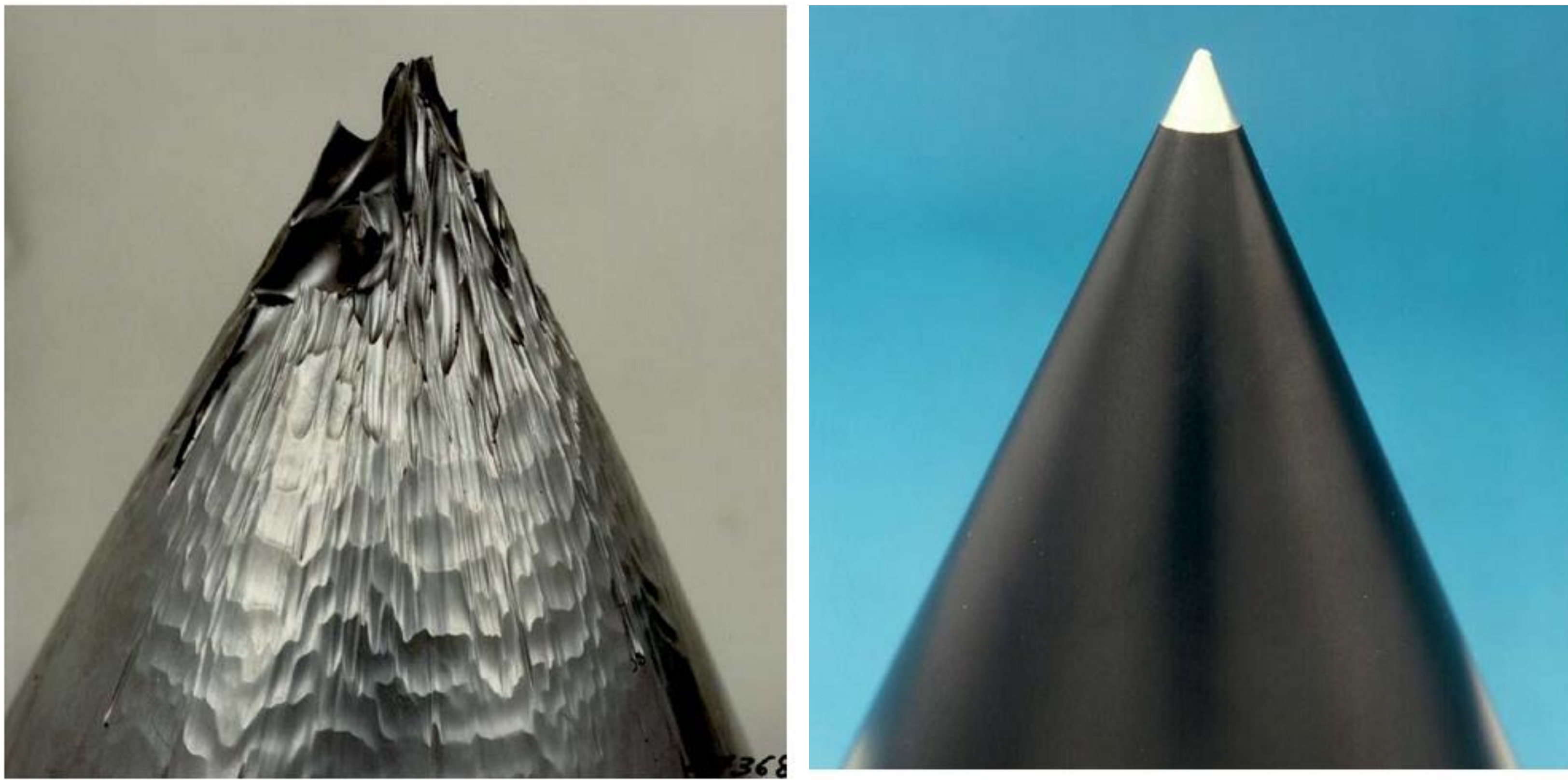
Procesy natryskiwania cieplnego - podstawy

Po co stosujemy natryskiwanie cieplne ?



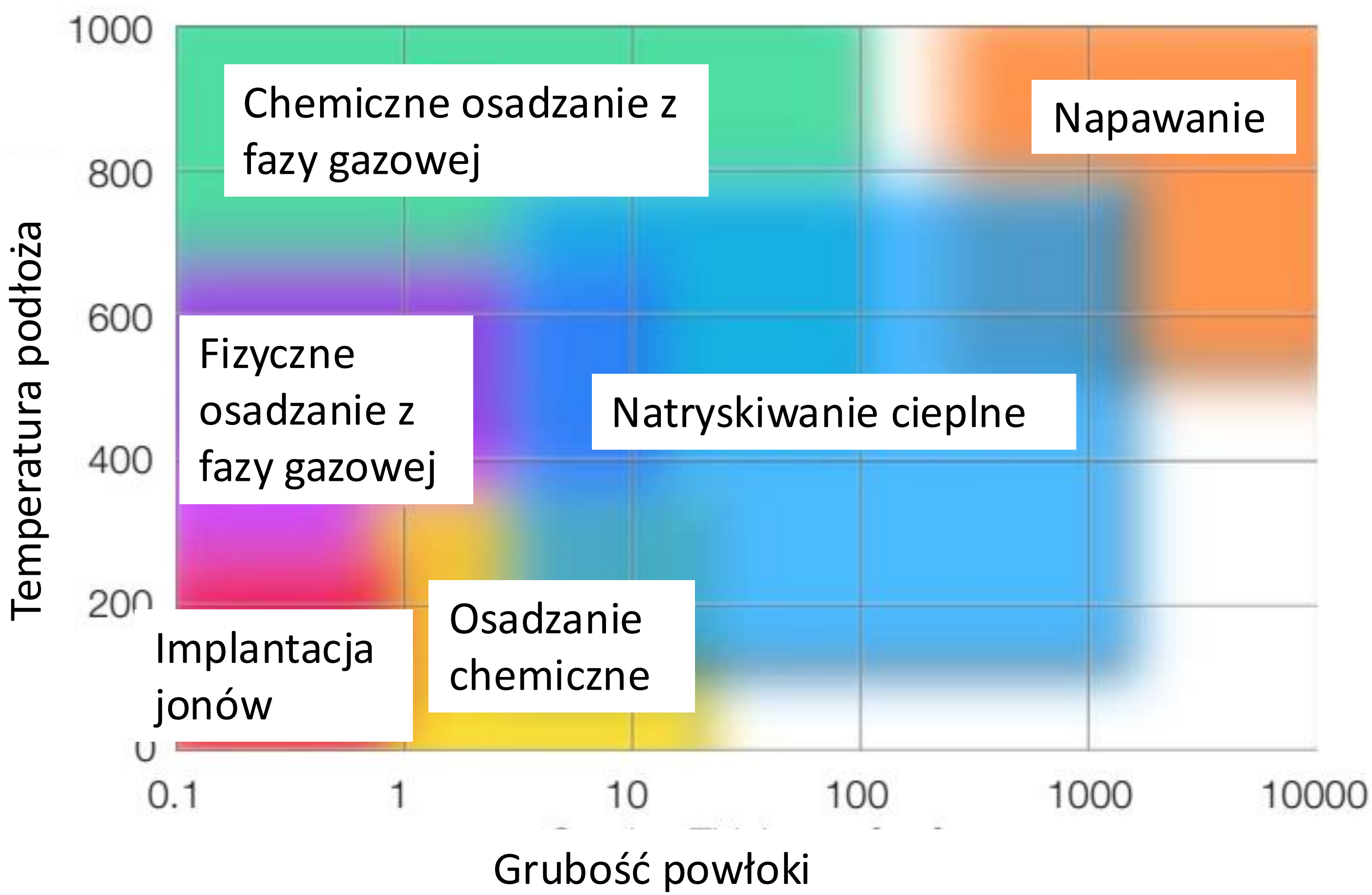
Wlot turbiny wodnej Peltona z powłoką tlenku chromu (APS) zabezpieczającą przed ścieraniem i kawitacją wytworzona w procesie natryskiwania cieplnego

Właściwości powłok wytwarzanych różnymi metodami

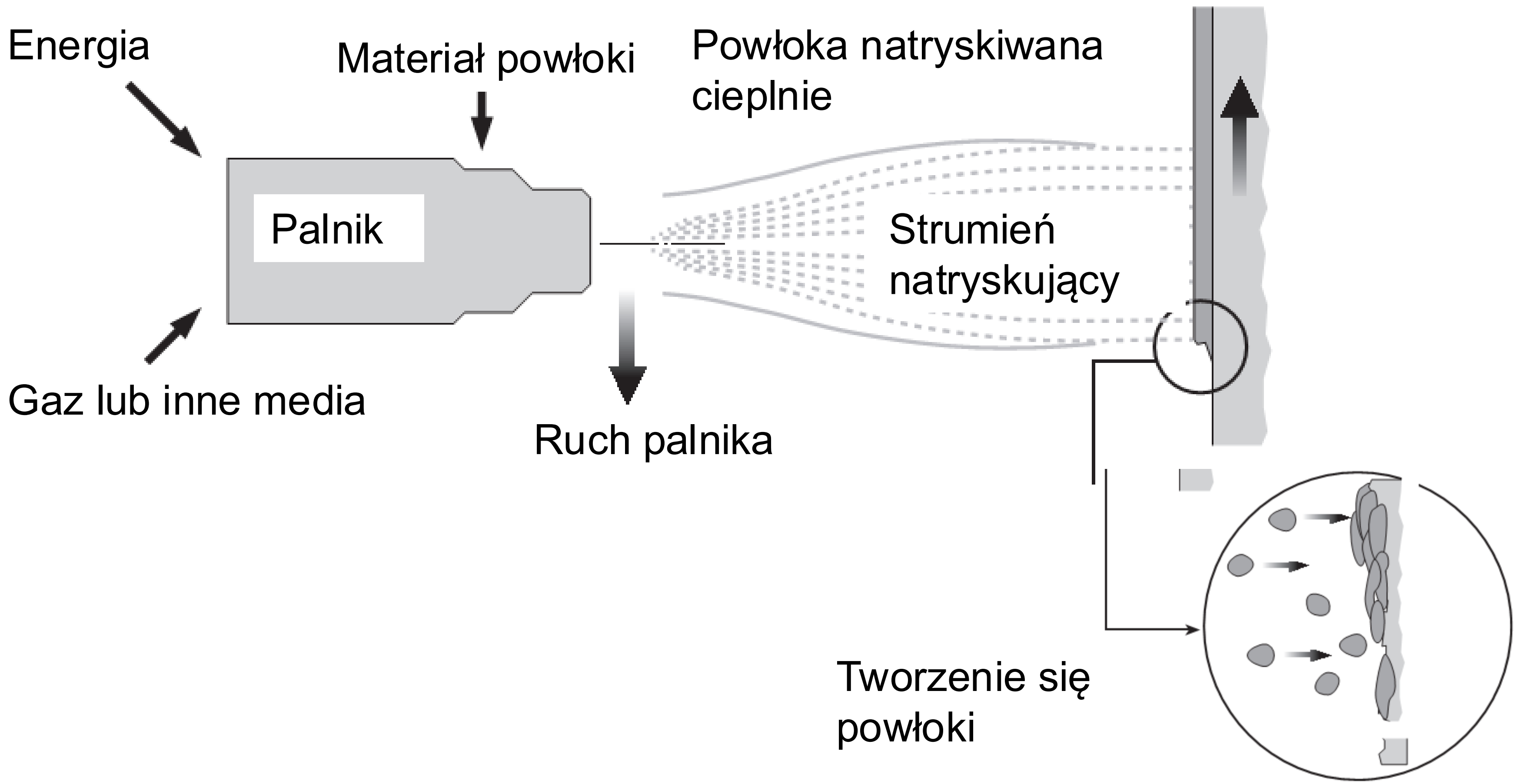
Coating Process	Typical Coating Thickness	Coating Material	Characteristics	Examples
PVD	1 – 5 µm (40 – 200 µin)	Ti(C,N)	Wear resistance	Machine tools
CVD	1 – 50 µm (40 – 2000 µin)	SiC	Wear resistance	Fiber coatings
Baked Polymers	1 – 10 µm (40 – 400 µin)	Polymers	Corrosion resistance, aesthetics	Automobile
Thermal Spray	0.04 – 3 mm (0.0015 – 0.12 in)	Ceramic and metallic alloys	Wear resistance, corrosion resistance	Bearings
Hard Chromium Plate	10 – 100 µm (40 – 4000 µin)	Chrome	Wear resistance	Rolls
Weld Overlay	0.5 – 5 mm (0.02 – 0.2 in)	Steel, Stellite	Wear resistance	Valves
Galvanize	1 – 5 µm (40 – 200 µin)	Zinc	Corrosion resistance	Steel sheet
Braze Overlay	10 – 100 µm (40 – 4000 µin)	Ni-Cr-B-Si alloys	Very hard, dense surface	Shafts

Table 1a • Principal coating processes and characteristics

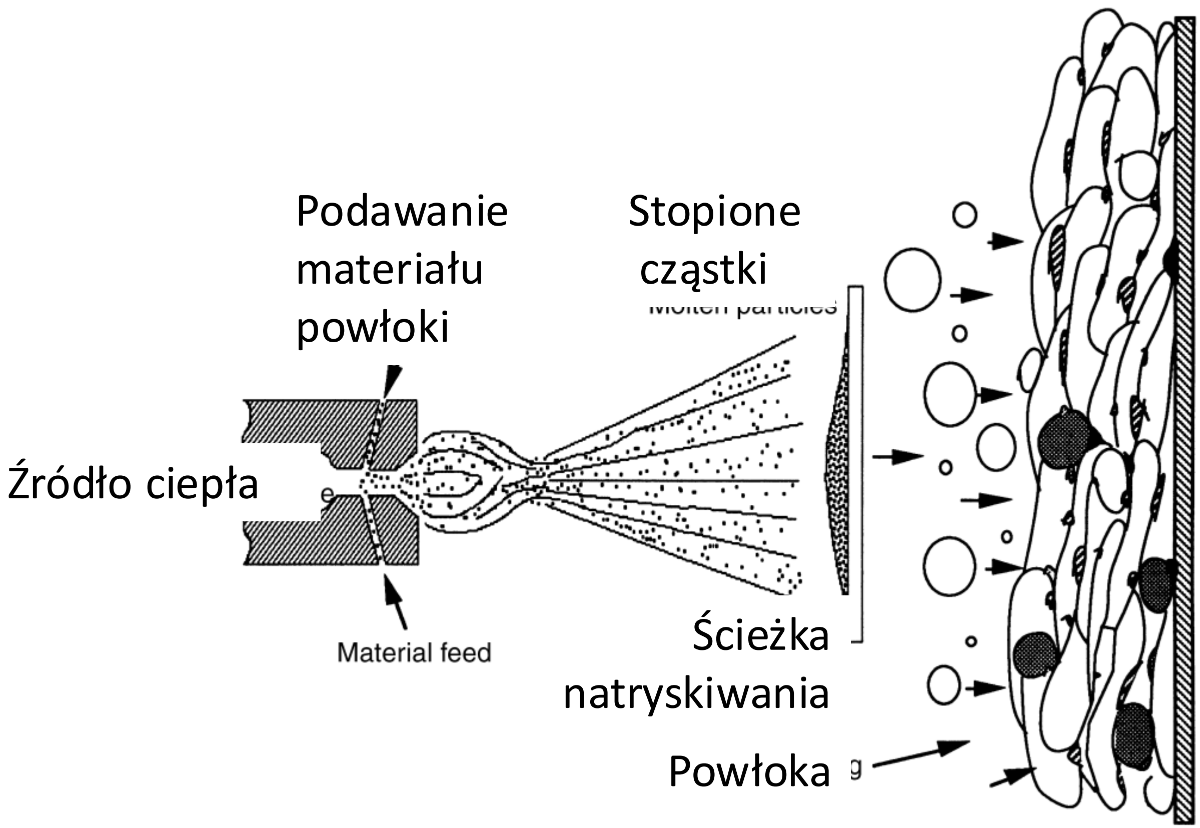
Grubość powłok i temperatura podłoża



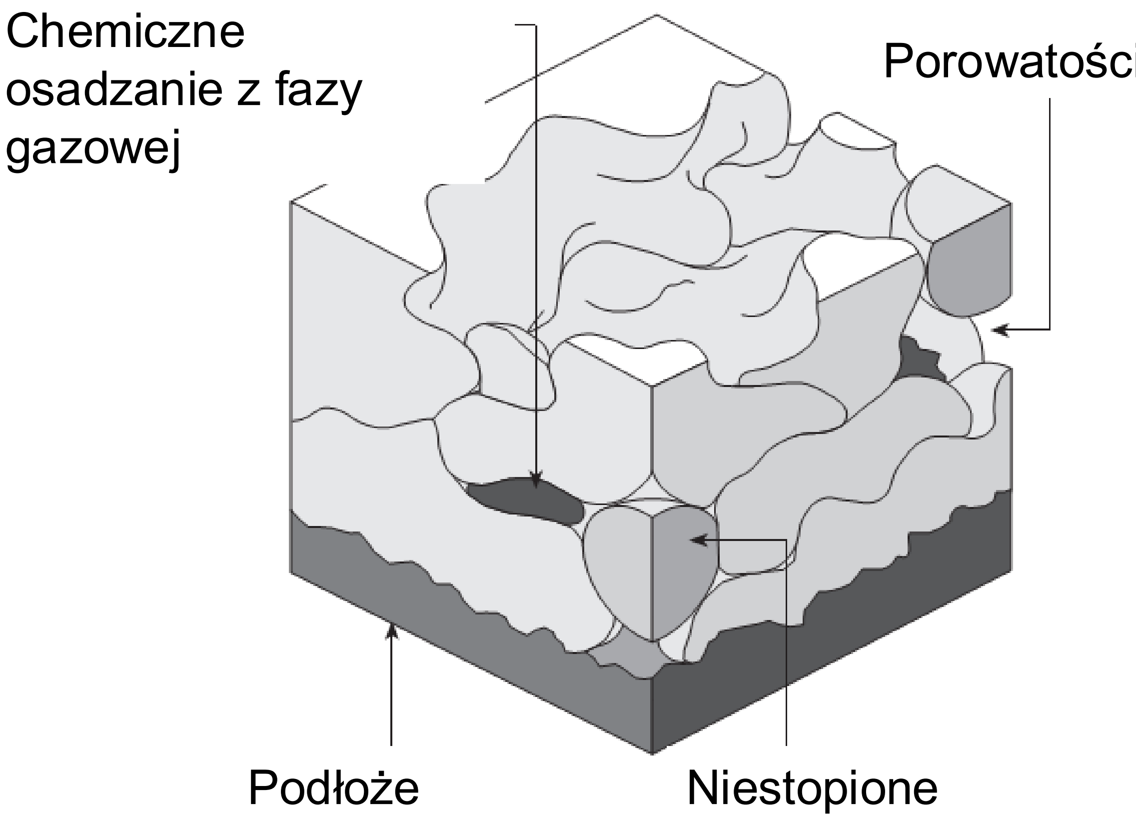
Istota procesów natryskiwania cieplnego



Ogólna zasada natryskiwania cieplnego



Budowa powłoki natryskiwanej cieplnie



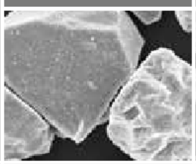
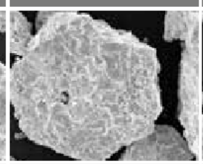
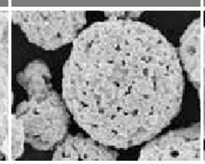
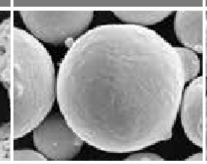
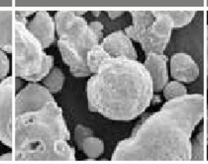
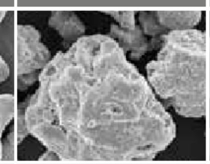
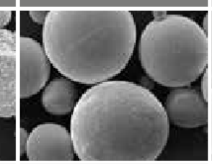
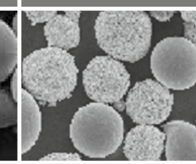
Budowa powłoki natryskiwanej cieplnie

