The materials that are apparently inert at room temperature become reactive at thermal spraying temperature. Some of the causes for this involve solid-liquid phase modification that activate energetically the atoms on the surface of the functional material, as well as the atomization, which increases the contact surface between the sprayed material and the working environment.
There are two mechanisms:
- the reaction between working environment – sprayed material,
- evaporation of the sprayed material and the reaction with the working environment.

The reaction working environment – functional material produces oxides with different oxidation degrees and nitrides, and the release of materials that have not reacted (in low quantities).
Pollution takes place based on the following mechanisms:

- oxidation and nitridation of the functional materials (metals, carbides, atmospheric spraying)
- carburization, nitridation (reactive spraying).

The nature of solid compounds in the shape of fumes (solid particles – gas dispersoids – with diameters over 1μm) depends on the thermal source, on the nature of atomized material and the environment in which the particles are dispersed.
Solid noxes originate exclusively from the sprayed material, and the substrate has no effect on the quantity of solid noxes that are generated.
Depending on the spraying method, the main categories of solid noxes are presented in table 2 [7, 8], based on the nature of materials specific to each process.

Table 2. Noxes emissions. Materials and processes [7, 8]

Process	Sprayed material	Critical components	Applications
LVPF - wire	Metallic materials	Total fumes, NO_2	reconstruction
	Zn, Al	ZnO_2, total fumes, NO_2	corrosion resistant layers Zn, Al, ZnAl
	Mo	Total fumes, NO_2	antifriction layers Mo
	FeCr Alloys	Total fumes, Cr_2O_3, NO_2	wear resistant layers
	FeCrFNi Alloys (Cr<27%, Ni<22%)	Total fumes, Ni oxides, NO_2	
	NiAl	Ni oxides, NO_2	adherent NiAl layers
	CuO, Cu_2O, SnO, ZnO, Al_2O_3	Cu Oxides, ZnO, total fumes, NO_2	bearings, bronze, brass
LVOF powders	FeCr Alloys	Cr_2O_3, NO_2	wear resistant layers Fe alloys
	NiCrBSi	Total fumes, Ni oxides, NO_2	wear resistant layers, NiCrBSi alloys
	CoCrW	Total fumes, Cr_2O_3	wear and corrosion resistant layers (STELLITE®)
HVOF	Fe_3O_4	Cr_2O_3, total fumes	wear resistant layers, Fe alloys
	NiO, WO, SiO_2	NiO, total fumes, NO_2	wear resistant layers, NiCrBSi alloys
	CoCrW	Total fumes, Cr_2O_3, NO_2	wear and corrosion resistant CoCrW layers (STELLITE)
	oxidic ceramics (TiO_2, Cr_2O_3, Al_2O_3)	Total fumes, NO_2	wear resistant layers, thermal barriers

APS	NiAl	Ni oxides, UV, O_3, noise	adherent NiAl layers
	oxidic ceramics (TiO_2, Cr_2O_3,Al_2O_3)	Total fumes, UV, O_3, noise	wear resistant layers, thermal barriers
Arc	CuSn, CuZn	Cu and Zn oxides Total fumes, UV, O_3, noise	bearings, bronze, brass
	Zn, ZnAl	ZnO, total fumes, UV, O_3, noise	corrosion resistant layers
	FeCr	Cr_2O_3, total fumes, UV, O_3	wear resistant layers

4. PERSONNEL PROTECTION AT THERMAL SPRAYING

Generally, the thermal spray process takes place in special enclosures; spraying systems are built with ventilation systems, for fumes and dust control, together with sound proof booth, for sound level control (figure 2, 3).