Najczęściej stosowane powłoki natryskiwane cieplnie

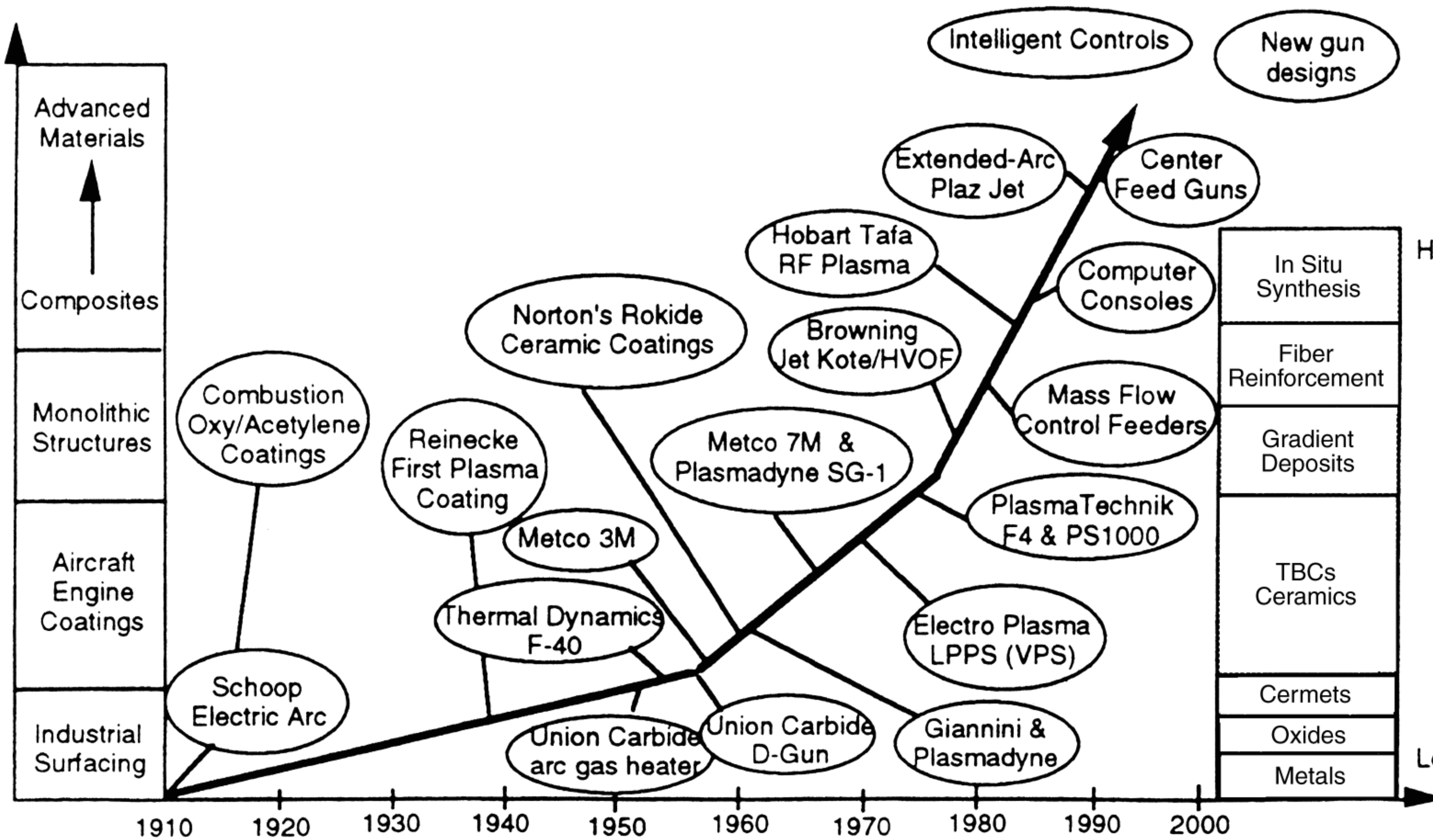
Material Class	Typical Alloy	Characteristics	Example Application
Pure metals	Zn	Corrosion protection	Bridge construction
Self-fluxing alloys	FeNiBSi	High hardness, fused minimal porosity	Shafts, bearings
Steel	Fe 13Cr	Economical, wear resistance	Repair
MCrAlY	NiCrAlY	High temperature corrosion resistance	Gas turbine blades
Nickel-graphite	Ni 25C	Anti-fretting	Compressor inlet ducts
Oxides	Al_2O_3	Oxidation resistance, high hardness	Textile industry
Carbides	WC 12Co	Wear resistance	Shafts

Table 2 • Common classes of thermal spray powder materials

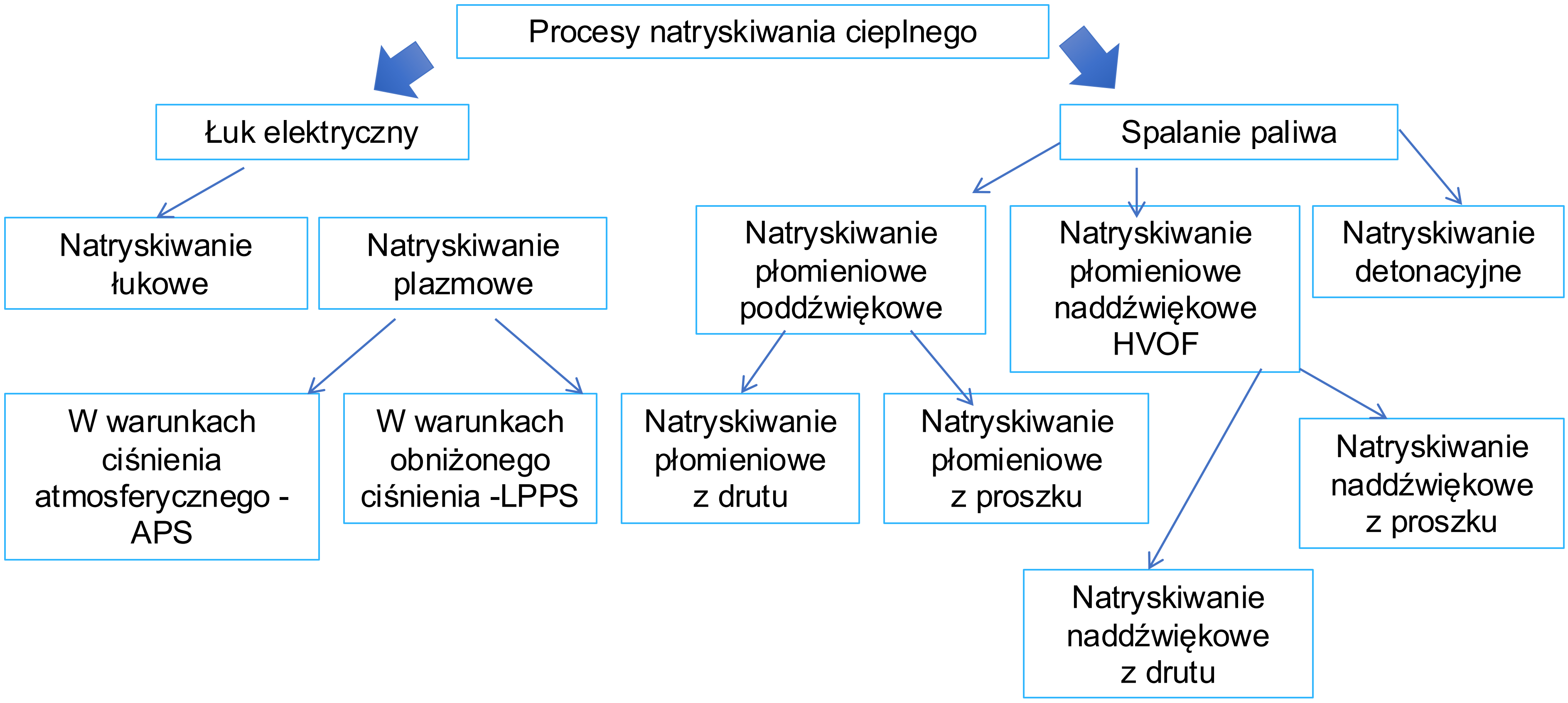
Proszki do natryskiwania cieplnego (HC STARK)

POWDER TYPE	Fused and crushed	Sintered and crushed	Agglomerated and sintered	Gas atomized	Water atomized	Dense coated	Spheroidized	Blended
								
PROCESS	Fusing in arc furnaces, followed by cooling and crushing	Sintering of raw materials, crushing	Spray drying of a suspension consisting of fine powders and organic binder and subsequent sintering	Atomizing molten metal or alloy with high pressure gas (Ar, N_2) stream into a chamber	Atomizing with water into a chamber and subsequent drying	Reduction of a metal salt solution	Feeding of agglomerates using a plasma flame to produce spherical shaped particles	Mixing of 2 or more powders
CHARACTE-RISTICS	Blocky, irregular, dense	Blocky, irregular, relatively dense	Spherical, porous, constituents homogenously distributed	Spherical, dense, high purity, low oxygen content	Irregular, dense, increased oxygen content compared to gas atomized	Blocky or irregular composite	Spherical, porous or hollow, partly open (shells)	Different morphologies, segregation possible
EXAMPLES	Al_2O_3; Cr_2O_3; ZrO_2-Y_2O_3	WC-Co; WC-CoCr	WC-Co Cr; Cr_3C_2-NiCr; ZrO_2-Y_2O_3	MCrAlY; Ni-, Co-base alloys; NiAl	NiCr; NiAl	Ni-Graphite	ZrO_2-Y_2O_3	NiSF + WC-Co; Mo + NiSF; Cr_3C_2-NiCr

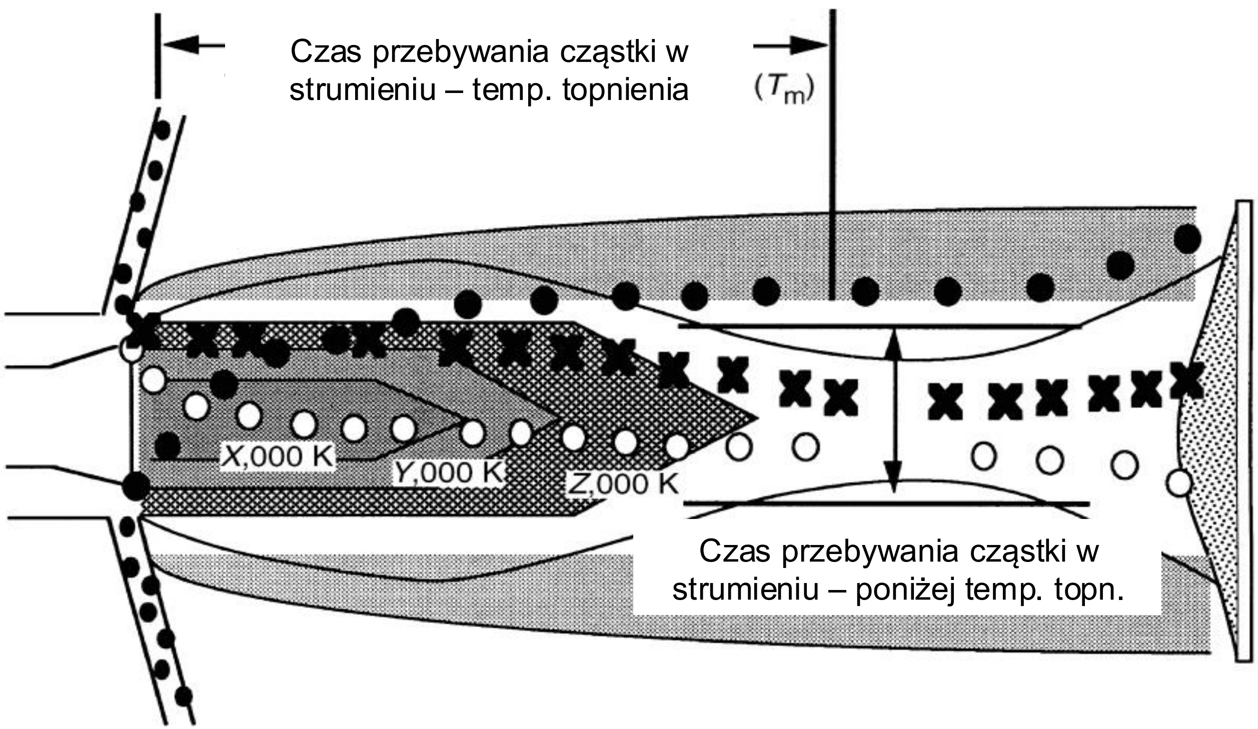
Historia rozwoju natryskiwania cieplnego



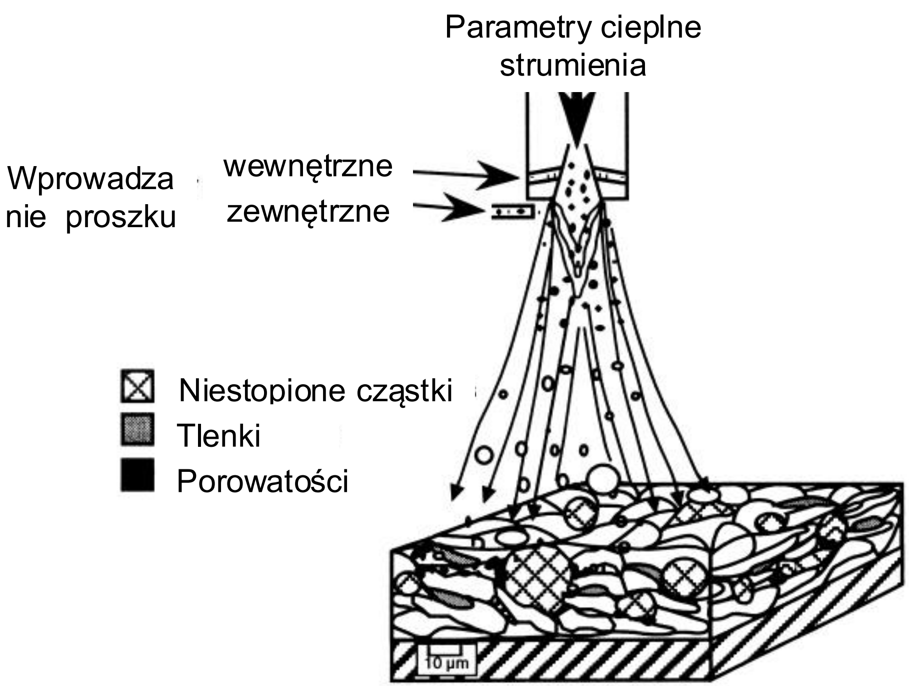
Podział procesów natryskiwania cieplnego



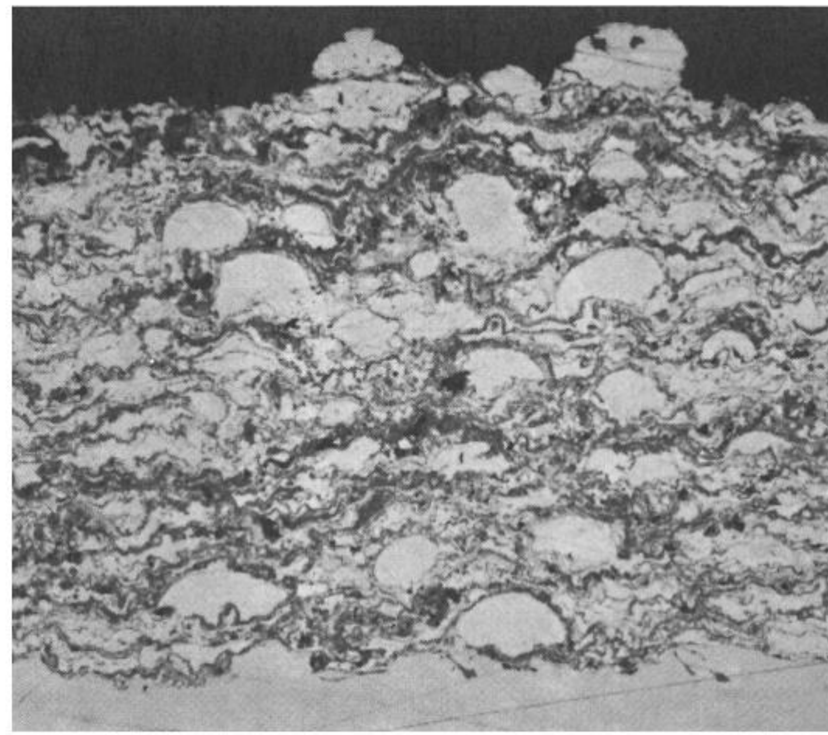
Teoria procesu natryskiwania



Proces natryskiwania cieplnego

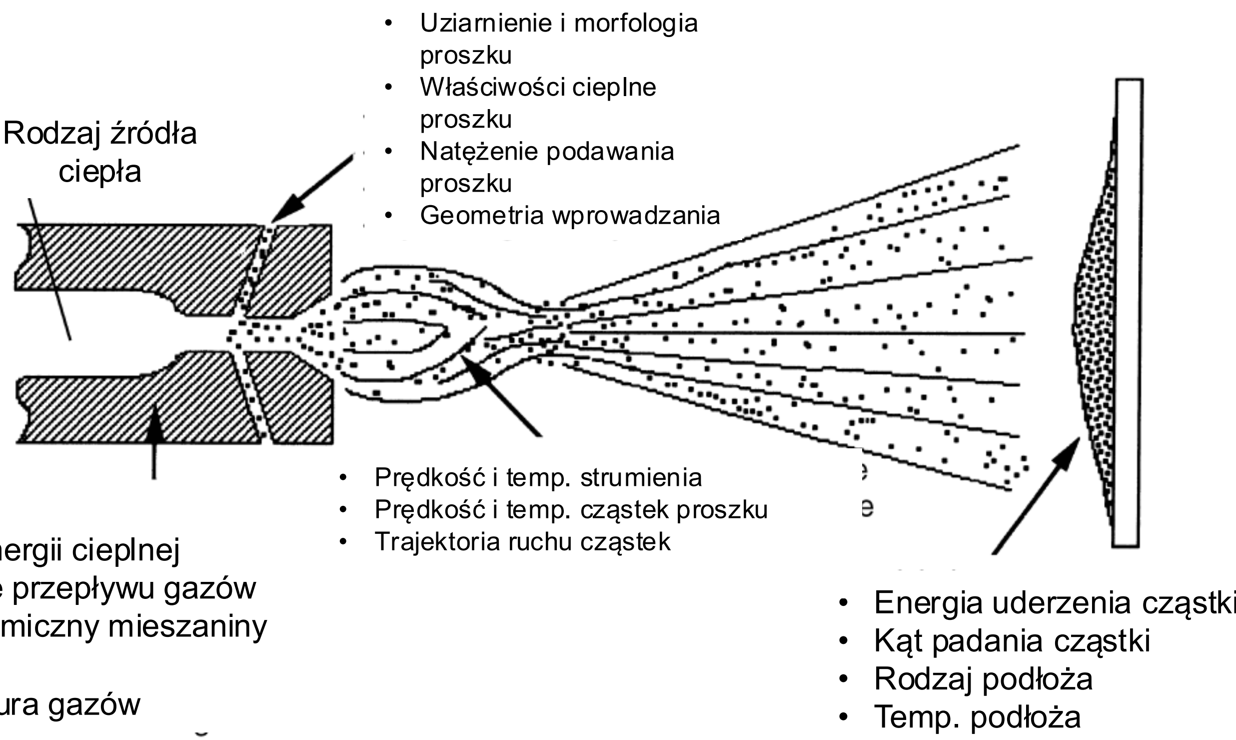


Schemat natryskiwania cieplnego proszku



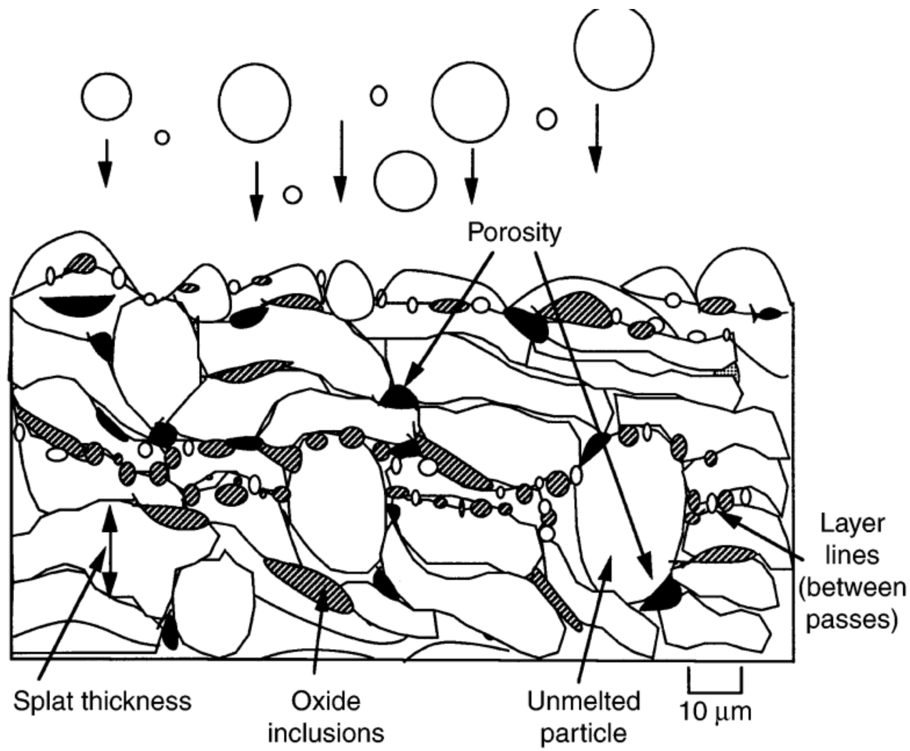
Mikrostruktura powłoki 80Ni-20Cr – proces HVOF

Zmienne w procesie natryskiwania cieplnego



Zmienne warunki procesu natryskiwania cieplnego

Budowa powłoki natryskiwanej cieplnie



Splat - budowa

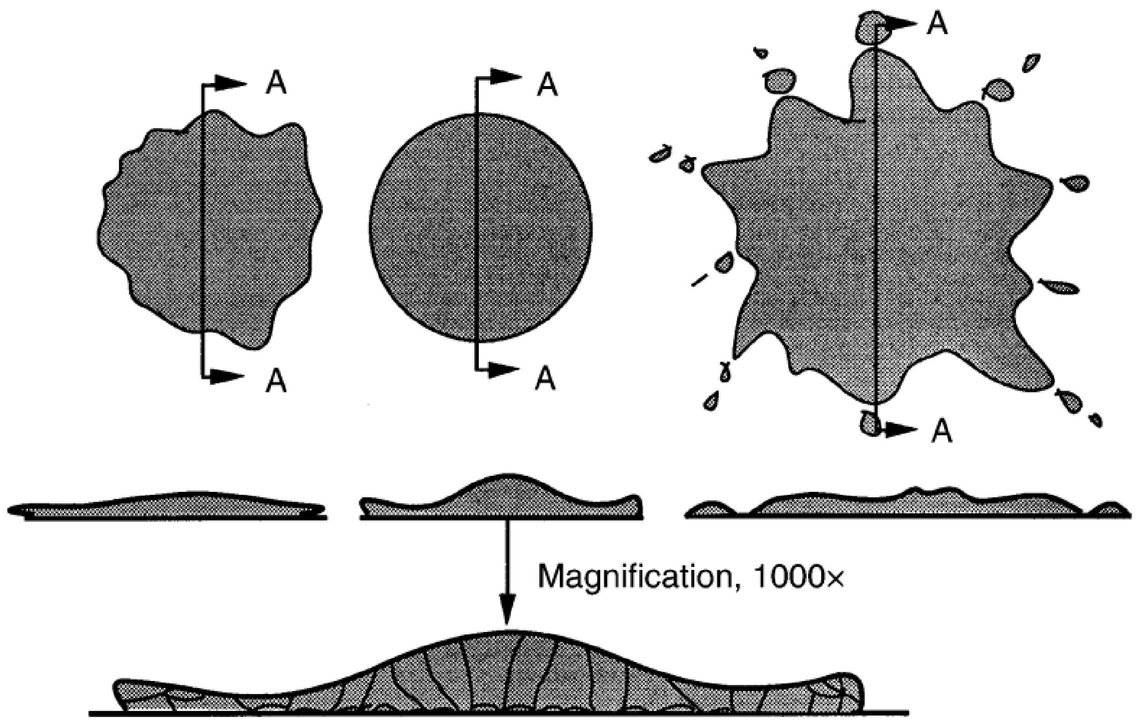


Fig. 2 Typical thermal spray splat structures

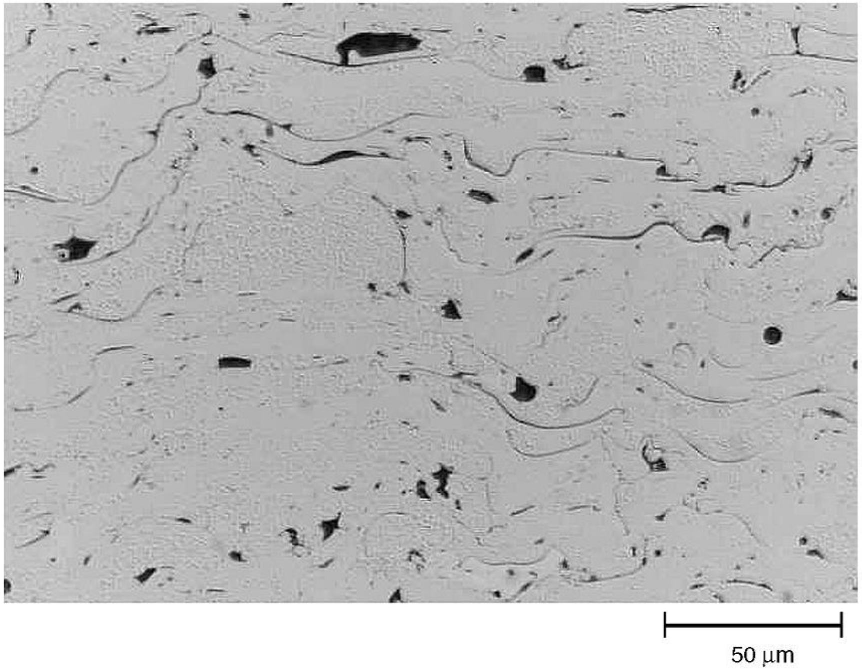


Fig. 3 Plasma-sprayed nickel-base alloy. Courtesy of Thermal Spray Technologies

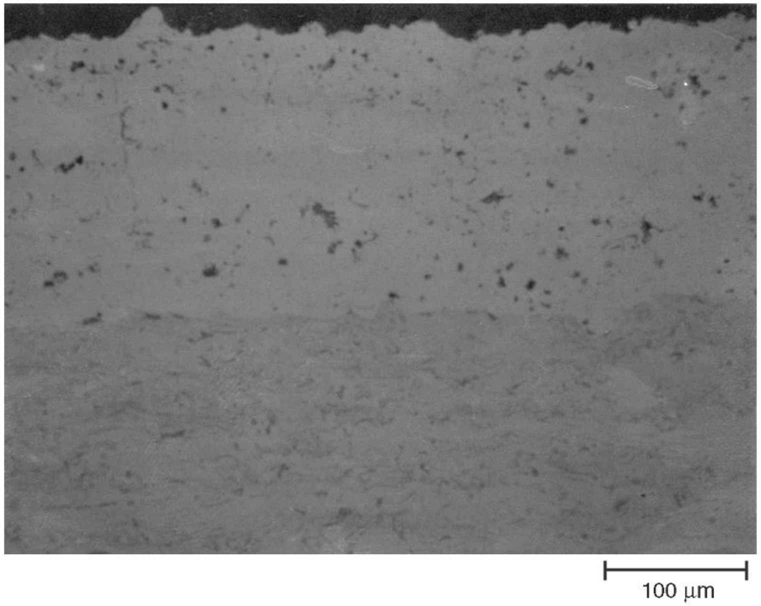


Fig. 4 Plasma-sprayed yttria-stabilized zirconia on vacuum plasma sprayed NiCrAlY. Courtesy of Drexel University

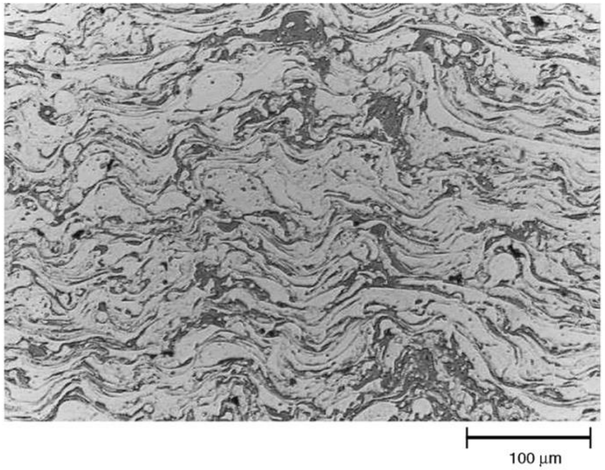


Fig. 5 Electric arc sprayed low-carbon steel. Courtesy of Thermal Spray Technologies

Wpływ metody natryskiwania na budowę powłoki

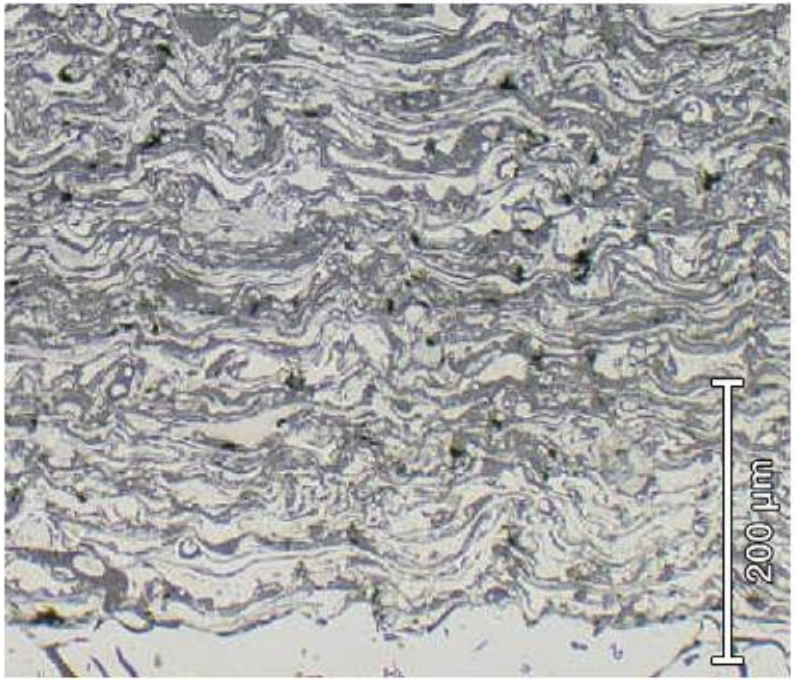
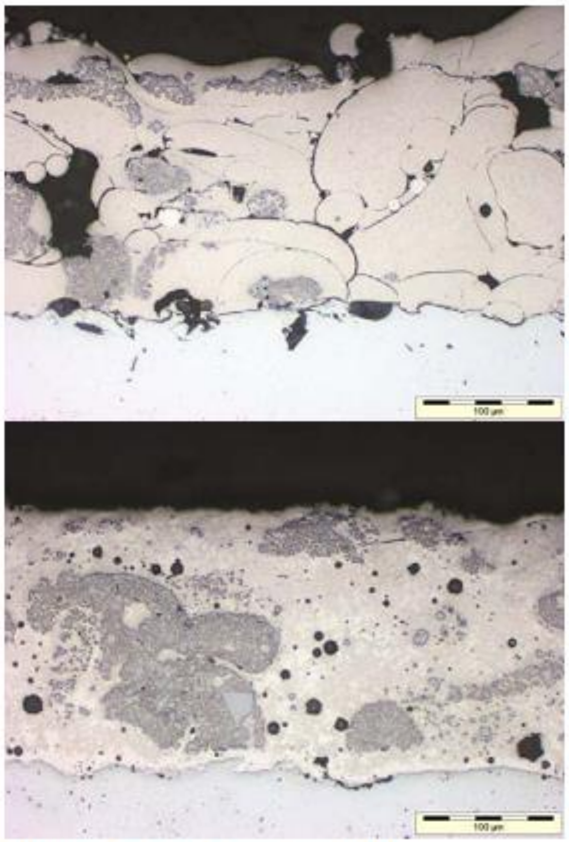


Figure 10 • Arc wire spray coating of X40 steel

Figure 11 • HVOF spray coating of WC 12(CoCr)