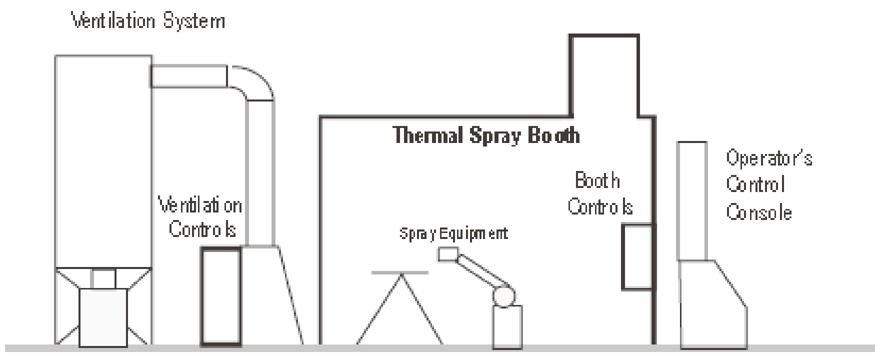

Fig. 2 Typical thermal spray booth configuration [2]

a) *b)*

Fig. 3 The Praxair system: a) dry cartridge dust collector, b) acoustical enclosure [3]

When used for repair operations and maintenance work, portable thermal spray equipment is dangerous and potentially harmful. There are numerous hazards associated with the thermal spray process, so it is not possible to describe all the measures to be taken for the safety control of the operators during manual operation.

Among the recommended measures for the control of process safety, we can find [1, 4, 5, 6]:

- *Radiation*. Workers must be protected from the effect of infrared or ultraviolet radiations, which can cause damage to eyes and skin. Ultraviolet radiations produced by thermal spray processes may affect exposed skin; they can cause sunburn, sun tanning, and changes in skin cell growth. Skin elasticity diminishes after repeated exposure to UV. This can give the appearance of premature aging and can lead to a higher risk of skin cancer [5].

Consequently, the operators must be endowed with eye protection (table 3) and protective clothing, including gloves and coveralls.

Table 3. Recommended shade lens for thermal spraying [6

Thermal spray process	Shade
Wire flame spraying	2-4
Powder flame spraying	3-6
Wire arc and powder plasma spraying	9-12
Wire arc if gun is equipped with arc shield	3-6

- *Noise*. Thermal spray operators must use all the time hearing protection devices, since the noise level during the process is elevated, and may cause permanent hearing loss. Table 4 presents the measurement to be taken to protect workers from noise.

Table 4. Typical noise level and recommended hearing protection for thermal spraying [6]

Thermal spray process	Noise level, dB	Minimum recommended protection
Wire flame spraying	114	Earplugs
Powder flame spraying	90-100	Earplugs
Wire arc	111-116	Earplugs and earmuffs
Plasma spraying	128-131	Earplugs and earmuffs

- *Metal fumes and dust*. Local exhaust or general ventilation systems should be used in order to evacuate gases, fumes and fine dust particles or vapors from the working space. The entire fine particles that are produced during thermal spraying are ignitable; they are dangerous when accumulated in the working environment. Nickel and chromium are carcinogens; fumes from zinc and copper alloys may cause a fever-type reaction known as brass chills, also overexposure to zinc fume is known to produce flu-like symptoms, often called metal fume fever [5, 6]. HEPA (High Efficiency Particulate Air filters) must be used when the process involves relatively toxic materials.

- *Gases and compressed air*. Since the thermal spray process requires the usage of high air pressures, some basic rules must be followed for the workers protection [5-8]:

- proper hoses, hose connections and regulators must be used;
- compressed air must be used only at pressures reccomended by the equipment's manufacturer;
- compressed air and other gases must not be use for clothing or protective equipment cleaning, neither for dusting purposes;
- breathing equipment must not be supplied with compressed air;
- various industrial gases are used for thermal spraying, when they are not in use they must be insulated from the rest of the equipment.

5. CONCLUSIONS

The paper summarizes the various types of noxes that result during the thermal spray process of metallic or ceramic materials. It also presents typical operating conditions for different thermal spray processes, together with the mechanisms involved in pollution generation. Finally, some of the measures to be taken for personnel protection at thermal spraying are presented.

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