Wpływ obróbki cieplnej



Coating structure after coating

Coating structure after fusing

Figure 12 • Self-fluxing coating

Zastosowanie powłok natryskiwanych cieplnie – geometria próbek części

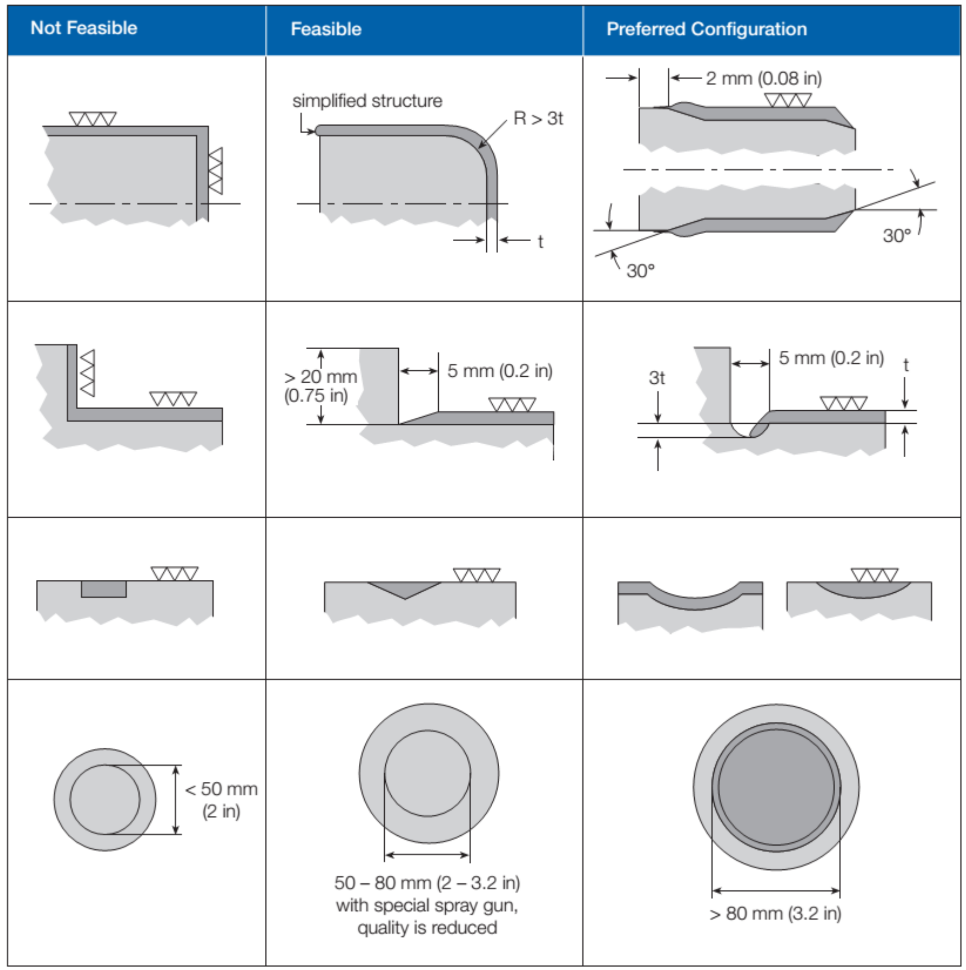


Figure 13 • Favorable coating geometries for coating

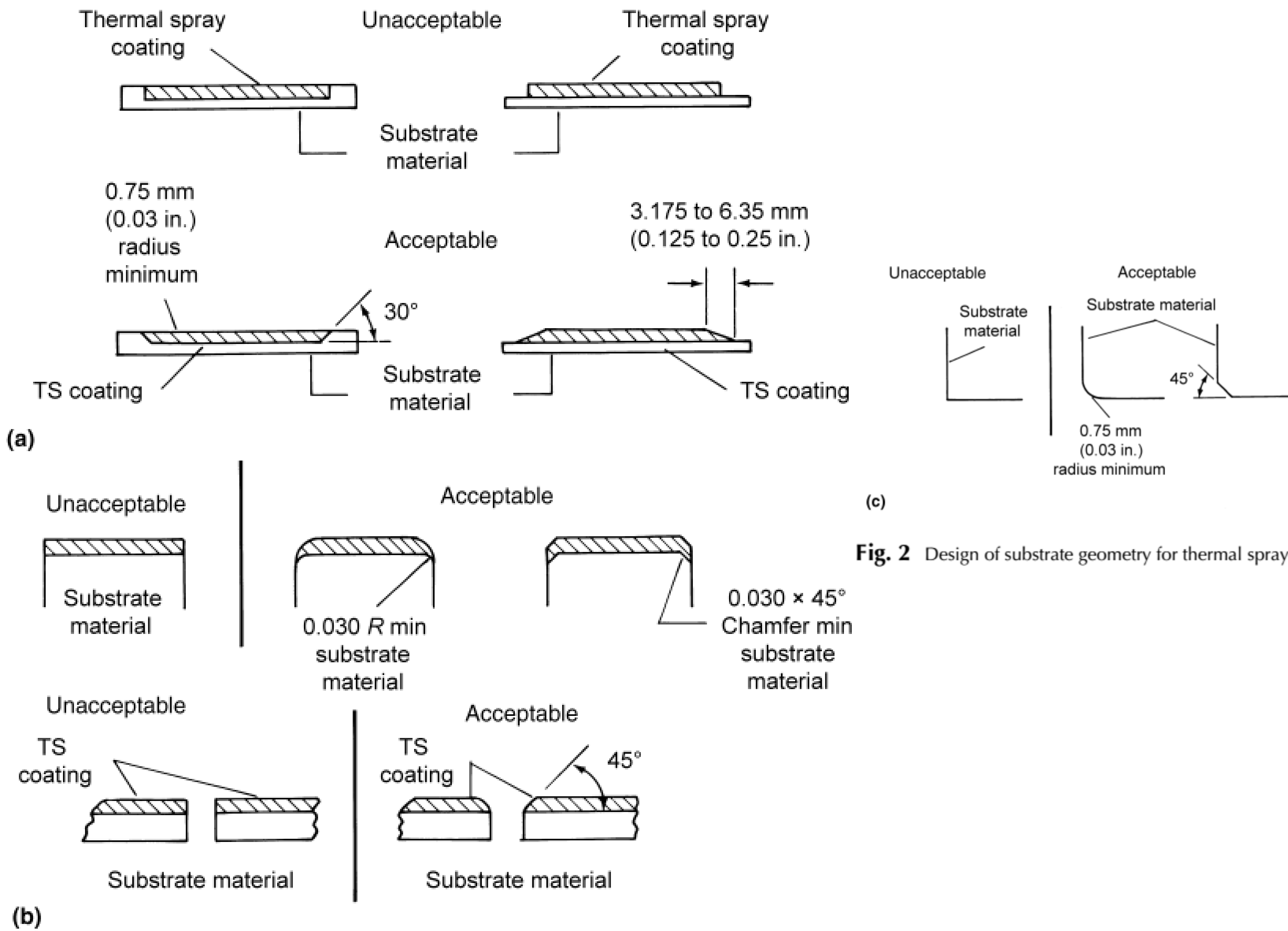


Fig. 2 Design of substrate geometry for thermal spray coating processes

Wady mikrostruktury powłok natryskiwanych cieplnie

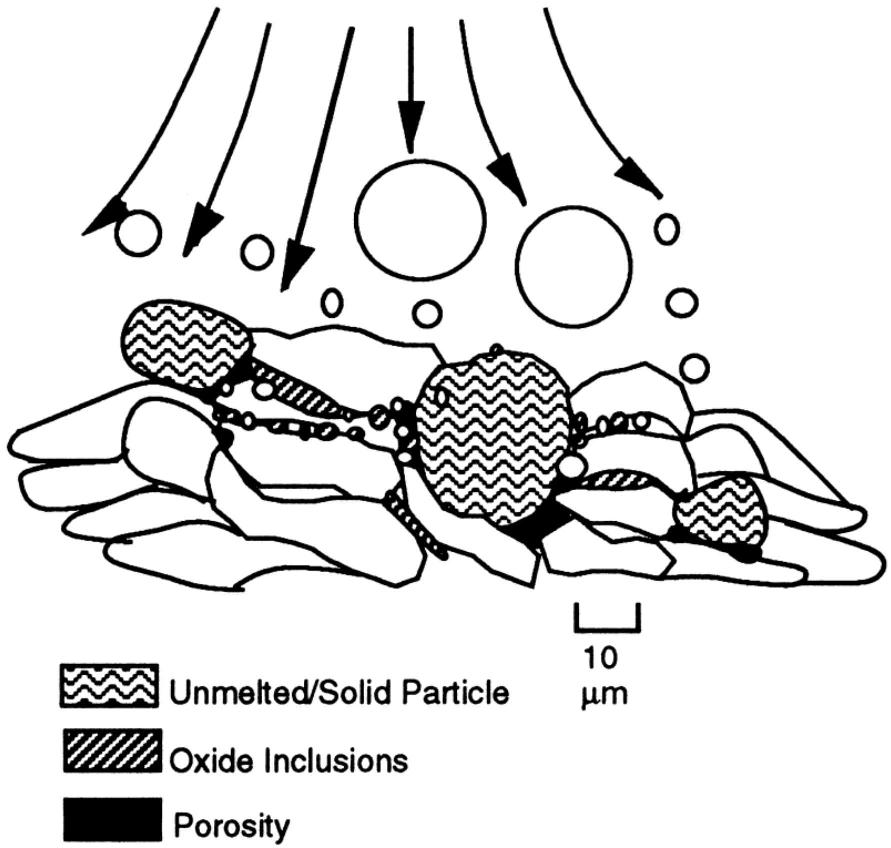


Fig. 6 Typical thermal spray coating defects

Wpływ kąta natryskiwania

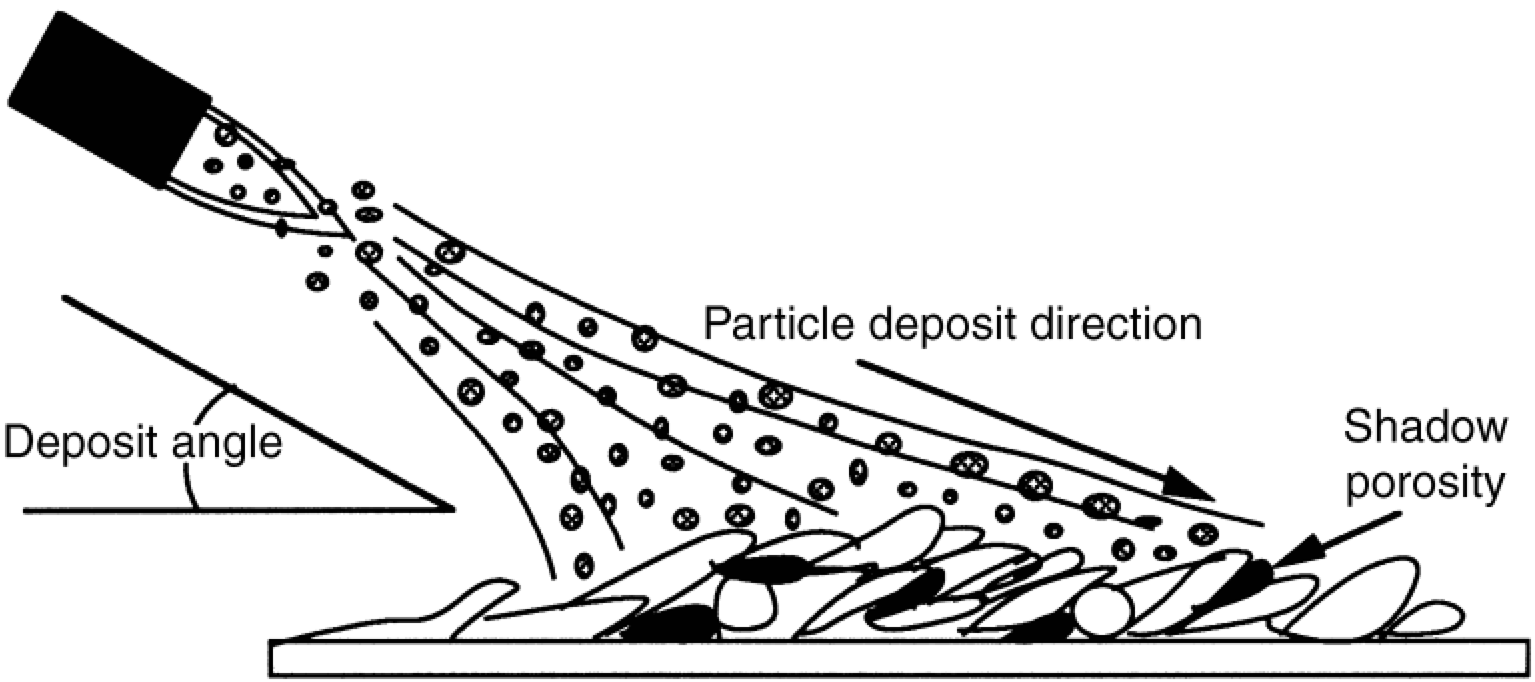
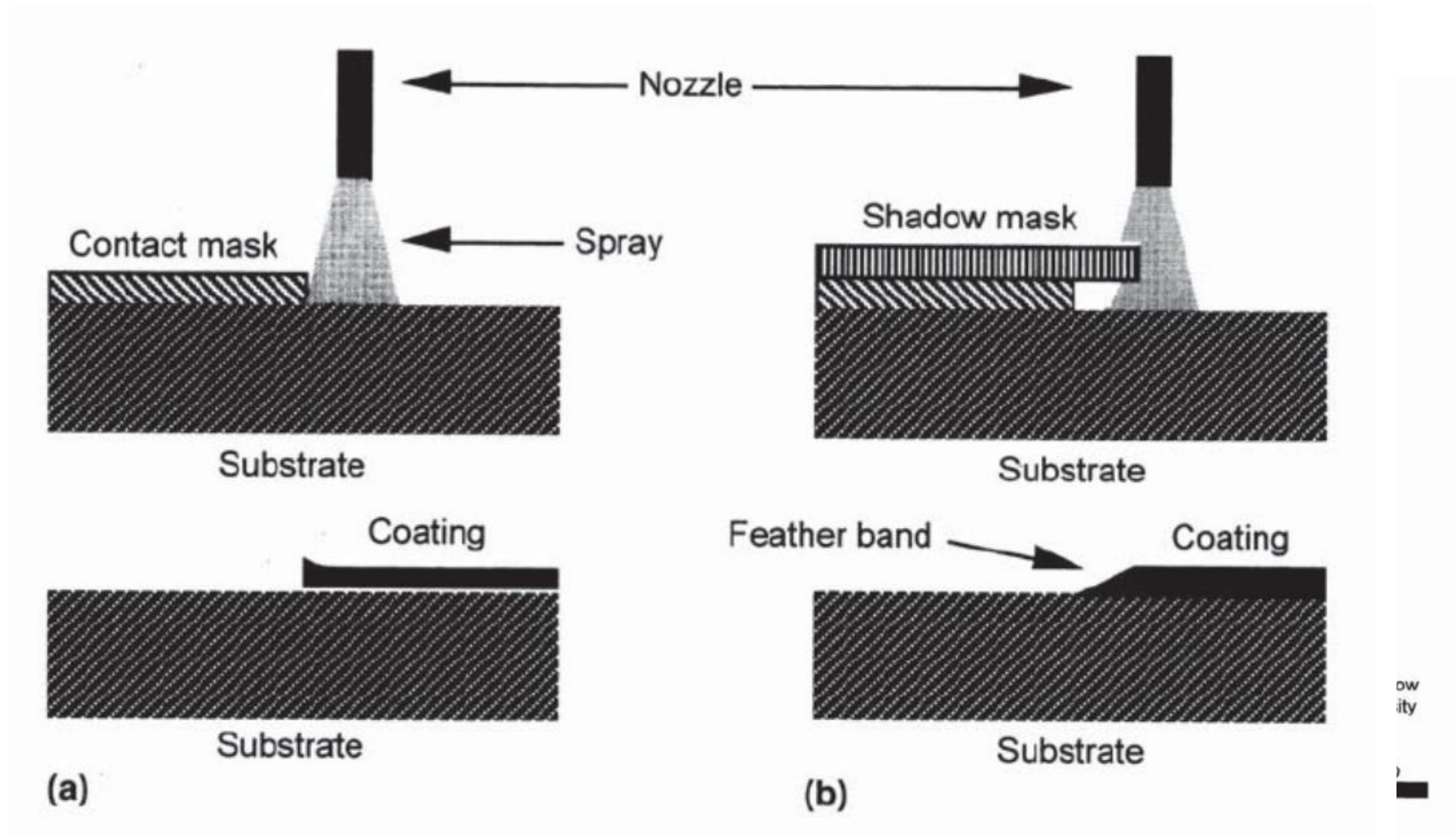


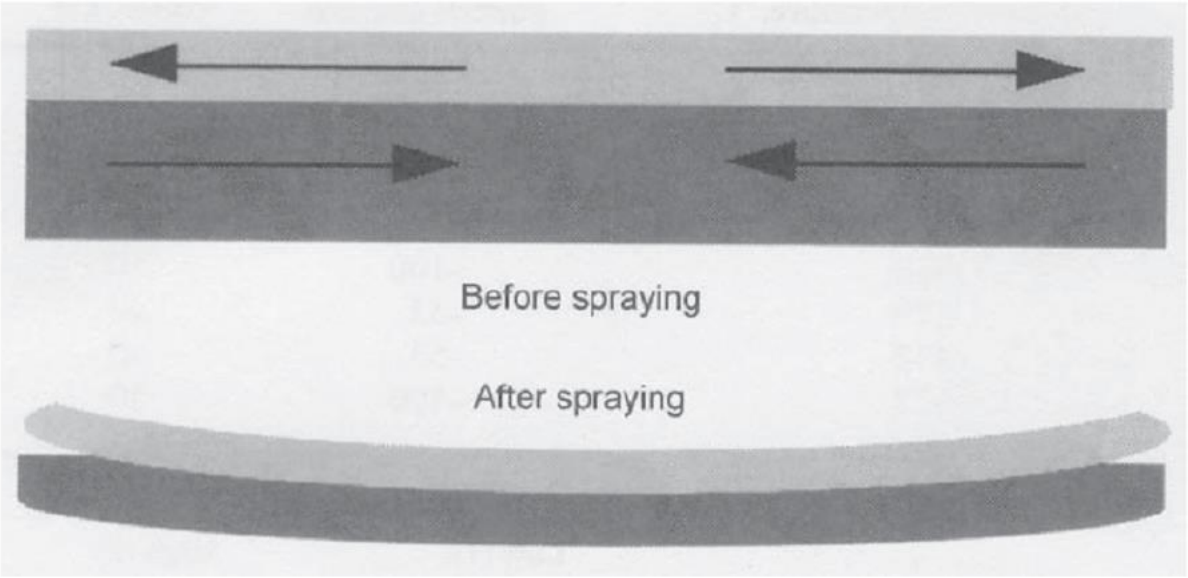
Fig. 8 Porosity created by shadowing resulting from off-axis spraying



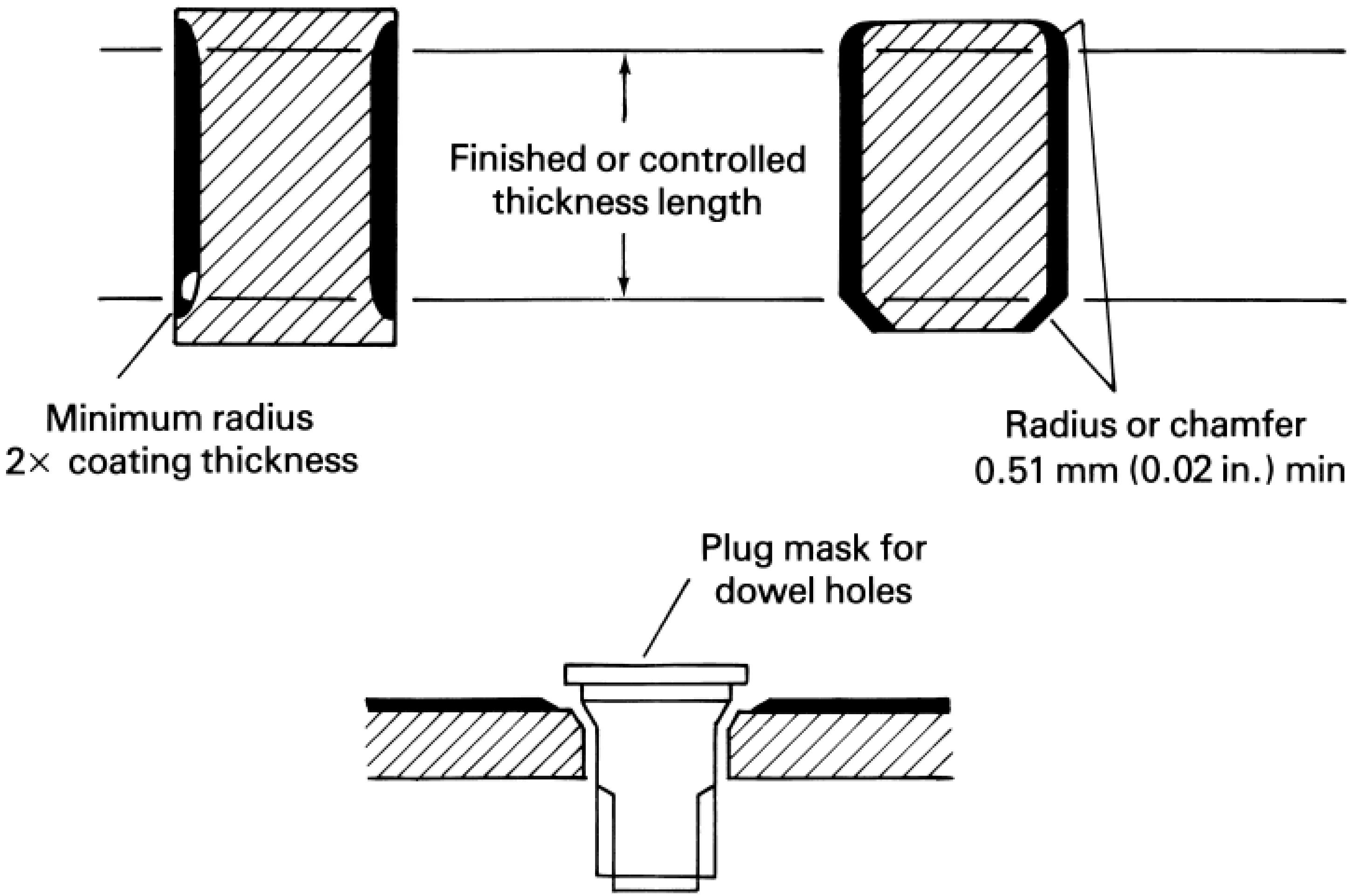
Coatings resulting from contact masks (a) versus shadow masks (b)

Thermal spray stream positions: (a) Good (b) Acceptable (c) Minimum acceptable (d) Formation of porosity in sprayed coatings when the spray angle is reduced to approximately 45 degrees. Particles impacting at angles of less than 90 degrees create a shadowing effect that results in increased coating porosity.

Wpływ temperatury na powłoki natryskiwane cieplnie



Maskowanie



Finished or controlled thickness length
Minimum radius 2× coating thickness
Radius or chamfer 0.51 mm (0.02 in.) min
Plug mask for dowel holes

Energia cząstek oraz temperatura strumienia dla najważniejszych metod natryskiwania cieplnego

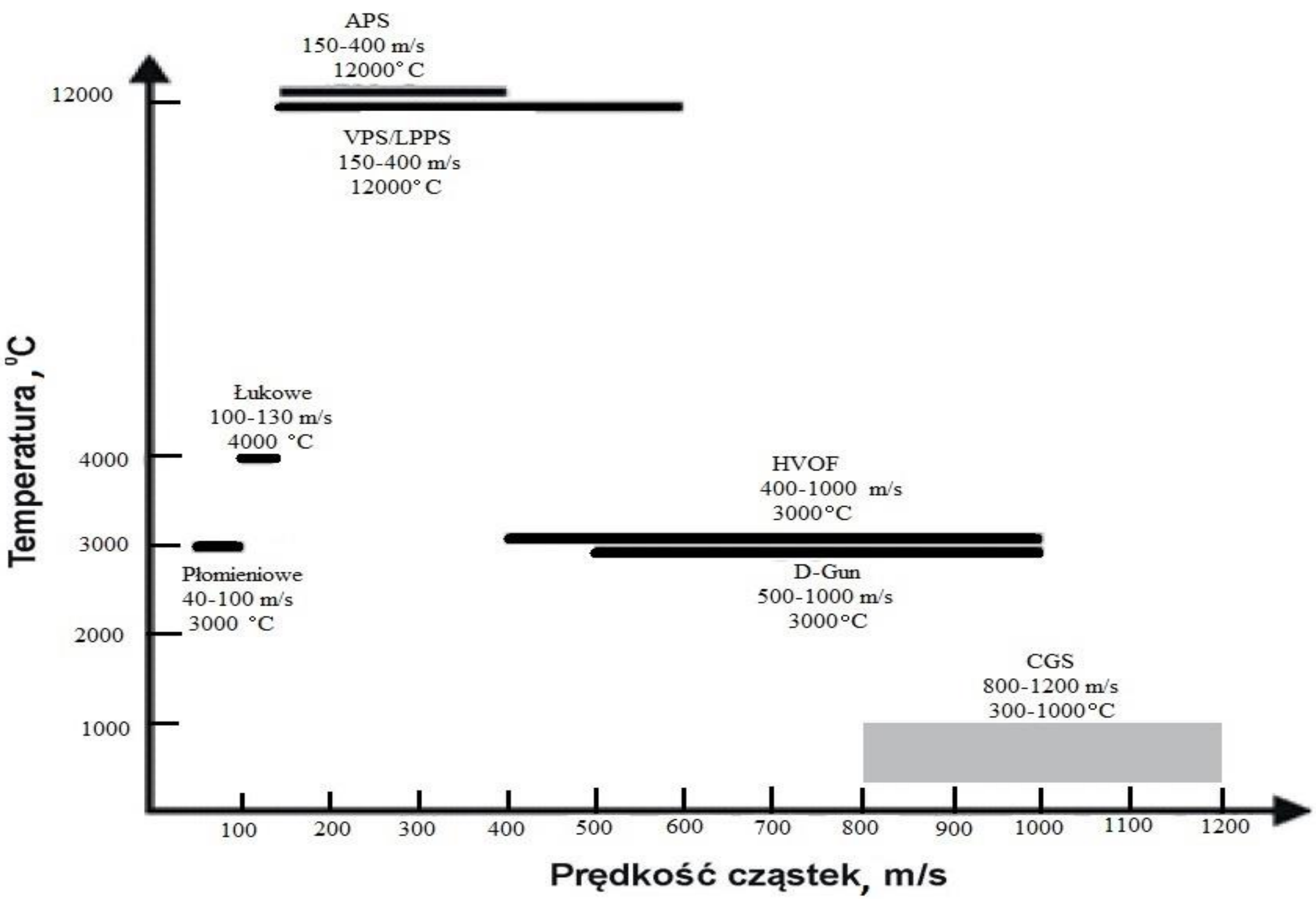
Heat energy input and particle velocity for common thermal spray processes

Process	Input heat energy to particle		Output particle velocity [a]				
	High	Low	Highest	High	Medium high	Medium	Low
Combustion wire	X					X	
Combustion powder	X						X
Standard plasma	X				X		
High-velocity plasma	X			X			
Vacuum plasma	X			X			
Standard wire arc	X					X	
Vacuum arc	X				X		
High-velocity oxyfuel		X	X				
Detonation gun		X	X				

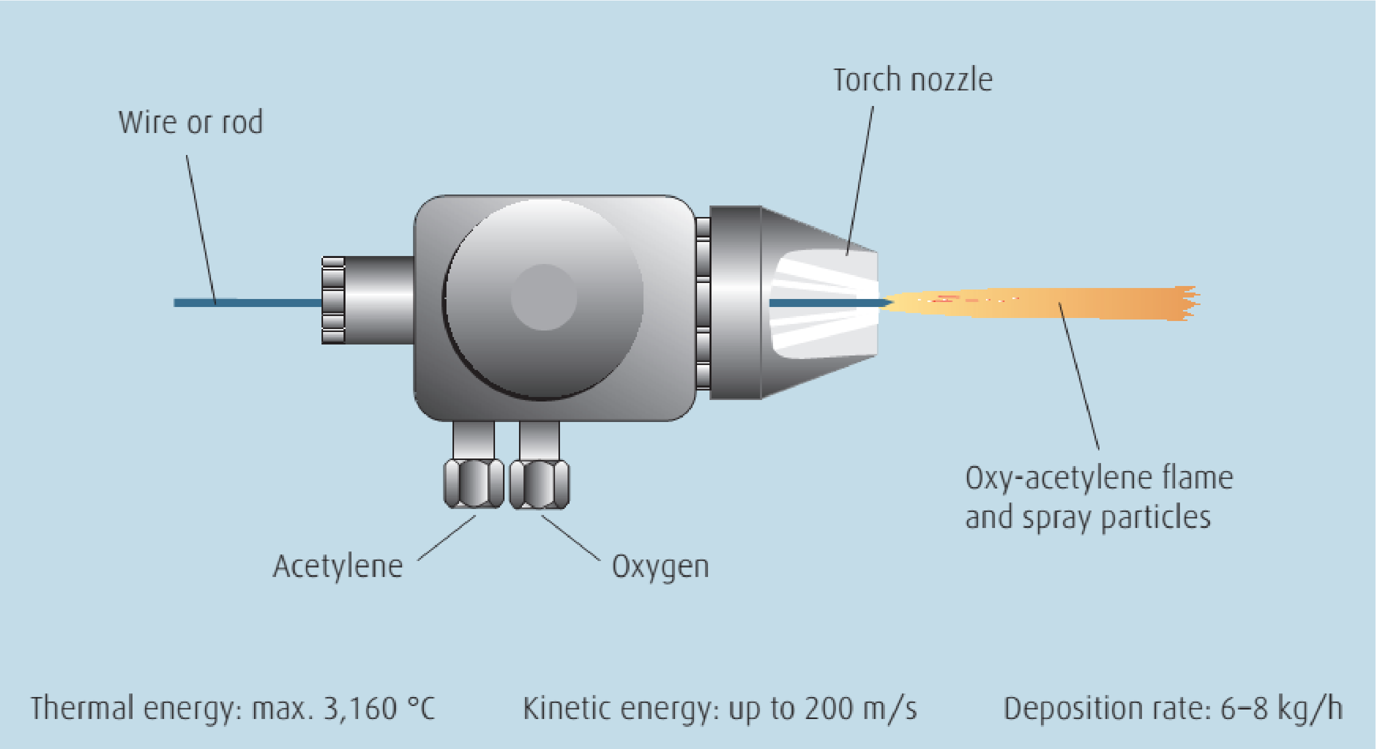
(a) Particle speed ranges from a high of approximately 1000 m/s (3000 ft/s) to a low of 25 m/s (80 ft/s). Further variations within each process depends on the particle size, material type and gas velocity

Source: ASM Handbook: Metallography and Microstructures, Vol.9, p.1038, 2004

Prędkość i temperatura cząstek w procesach natryskiwania cieplnego



Natryskiwanie płomieniowe proszku



Natryskiwanie płomieniowe proszku

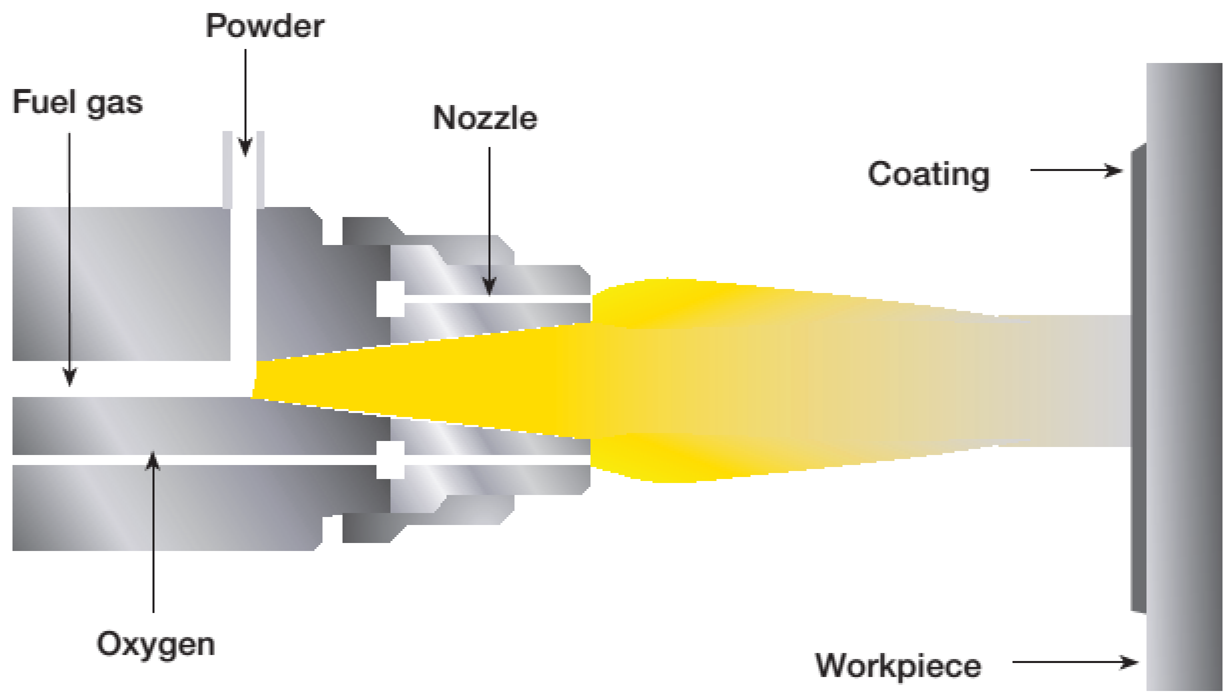


Figure 4b • Schematic diagram of the powder flame spray process

Natryskiwanie płomieniowe proszkiem - system

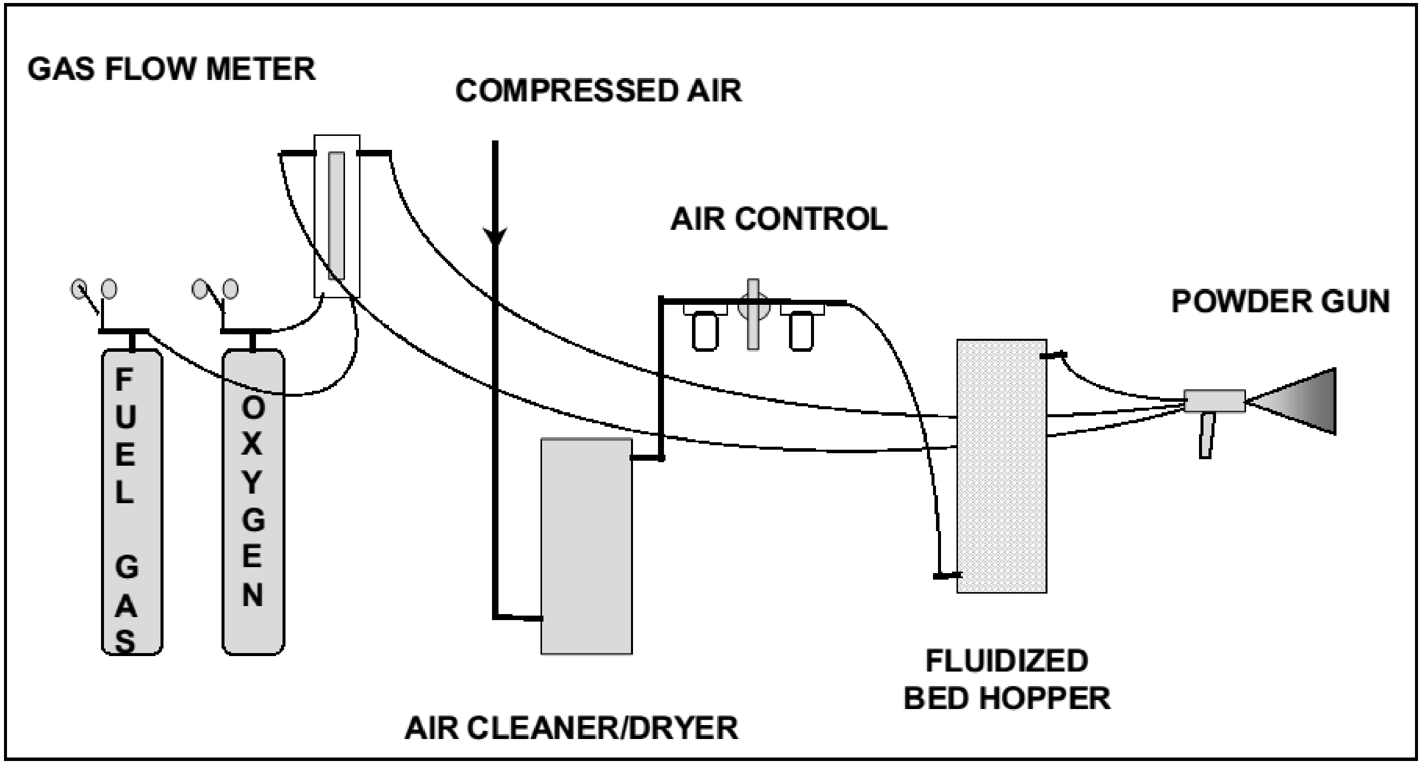
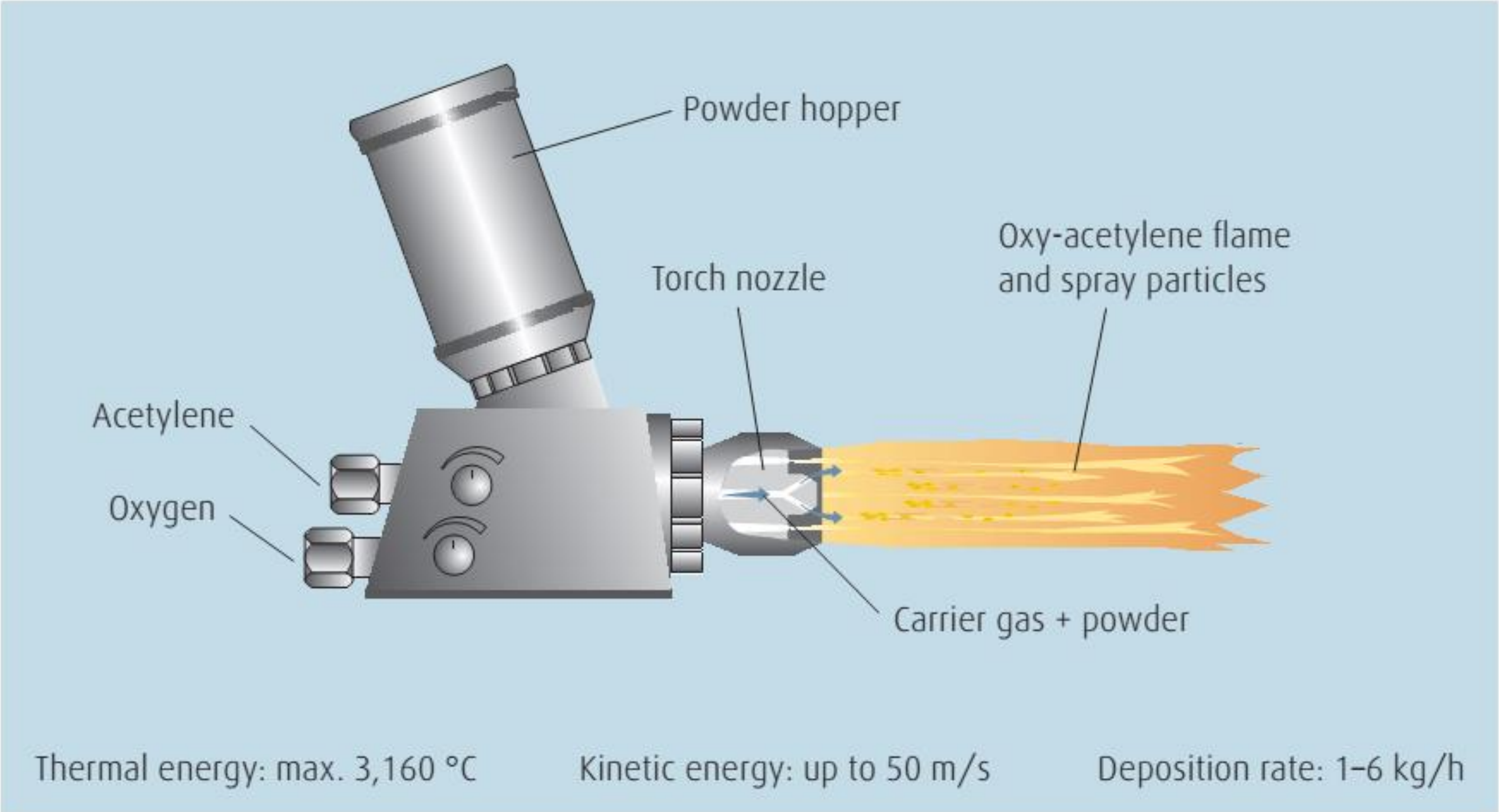


Figure 2-4. Typical combustion powder gun installation

Natryskiwanie płomieniowe z proszku - gazy procesowe

Gases for flame spraying with powder
Acetylene-oxygen
Hydrogen-oxygen
Propane-oxygen
Propylene-oxygen
Carrier gas: e.g. nitrogen, argon, oxygen

Natryskiwanie płomieniowe -drut



Natryskiwanie płomieniowe -drut

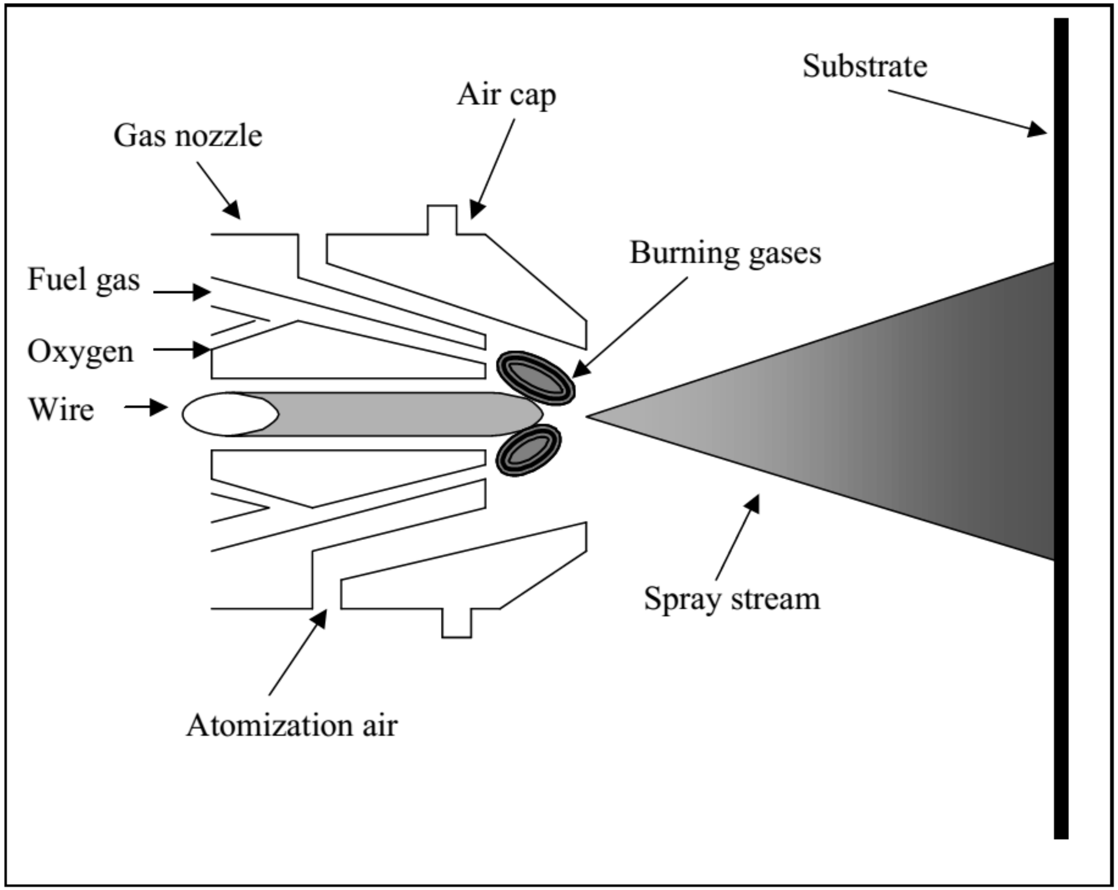


Figure 2-3. Typical flame spray gun

Natryskiwanie płomieniowe z drutu - system

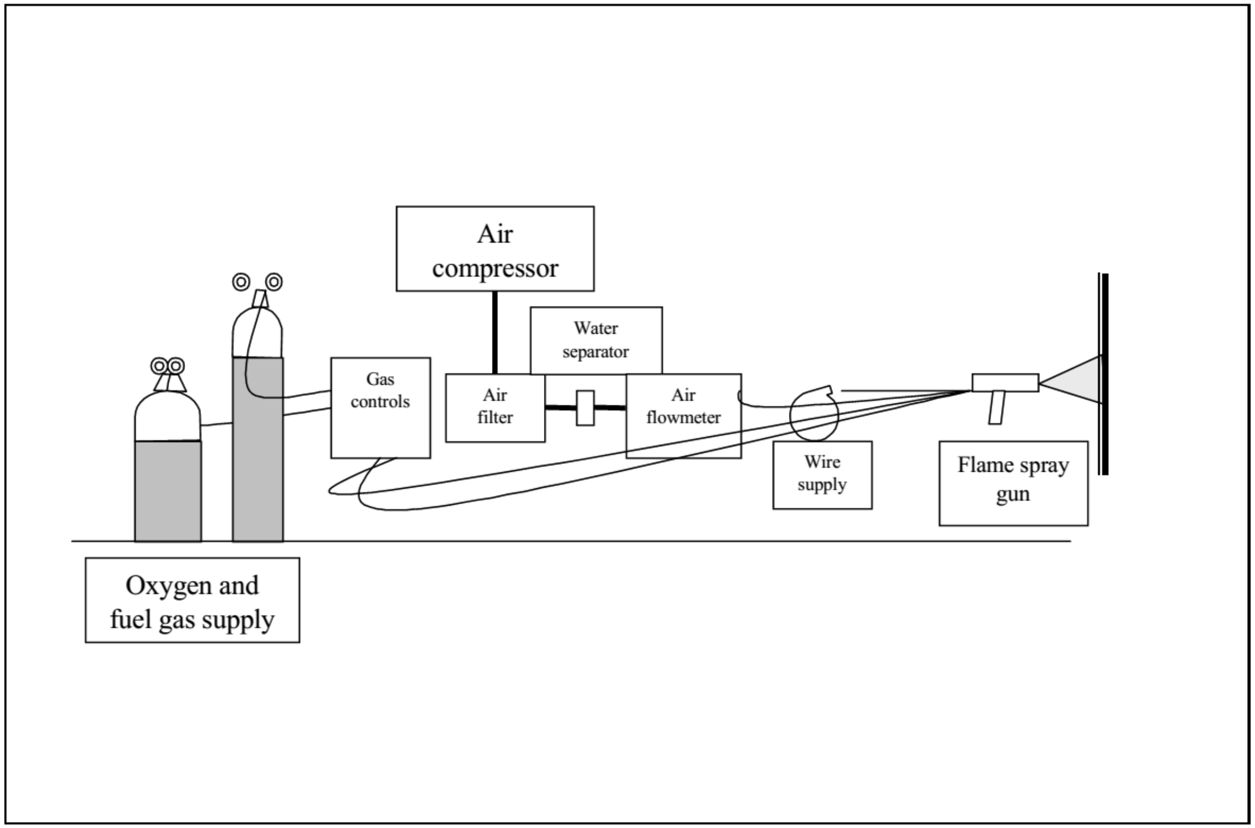
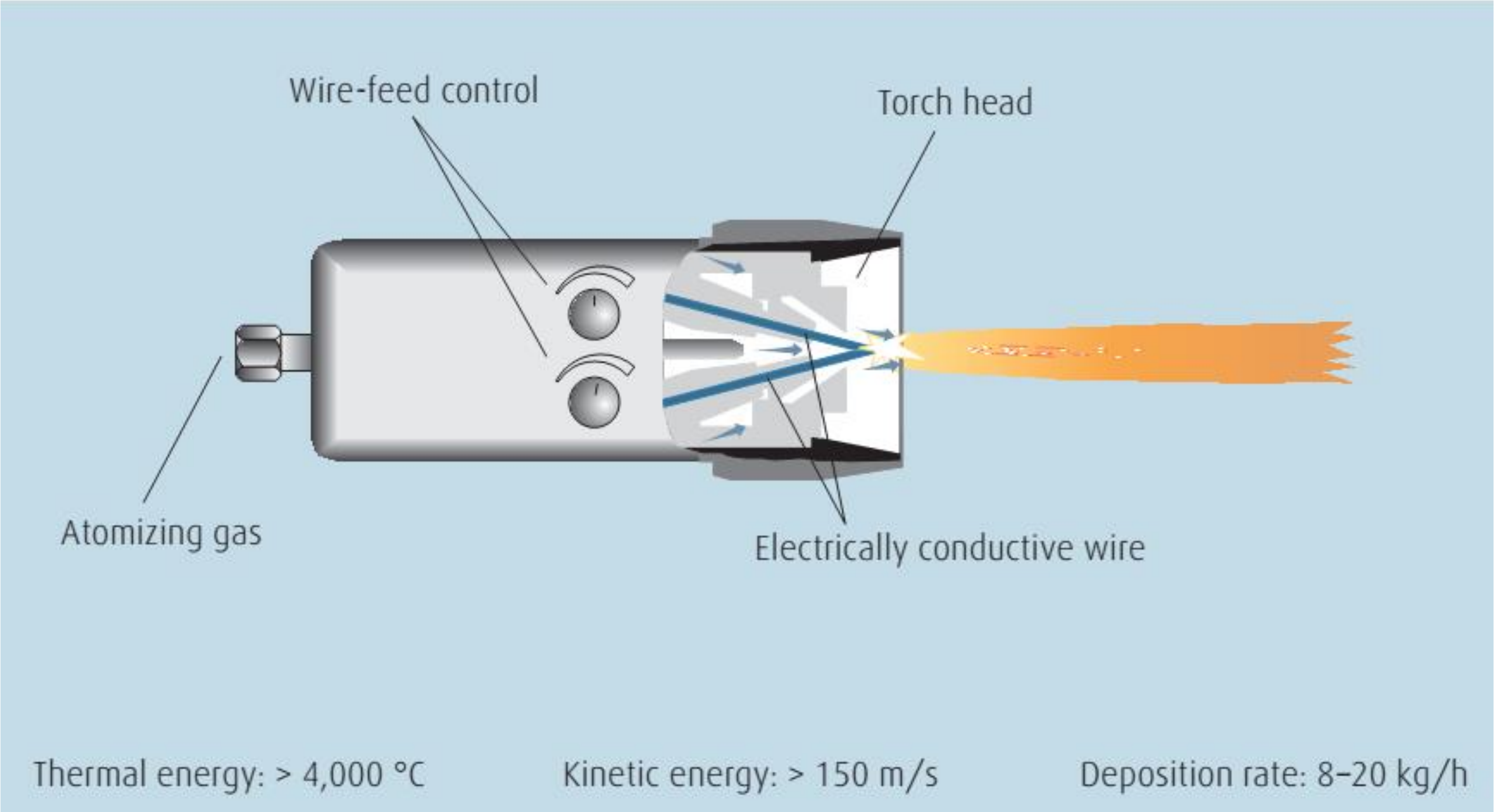


Figure 2-2. Typical flame spray system

Natryskiwanie płomieniowe z drutu – gazy procesowe

Gases for flame spraying with wire or rod
Acetylene-oxygen
Hydrogen-oxygen
Propane-oxygen
Propylene-oxygen
Atomizing gas: e.g. air, nitrogen

Natryskiwanie łukowe



Natryskiwanie łukowe z drutu

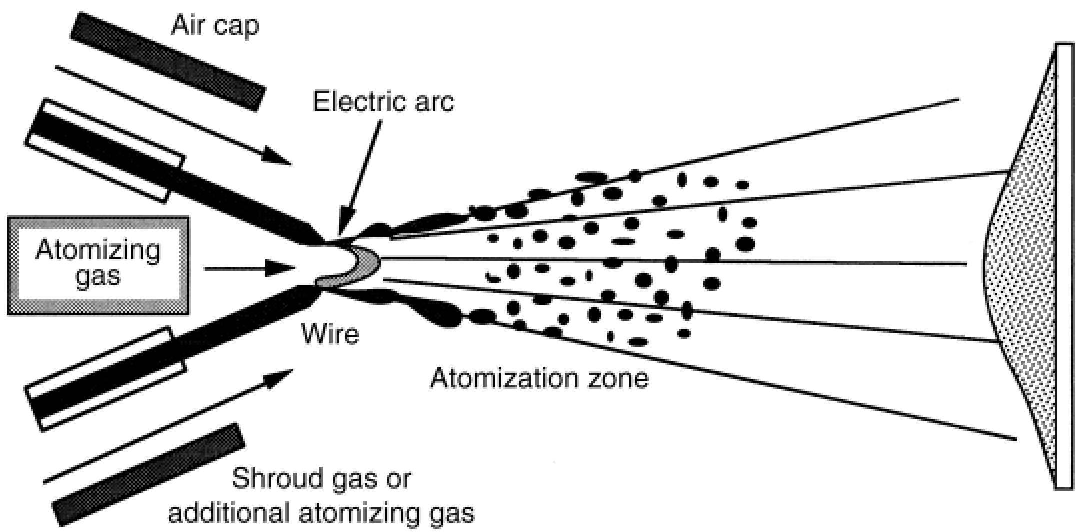


Fig. 8 Electric arc spray process

Natryskiwanie łukowe – ilość podawanego proszku

Table 2 Electric arc spray rates for various materials

Wire	g/min (lb/h)/100 A dc
Aluminum	45 (6)
Babbitt	379 (50)
Brass	83 (11)
Copper	83 (11)
Molybdenum	76 (10)
Steel	76 (10)
Stainless steel	76 (10)
Tin	341 (45)
Titanium	23 (3)
Zinc	182 (24)

Natryskiwanie łukowa – budowa pistoletu

Fig. 10 Commercial electric arc spray gun from a push/pull system. Courtesy of Praxair Surface Technologies

Natryskiwanie łukowe- urządzenia

Fig. 9 Push-type electric arc spray components. (a) System with door open showing drive components. (b) Gun. Courtesy of Thermach, Inc.

Konwencjonalne natryskiwanie łukowe drutem

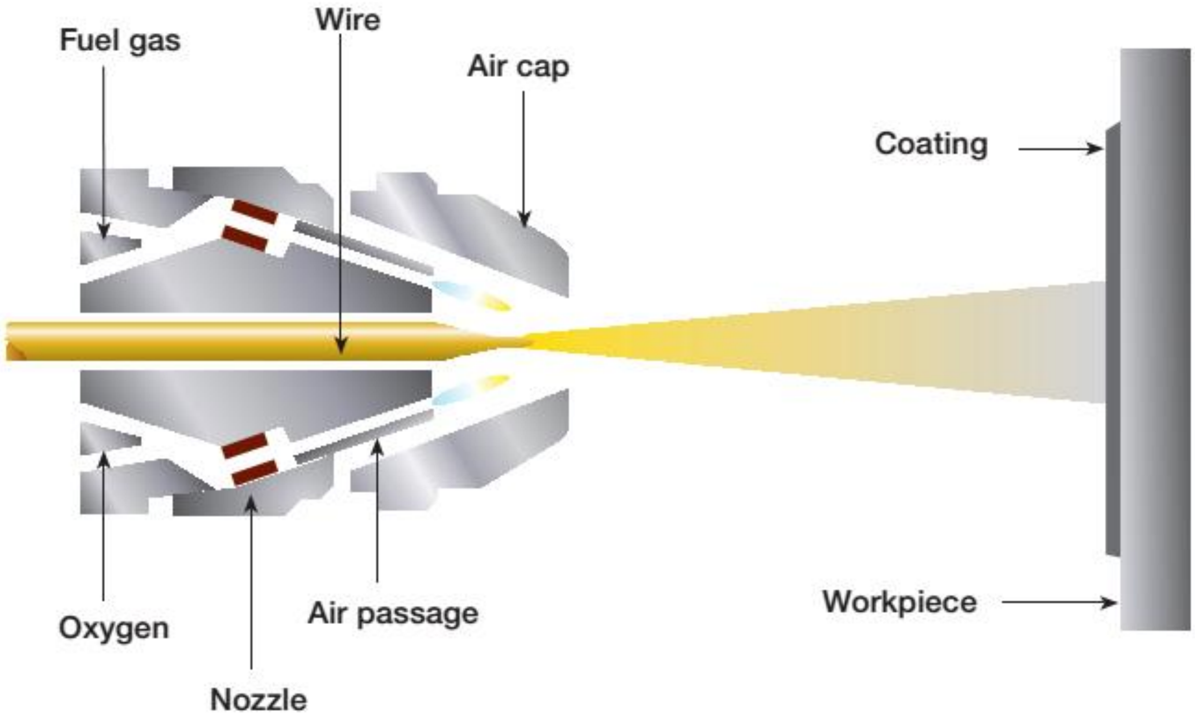


Figure 4a • Schematic diagram of the wire flame spray process

Natryskiwanie łukowe proszku

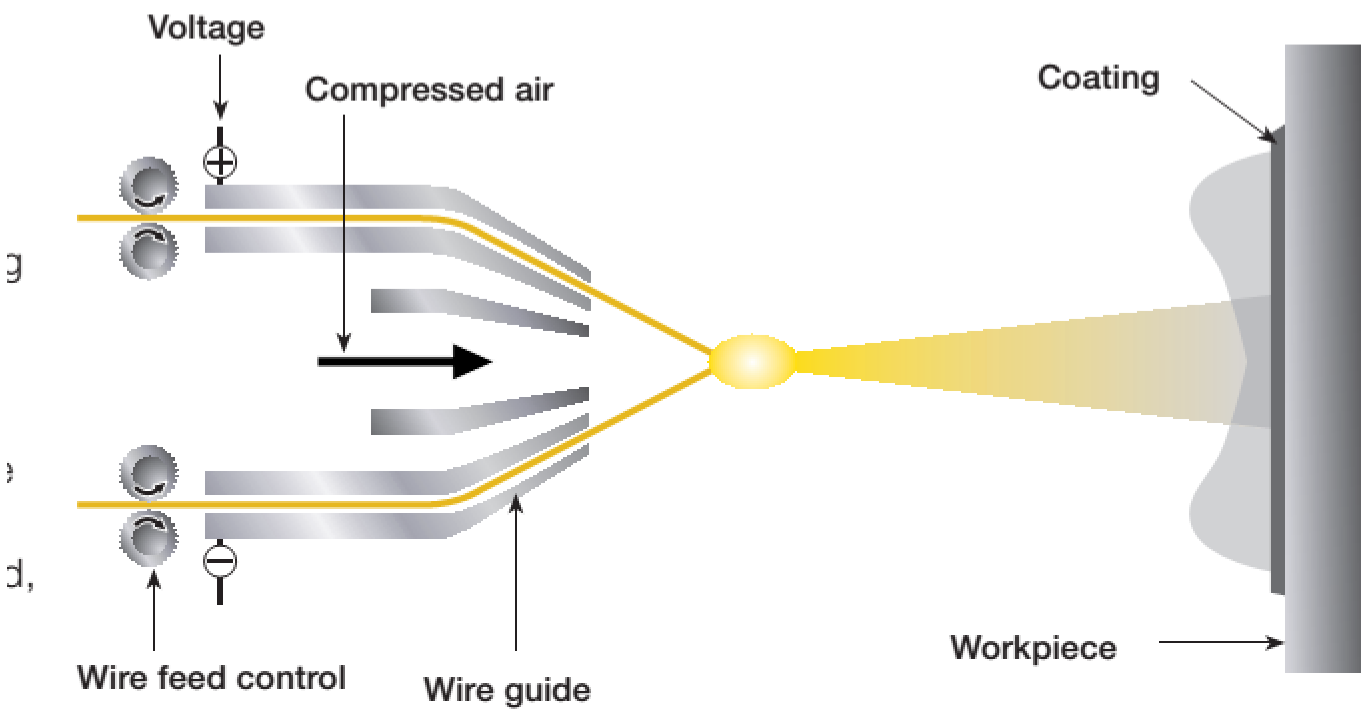


Figure 5 • Schematic diagram of the electric arc wire spray process

Natryskiwanie łukowe z drutu

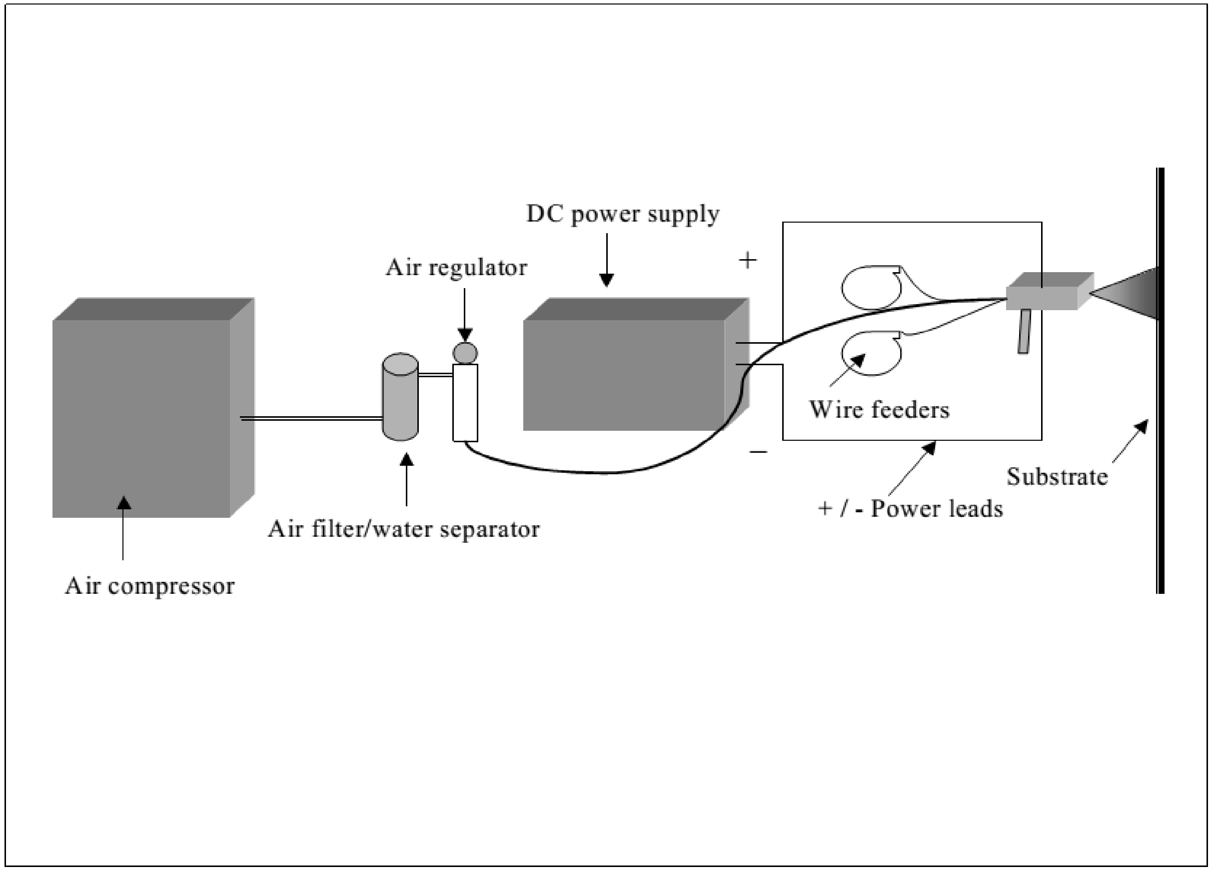


Figure 2-6. Typical two-wire arc spray system

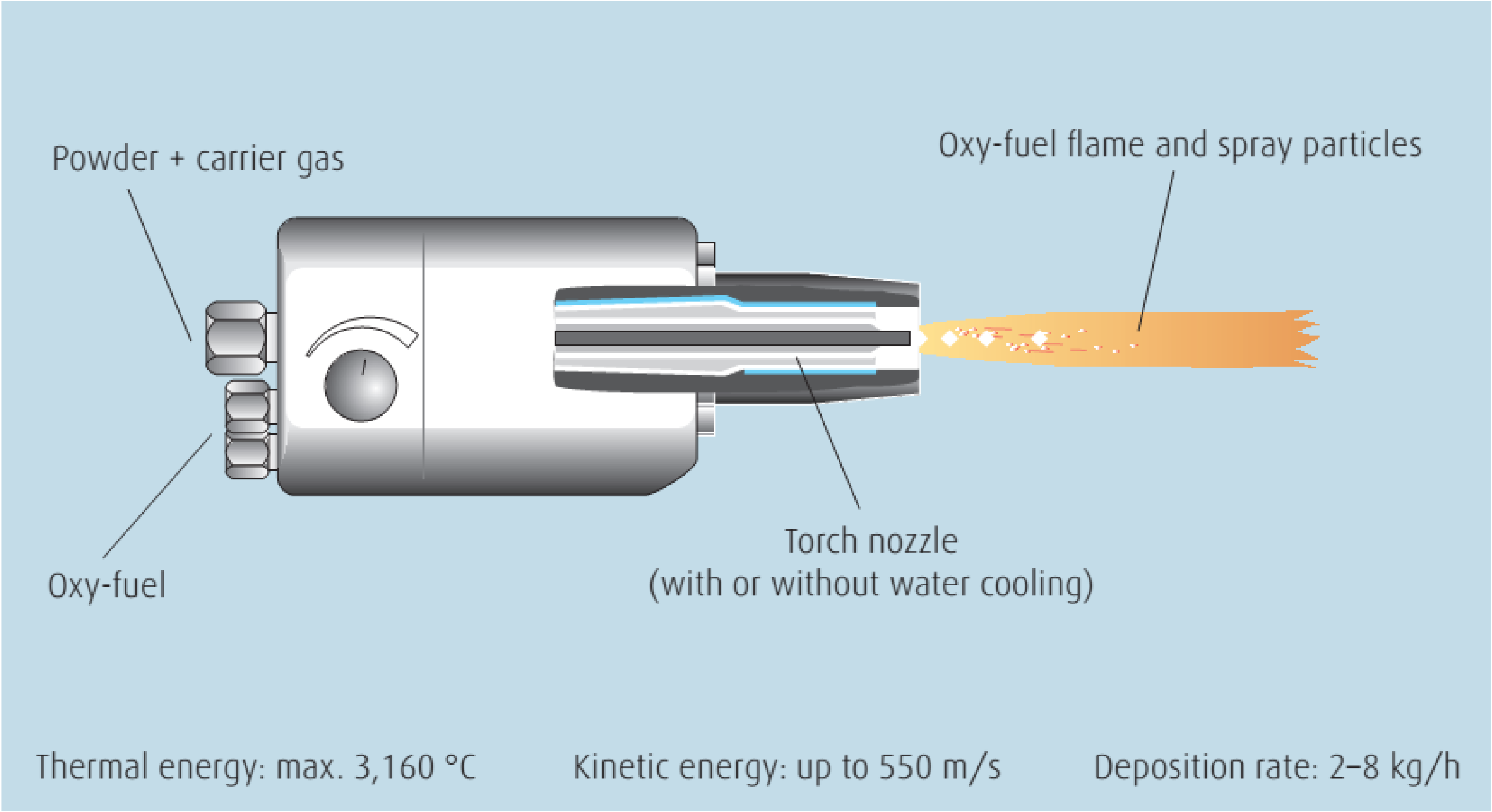
Natryskiwanie łukowe- gazy

Gases for arc spraying
Atomizing gas: e.g. nitrogen, argon, oxygen or their mixtures

Natryskiwanie naddźwiękowe HVOF - gazy stosowane w procesie

Gases for high velocity oxy-fuel spraying
Ethene-oxygen
Propane-oxygen
Propylene-oxygen
Hydrogen-oxygen
Acetylene-oxygen
Carrier gas: e.g. nitrogen, argon

Natryskiwanie naddźwiękowe HVOF



Natryskiwanie naddźwiękowe HVOF

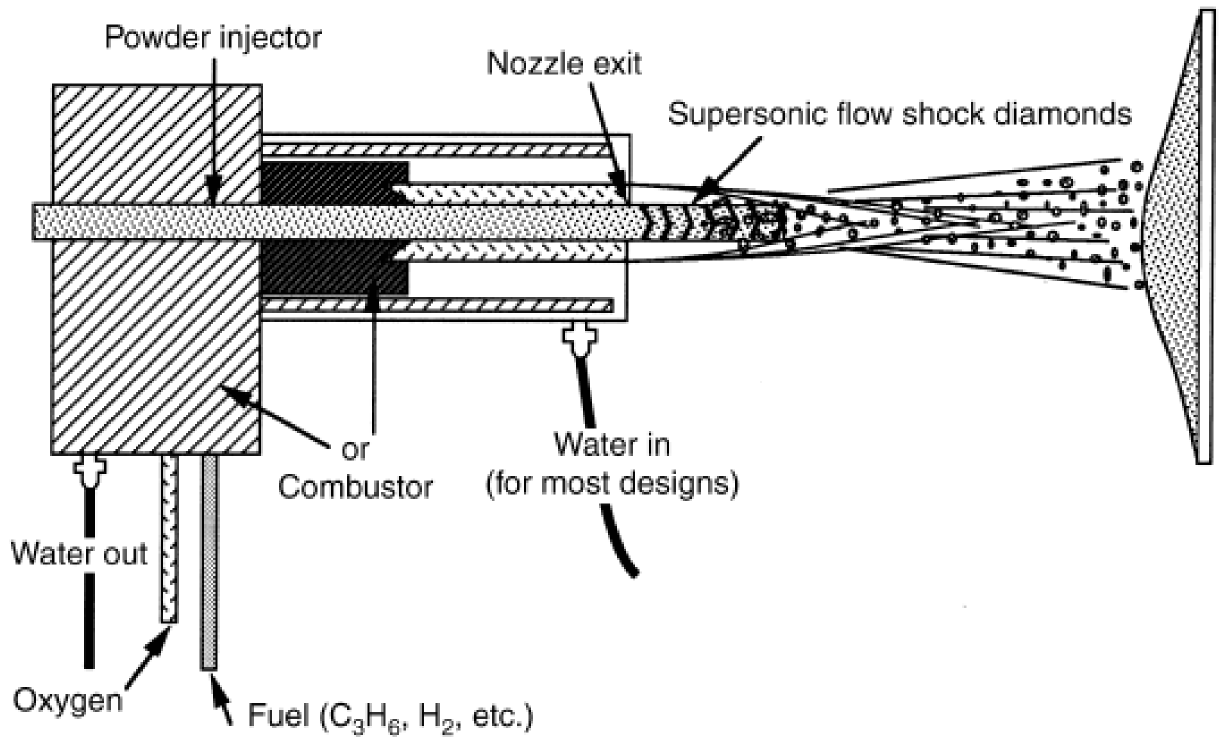
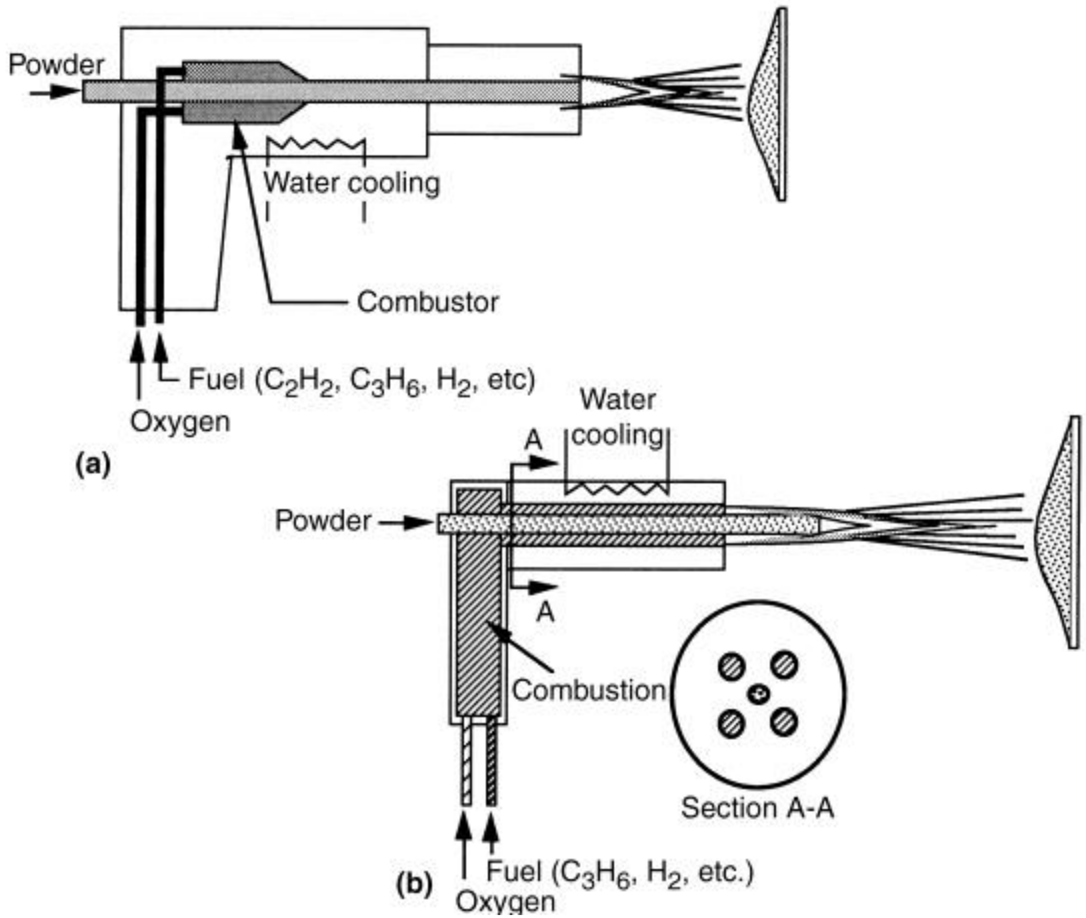
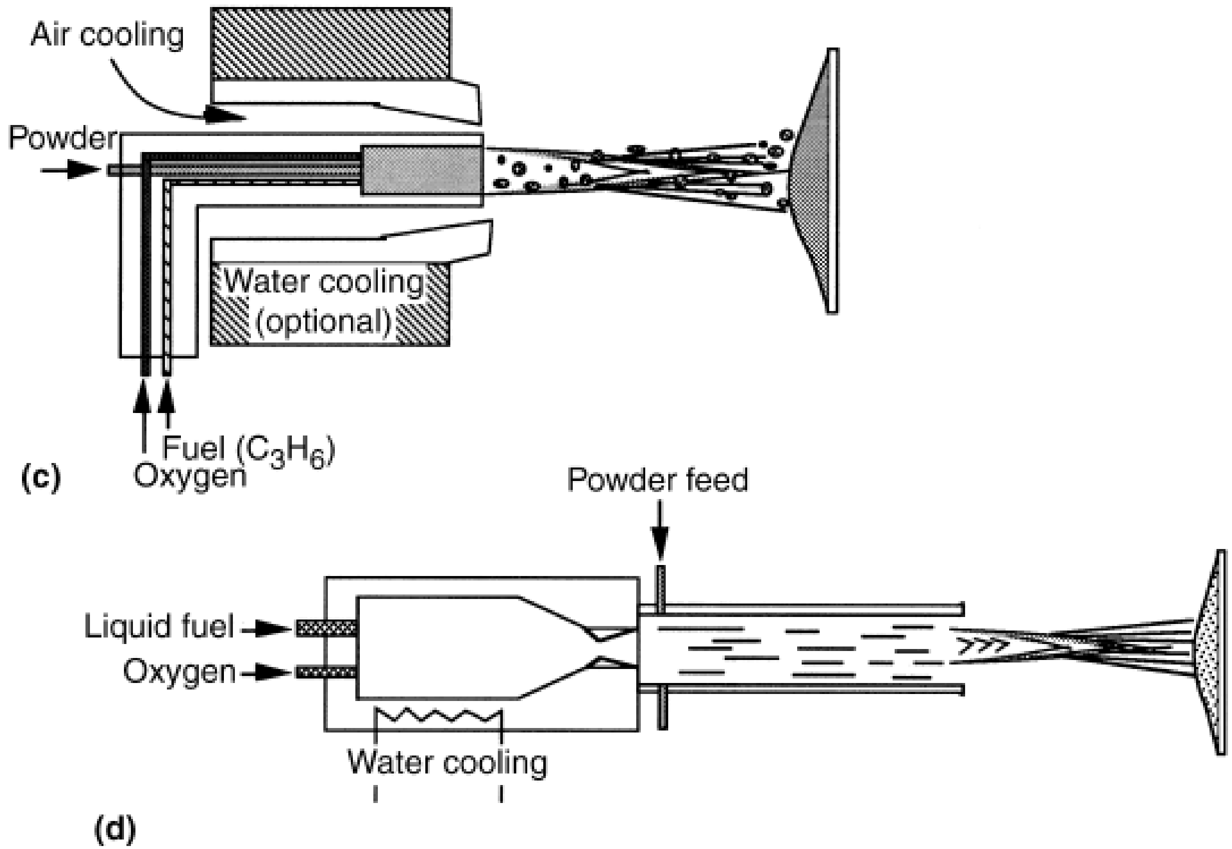


Fig. 5 High-velocity oxyfuel gun features

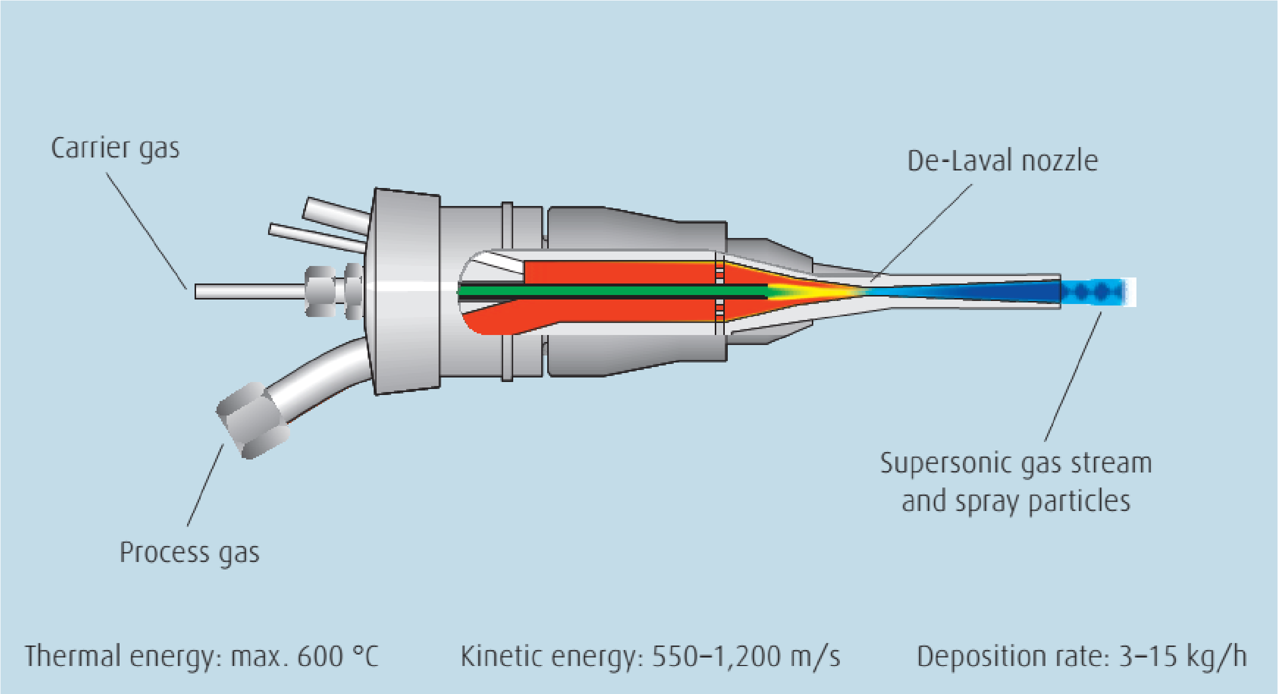
Natryskiwanie naddźwiękowe HVOF – rozwiązania palników HV 2000 i JetKote



Natryskiwanie naddźwiękowe HVOF -Diamond Jet oraz JP-5000



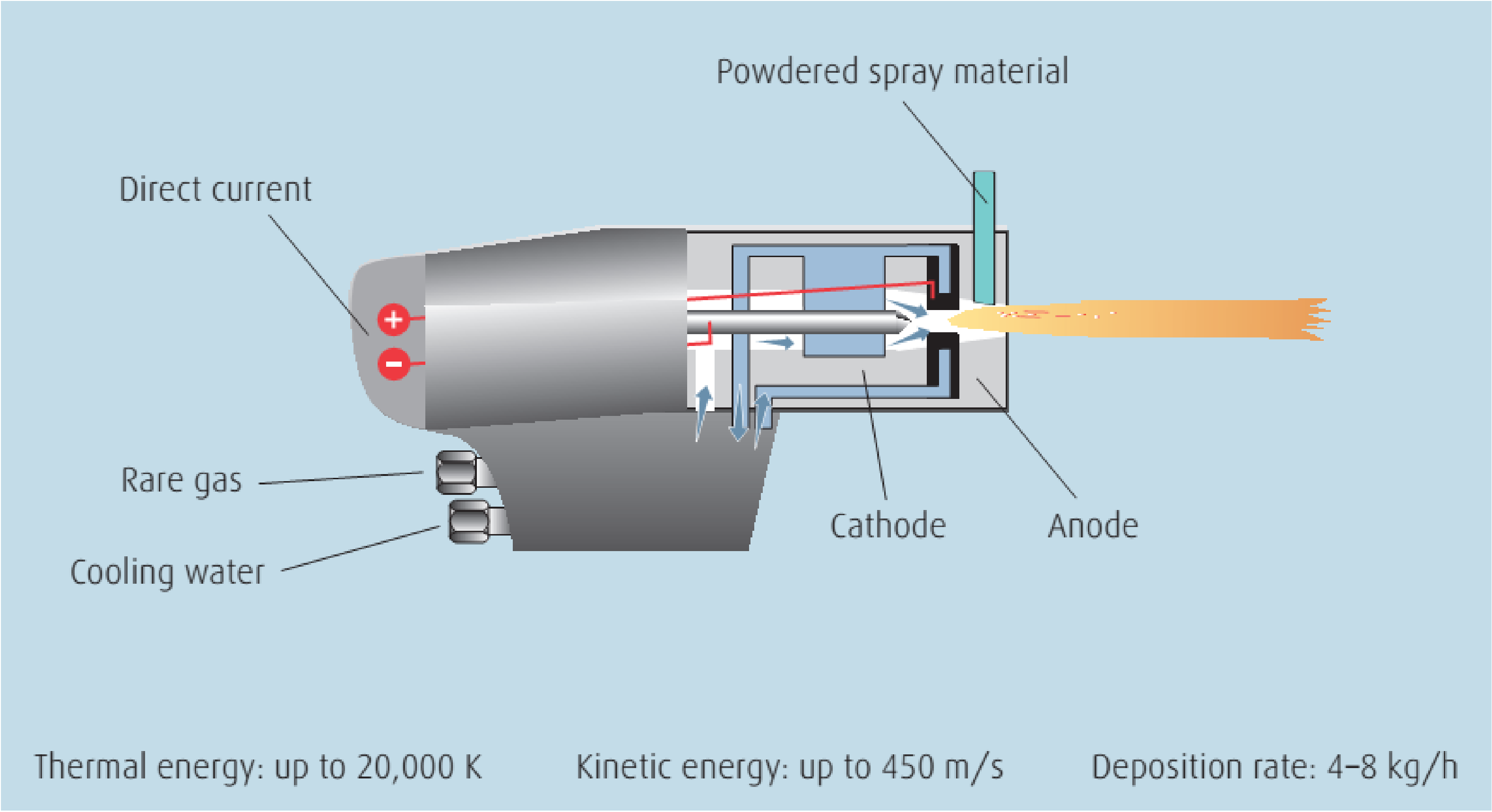
Cold Spray


Carrier gas
De-Laval nozzle
Supersonic gas stream
and spray particles
Process gas
Thermal energy: max. 600 °C
Kinetic energy: 550–1,200 m/s
Deposition rate: 3–15 kg/h

Cold Spray – gazy procesowe

Gases for cold spraying
Nitrogen
Helium or their mixtures

Natryskiwanie plazmowe APS



Natryskiwanie plazmowe APS

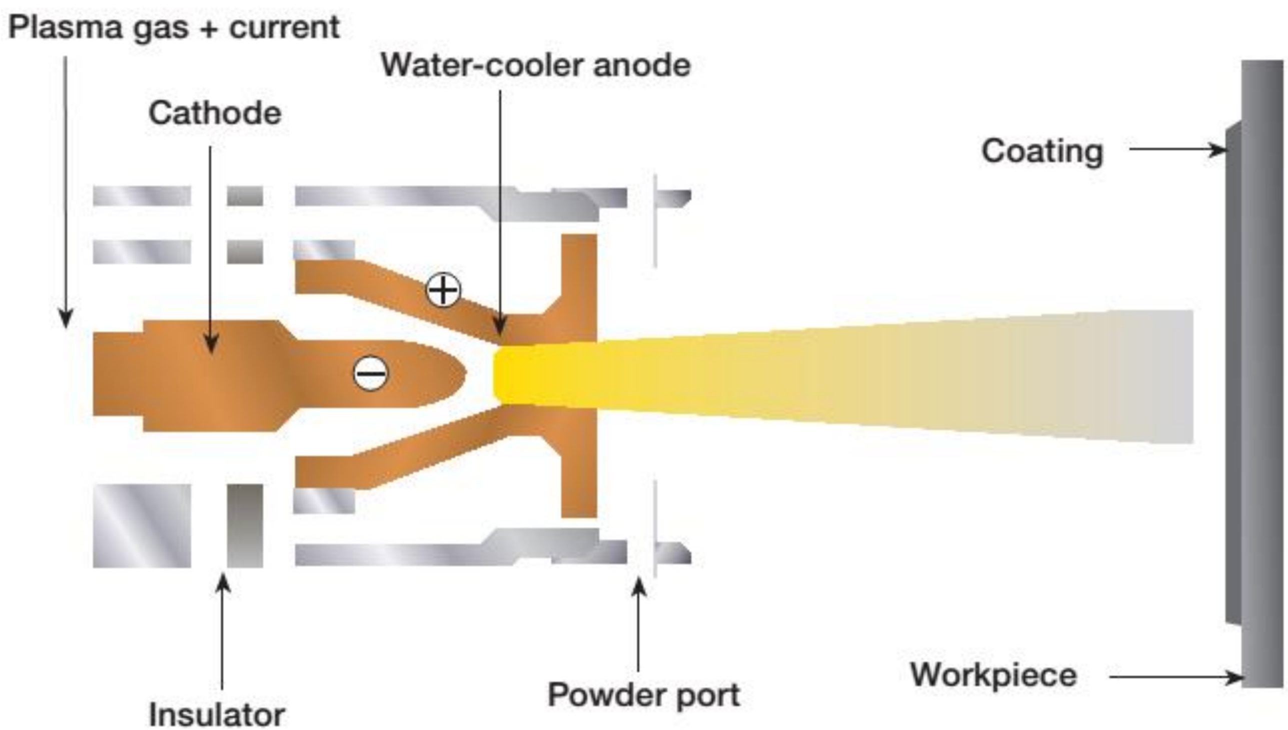


Figure 6a • Schematic diagram of the plasma spray process

Natryskiwanie plazmowe – budowa palnika

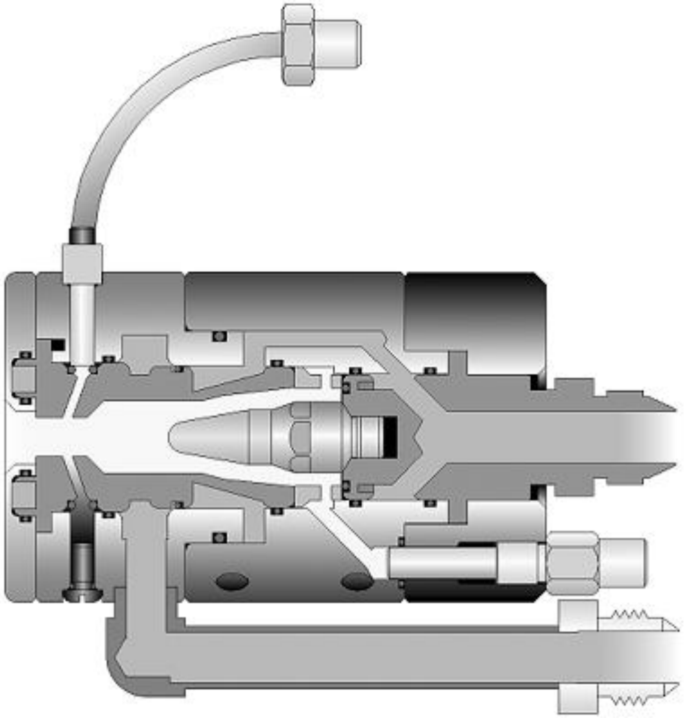


Fig. 16 Cross section of an internal injection plasma spray gun. Courtesy of Praxair Surface Technologies

Natryskiwanie plazmowe – gazy procesowe

Gases for plasma spraying
Argon
Nitrogen
Helium
Hydrogen or their mixtures
Carrier gas: e.g. nitrogen, argon

Natryskiwanie plazmowe w atmosferze ochronnej

Figure 6b • Controlled atmosphere plasma spraying

Właściwości powłok wytwarzanych różnymi metodami natryskiwania cieplnego

Characteristics		Coating Type	Powder Flame Spray	HVOF Spray	Electric Arc Wire Spray	Plasma Spray
Gas temperature	[°C] [°F]		3000 5400	2600 – 3000 4700 – 5400	4000 (Arc) 7200 (Arc)	12000 – 16000 21500 – 29000
Spray rate	[kg/h] [lb/h]		2 – 6 4.5 – 13	1 – 9 2 – 20	10 – 25 22 – 55	2 – 10 4.5 – 22
Particle velocity	[m/s] [ft/s]		up to 50 up to 160	up to 700 up to 2300	approx. 150 approx. 500	up to 450 up to 1500
Bond strength	[MPa] [psi]	Ferrous alloys	14 – 21 2000 – 3000	48 – 62 7000 – 9000	28 – 41 4000 – 6000	21 – 34
	[MPa] [psi]	Non-ferrous alloys	7 – 34 2000 – 5000	48 – 62 7000 – 9000	14 – 48 4000 – 7000	14 – 48 4000 – 7000
	[MPa] [psi]	Self-fluxing alloys	83+ (fused) 12000+ (fused)	70 – 80 10000 – 11500	15 – 50 2200 – 7200	--- ---
	[MPa] [psi]	Ceramics	14 – 34 4000 – 5000	--- ---	--- ---	21 – 41 3000 – 6000
	[MPa] [psi]	Carbides	34 – 48 5000 – 7000	83+ 12000+	--- ---	55 – 69 8000 – 10000

Właściwości powłok wytwarzanych różnymi metodami natryskiwania cieplnego

Characteristics		Coating Type	Powder Flame Spray	HVOF Spray	Electric Arc Wire Spray	Plasma Spray
Coating thickness	[mm]	Ferrous alloys	0.05 – 2.0	0.05 – 2.5	0.1 – 2.5	0.4 – 2.5
	[in]		0.002 – 0.080	0.002 – 0.100	0.004 – 0.100	0.015 – 0.100
	[mm]	Non-ferrous alloys	0.05 – 5.0	0.05 – 2.5	0.1 – 5.0	0.05 – 5.0
	[in]		0.002 – 0.200	0.002 – 0.100	0.004 – 0.200	0.002 – 0.200
	[mm]	Self-fluxing alloys	0.15 – 2.5	0.05 – 2.5	---	---
	[in]		0.006 – 0.100	0.002 – 0.100	---	---
	[mm]	Ceramics	0.25 – 2.0	---	---	0.1 – 2.0
	[in]		0.010 – 0.075	---	---	0.004 – 0.080
	[mm]	Carbides	0.15 – 0.8	0.05 – 5.0	---	0.15 – 0.8
	[in]		0.006 – 0.030	0.002 – 0.200	---	0.006 – 0.030
Hardness *(see Table A1 in the Appendix)*	[HRC]	Ferrous alloys	35	45	40	40
		Non-ferrous alloys	20	55	35	50
		Self-fluxing alloys	30 – 60	30 – 60	---	30 – 60
		Ceramics	40 – 65	---	---	45 – 65
		Carbides	45 – 55	55 – 72	---	50 – 65
Porosity	[%]	Ferrous alloys	3 – 10	< 2	3 – 10	2 – 5
		Non-ferrous alloys	3 – 10	< 2	3 – 10	2 – 5
		Self-fluxing alloys	< 2 (fused)	< 2	---	---
		Ceramics	5 – 15	---	---	1 – 2
		Carbides	5 – 15	< 1	---	2 – 3

Table 3 • Comparison of thermal spray process coating characteristics (approximate values)

Budowa systemu do natryskiwania cieplnego

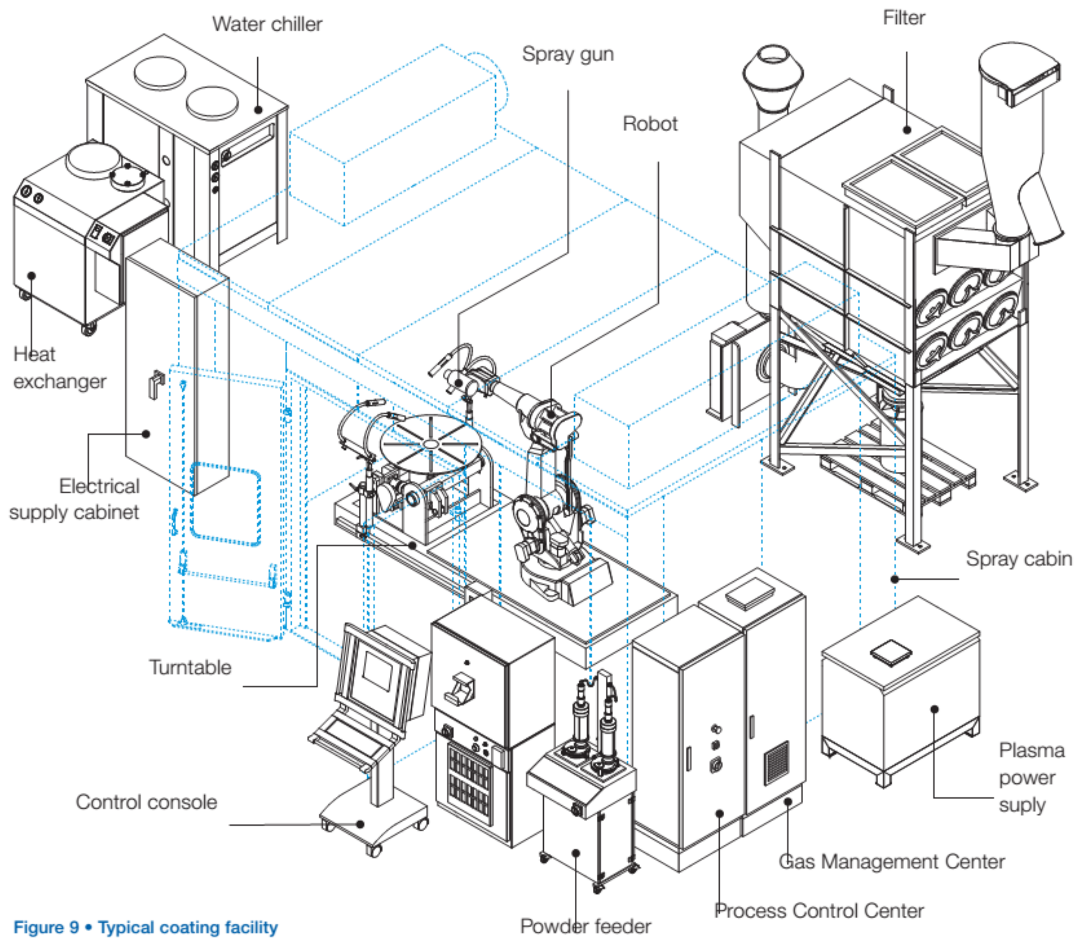


Figure 9 • Typical coating facility

Zastosowanie powłok natryskiwanych cieplnie

After fusing Figure 14 • Nose gear of an F5 Tiger with a WC/CoCr coating

Zastosowanie powłok natryskiwanych cieplnie

Figure 15 • Biocompatible **SUME™*PLANT*** titanium coating on a hip implant

Zastosowanie powłok natryskiwanych cieplnie

Figure 16 • Various textile machinery components

Zastosowanie powłok natryskiwanych cieplnie

Figure 17 • Coated gas turbine vanes

Zastosowanie powłok natryskiwanych cieplnie

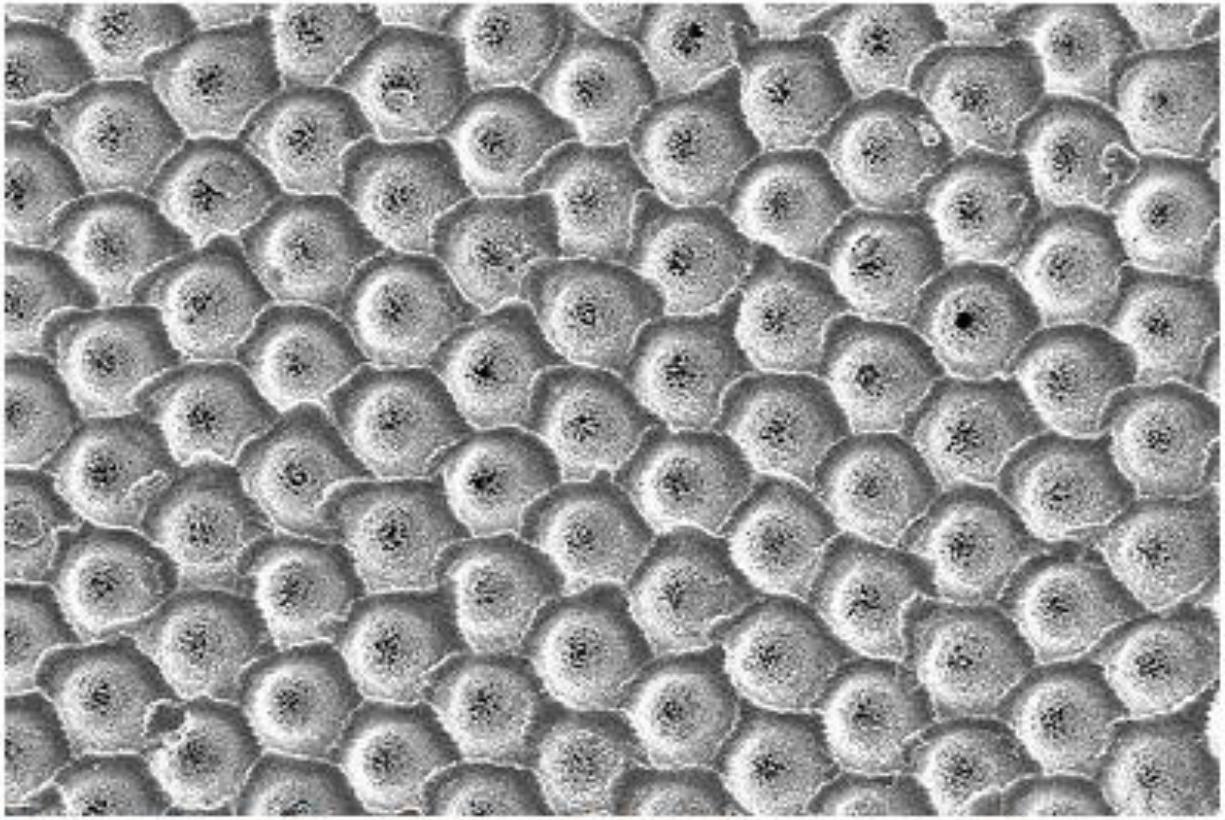


Figure 18 • Anilox printing roll with a laser engraved SUME™ *PRINT* coating

Zastosowanie powłok natryskiwanych cieplnie

Figure 19 • Bearing shaft with a babbitt coating

Zastosowanie powłok natryskiwanych cieplnie

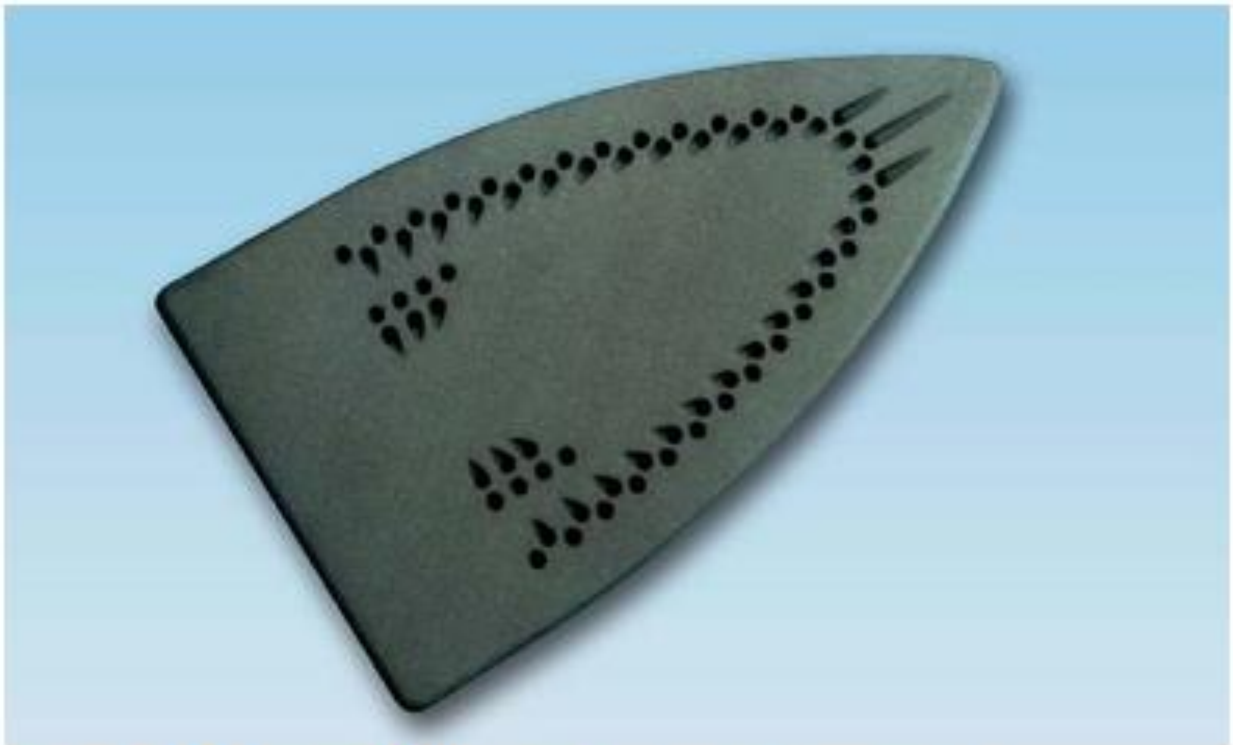


Figure 20 • Coated household steam iron soleplate

Zastosowanie powłok natryskiwanych cieplnie

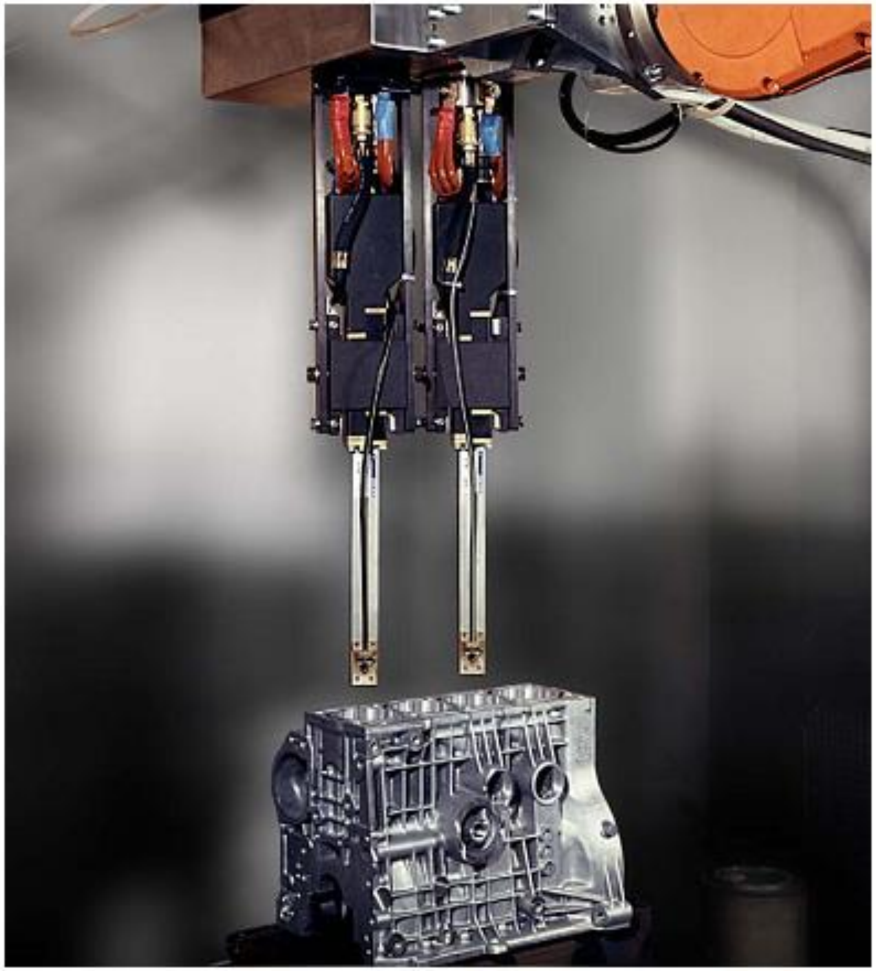


Figure 21 • Dual-RotaPlasma™

Zastosowanie powłok natryskiwanych cieplnie

Figure 22 • HVOF coating of a sink roll

Zastosowanie powłok natryskiwanych cieplnie

Figure 23 • SUME™CAL coating after superfinishing

Zastosowanie powłok natryskiwanych cieplnie

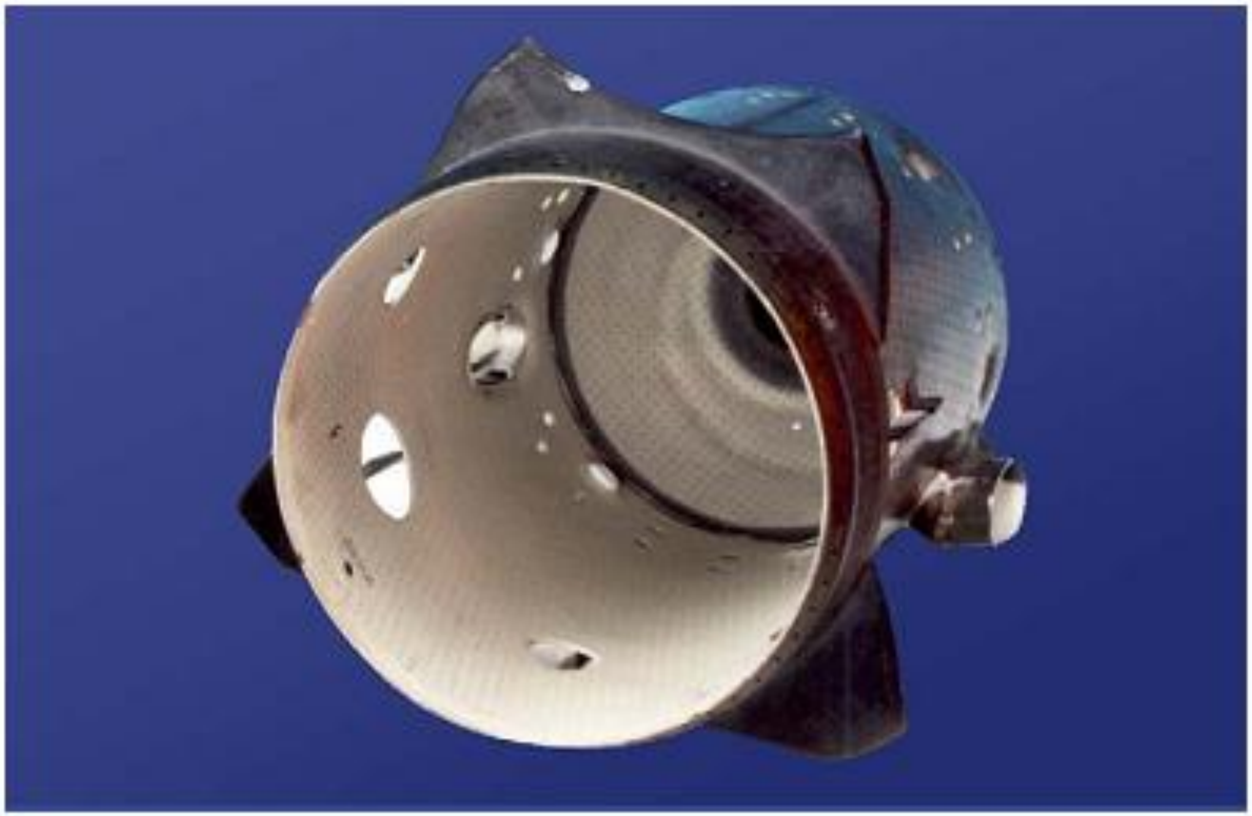


Figure 24 • Combustion Chamber

Zastosowanie powłok natryskiwanych cieplnie

Figure 26 • A modern LPPS high-volume production system for coating gas turbine blades

Natryskiwanie plazmowe

Energia i prędkość cząstek w procesach natryskiwania cieplnego

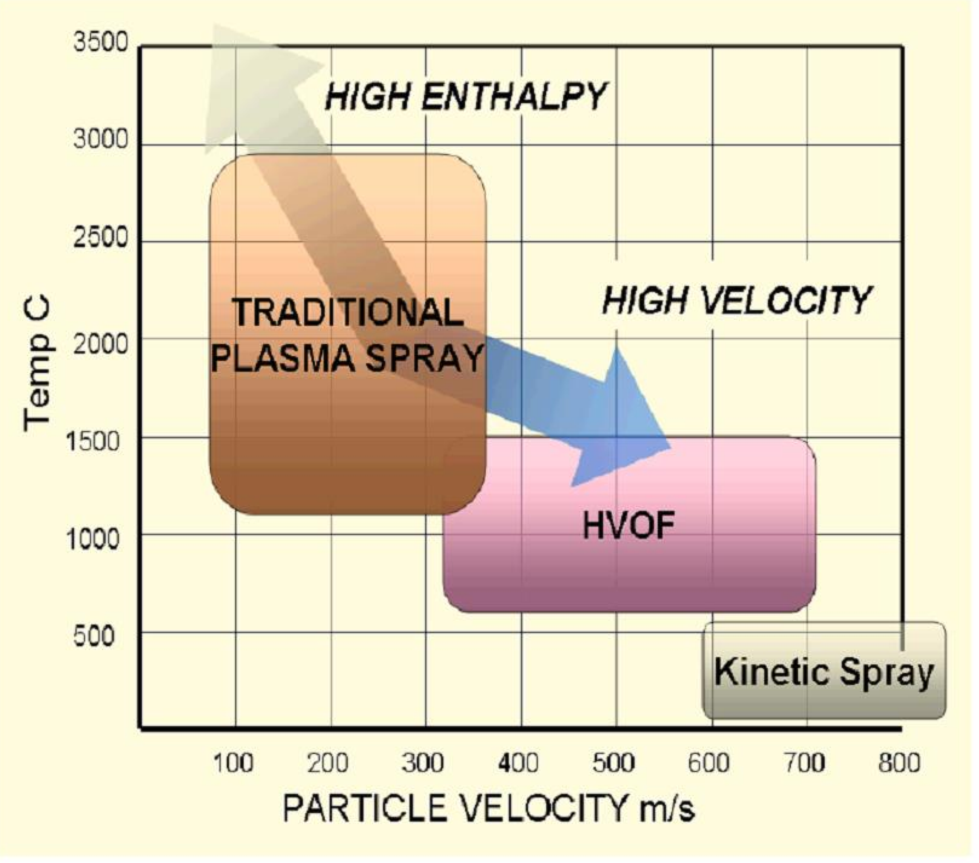


Fig. (1). Temperature range for different applications of thermal spraying [1].